Study on Return and Volatility Spillover Effects among Stock, CDS, and Foreign Exchange Markets in Korea

by

TaLy I

1. Introduction

A number of studies have examined the effect of macroeconomic variables on financial asset returns. Since the work of Ross (1976), various macroeconomic variables such as GDP, inflation, and the trade balance as well as financial market variables such as interest rates and exchange rates have been tested to identify the influential factors for the expected return of a financial asset. However, few studies have been conducted about the relationships between macroeconomic volatility and asset market volatility. Schwert (1989) states that volatility in macroeconomic fundamentals and financial market factors are helpful in predicting stock return volatility, and vice versa.

The key objective of this study is to investigate the return and volatility spillover effects between domestic and international financial and asset markets focused on the Korean economy. In particular, the presence of return and volatility spillover effects from country risk and advanced economy asset markets to Korean asset markets is the primary interest in this study. Before approaching the main subject, it is necessary to specify the concept of country risk and advanced economy asset market.

The credit default swap (CDS) spread underlying government bonds is used as a measure of country risk in this paper. A credit default swap (CDS) is a swap contract between two parties, a protection buyer, and a protection seller. A protection buyer who wants to transfer the credit risk pays a premium (spread) to the protection seller in exchange for a payment if a credit event occurs with a reference entity.[1] As a bond holder buys a CDS to hedge the default risk, the characteristics of a CDS are similar to that of credit insurance. Another characteristic of a CDS is that it is a financial good which can be bought and sold by investors. The CDS premium generally rises when credit risk of the underlying asset increases. That is, the higher the default probability of underlying asset, the more payment is needed to cover the risk. Hence, the CDS premium is interpreted as a measure of credit rating of the authorities or the institutions which issue the underlying asset. For this reason, the CDS premium which is on the basis of bond in foreign money issued by the each country's government is used well as an indicator which reflects the country's credit rating.

Previous research related to the CDS market has made little progress, because the history of the credit derivatives market is not long enough, and there is limited data collection for empirical test due to the characteristic of over-the-counter transactions. Rrecently, by virtue of accumulated time series data and quantitative development in the CDS market, further research on the stock market is being carried out to obtain meaningful information (see Cossin and Hricko (2001), Norden and Weber (2004), Nam and Byun (2006), Elmahadaoui and Dugas (2009), Kim (2009), Baum and Wan (2010) and Longstaff *et al*. (2011)).[2]

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[1] The CDS premium is often referred to as the CDS spread. I also use CDS premium and CDS spread interchangeably in this paper.

[2] Since JP Morgan's first transaction of CDS in 1995, the Asian financial crisis provided momentum to develop the CDS market by increasing demand to hedge credit risk. According to the market survey of the International Swap and Derivatives Association (ISDA), the CDS contract balance at the end of 2001 was \$0.9 trillion, but the market increased tremendously by the end of 2007; the outstanding amount was \$62.2 trillion, falling to \$30.4 trillion of outstanding CDS trades by the end of 2009 due to the effect of the global financial crisis (www2.isda.org).

Figure 1 shows the time series of the CDS spread underlying Korean government bonds and the Korean stock market index (KOSPI) from the first week of January 2002 to the fourth week of February 2010. With the exception of the moment that CDS spread rose rapidly due to the SK accounting fraud and the credit card debacle in March 2003, the CDS spread maintained its downward stability for several years due to some favourable factors such as reduced risk of North Korea's nuclear problem and the prospect of upgrading Korea's sovereign credit rating since 2004. However, the CDS spread was affected by the sub-prime mortgage crisis in the U.S. in July 2007, and since then the trend had been changed to upward. In particular, the highest point of the CDS spread was recorded at the time of the Lehman Brothers' collapse in September 2008, and thereafter, it showed a sharp decline due to the currency swap contract between the U.S. and Korea in November 2008. Following that time, the CDS spread has fluctuated according to the changes in international and domestic financial markets as well as domestic economic conditions. Although the CDS spread has been stabilizing by degrees, it has still remained at a high level since the beginning of the global financial crisis in 2008. In this way, increase in the CDS spread underlying government bonds implies increasing sovereign risk and, in contrast, decrease in the CDS spread means decreasing sovereign risk.

For the Korean stock market index, Korea composite stock price index (KOSPI) is used to represent the asset market condition as well as the general Korean economic condition. The time path of Korean stock market index illustrated in Figure 1 shows negative process compared to the time path of CDS spread. This implies that the Korean stock market booms during economically stable periods of low country risk. Figure 1 displays the gradual increase in the Korean stock market index to more than double when the CDS spread was low during the stable period from 2004 to 2007. However, the Korean stock market index dropped immediately when the CDS spread soared in 2008. Hence, it is expected that there might be a negative relationship between Korean stock price and country risk.

Another interesting issue, which is one of the main objectives for this study, is the identification of the contagion from the advanced asset market to the Korean asset market. Many international investors have taken interest in the Korean stock market for diversification to explore higher returns due to its rapid economic growth and its increased link with international capital markets over the past decades. Figure 2 shows the time series of stock market indices for the U.S. and Japan. The stock market is employed in this paper as a representative asset market for three countries: Korea, the U.S., and Japan. The U.S. stock price is adopted as a global stock price, and the Japanese stock price is adopted as a regional stock price. The time paths of these two indices look very similar to that of the Korean stock market index in Figure 1. From these figures, it is also expected that the Korean stock market has a close relationship with the U.S. and Japanese stock market.[3]

Along with the CDS spread, fluctuations in the exchange rate also reflect variation of domestic country risk since the exchange rate generally shows a sensitive response to the credit status of the country. In addition, the foreign exchange market delivers international risk to the domestic economy, serving the role of a bridge. The foreign exchange market plays a role in establishing the first contact from the variation in international financial markets through the exchange rate, and it spreads the effect to the

[3] Chung (2002) finds that the influence of the U.S. stock price on the Korean stock price has grown more since the Asian financial crisis in 1997, and the Japanese stock price also has been closely connected with the Korean stock price.

domestic economy. For instance, due to the sharp rise of the credit risk in Korea at the time of the Asian financial crisis in 1997, the Korean won depreciated more than double in an instant.

The time series of the Korea won/U.S. dollar exchange rate and Korea won/Japanese yen exchange rate are illustrated in Figure 3 from the first week of January 2002 to the fourth week of February 2010. The two time series of exchange rates show similar fluctuations through the time path, and their fluctuations are also similar to the CDS spread variation in Figure 1. Hence, it is expected that there is a positive relationship between the CDS spread underlying Korean government bonds and exchange rates. In addition, time paths of two exchange rates show a negative process in comparison to the time path of the Korean stock market index illustrated in Figure 1. Thus, it is expected that exchange rates might have a negative relationship with the Korean stock price.

To specify the main objective, the following four questions are suggested. First, are there return and volatility spillover effects among foreign exchange markets, the Korean CDS market, and the Korean stock market? Second, are there return and volatility spillover effects from U.S. and Japanese stock markets to the Korean stock market and Korean CDS market? Third, how do the Korean CDS spread change, exchange rate change, and Korean stock return respond to each increasing return (change) shock? Fourth, how do the Korean stock return and Korean CDS spread change respond to increasing shocks in U.S. and Japanese stock returns? To answer these questions, weekly data of CDS spread, foreign exchange rates, and stock prices for three countries are used over the period of 2002 to 2010 using a multivariate GARCH model.

The results for these questions can be briefly summarized as follows. First, there are significant return spillover effects from the two foreign exchange markets to the Korean

CDS market and Korean stock market and unidirectional volatility spillover effects from foreign exchange markets to the Korean CDS market. Second, return spillover effects from the U.S. stock market to the Korean CDS market and the Korean stock market are significant, whereas volatility spillover effects from the Japanese stock market to the Korean CDS market and the Korean stock market are significant. In most cases, there are bidirectional return and volatility spillover effects between the Korean CDS market and Korean stock market. Third, increase in exchange rate changes leads to increase in Korean CDS spread change and decrease in Korean stock return. Fourth, increase in U.S. and Japanese stock returns lead to decrease in Korean CDS spread change and increase in Korean stock return.

The rest of the paper is organized as follows. Section 2 presents descriptive statistics and results of the tests on data. Section 3 lays out the econometric methodology. The main results are presented in section 4, and section 5 summarizes the main findings and offers some concluding remarks.

2. Descriptions of Data and Statistical Characteristics

Weekly data for Korean, U.S., and Japanese stock returns, Korean CDS spread change, and Korean-U.S. and Korean-Japanese exchange rate changes are used to compose financial and asset market variables for the MGARCH model. KOSPI, S&P 500, and NIKKEI 225 are used for Korean, U.S. and Japanese stock market indices, respectively, which are obtained from the Korea Centre for International Finance (KCIF). The CDS spread underlying the five-year maturity Korean government bond is used, because the five-year is not only the most common liquid maturity in the swap market but it is also widely announced to the public. The Korean CDS spread data are obtained from the KCIF. The data source of the two exchange rates is the Bank of Korea. The data period starts from the first week of January 2002 and ends at the fourth week of February 2010. All weekly data are composed on the basis of Friday's observation. When there is no observation on Friday due to reasons such as public holiday, observation of the day before (Thursday) is used as a replacement.

The first difference of the log of stock prices, exchange rates, and CDS spread are used for computing stock returns and changes in exchanges rates and CDS spread. Let p_t be the price of each market at time *t*. The returns and changes in financial markets at time *t* (y_t) can be calculated as follows:

$$y_t = \ln(\frac{p_t}{p_{t-1}}) \tag{1}$$

When using the first difference variables, some information regarding a possible linear combination between the levels of the variables may be lost. However, relationships between financial markets are analysed using the first difference of the log of returns and changes instead of using the original level series of financial data in this paper. I concentrate on returns because financial time series usually do not satisfy the basic assumption of the stationary process required to avoid spurious inferences based on regression analysis. Thus, before performing the main analysis, it is necessary to test the unit roots for each return and change as well as level of each financial variable.

2.1. Unit Root and Autocorrelation Tests

To check whether the return series of data is stationary, two standard unit-root tests − the augmented Dickey-Fuller (ADF) test and Phillips-Perron (PP) test − are performed. The results of ADF test and the PP test are reported in Table 1. Table 1 shows that there is no unit root in the returns and changes at the 5% level of critical value without exception, although every level variable has unit root. Thus, it is indisputable that returns and changes in all financial and asset markets are of stationary process.

The Ljung-Box *Q*-statistics are used to test for independence of higher relationships as manifested in volatility clustering by the MGARCH model (Huang and Yang, 2000, pp. 329). The Ljung-Box *Q*-statistics and their *p* values by 20 lags and leads are reported in Table 2. The null hypothesis is that several autocorrelation coefficients are 0 at the same time. According to the Ljung-Box *Q*-statistics and *P*-values in Table 2, there exist autocorrelations in won/dollar exchange rate and won/yen exchange rate changes and U.S. stock return by rejecting the hypothesis. On the other hand, the hypothesis of no autocorrelation up to order 20 is accepted in the CDS spread change and Japanese and Korean stock returns; thus, there are no autocorrelations in these change and returns. The significance of the Ljung-Box *Q*-statistics for the return and change series indicate linear dependencies due to the strong conditional heteroskedasticity (Higgs and Worthington, 2004).

2.2. Cross-Correlation Test

The cross-correlation test is used to estimate the degree to which two time series are correlated. This test helps to identify which return (change) is a leading indicator of the other return (change) or how much of one return (change) can be predicted by movement in the other return (change).

The results from the cross-correlation test for Korean CDS spread change and the Korean stock return series relative to the other financial market variables by 20 lags and leads are reported in Table 3. Positive cross-correlation implies that when one return (change) series in (A) rises, the other return (change) series in (B) can be predicted to rise at a rate of coefficient value. In the same sense, negative cross-correlation means that, when one return (change) series in (A) rises, the other return (change) series in (B) falls. The strength of the relationship between two returns (changes) is perfect when the numerical value is at ±1, and it gradually decreases to the minimum value of 0 as lags and leads increase. The coefficient value at 0 lag and lead is usually used to interpret as an ordinary correlation.[4] The Korean CDS spread change is positively correlated with two exchange rate changes (0.374, 0.445) and negatively correlated with three domestic and foreign stock returns (-0.439, -0.489, -0.558). In particular, the correlation between the Korean CDS spread change and Korean stock return is the highest (-0.558). On the other hand, Korean stock return is negatively correlated with two exchange rate changes (-0.373, -0.417) and positively correlated with the other two foreign stock returns (0.537, 0.686). Additionally, the Korean stock return looks more correlated with two foreign stock returns (0.537, 0.686) than two exchange rate changes (-0.373, -0.417). These results of cross-correlation between domestic and foreign financial market returns and changes are consistent with the observations for each time series presented in Figures 1, 2, and 3, although they are not return or change series but level variables.

2.3. Characteristics of Financial Time Series

Although volatility is not directly observable, it has some characteristics that become known empirically and are commonly seen in financial market returns (changes) as cases of "stylized fact."[5] First, financial market returns exhibit volatility clustering,

[4] Although covariance can be used to measure the movement between two variables, it has a problem in terms of which unit is applied to measure the scale of variable. Hence, correlation is used to investigate the relationship between two variables, as it is an unrelated indicator with data measurement scale.

[5] Here volatility refers to the conditional variance of the underlying financial market return. Volatility can

which means that large volatilities tend to be followed by large volatilities and small volatilities tend to be followed by small volatilities. Second, volatility does not diverge to infinity. This means that volatility varies within some fixed range over time. Third, the empirical distribution of financial market returns shows characteristics of non-normal distribution such as leptokurtic, skew, and fat tail. Before modelling and estimating the spillover effects, investigation regarding the presence of these stylized facts in three asset market returns and three financial market changes is performed.

In Figure 4, the left column displays the time plots of returns and changes in each financial market (y_t), and the right column illustrates the squared series from the original returns and changes (y_t^2) for the period from Jan. 2002 W1 to Feb. 2010 W4.[6] According to the right columns in Figure 4, the volatility clustering is observed in six asset market returns and financial market changes. Figures show that large returns (changes) tend to be followed by large returns (changes). Moreover, the fact that volatility varies within some fixed range over time is also observed.

To examine another characteristic of non-normal distribution, Table 4 provides a summary of the descriptive statistics of each asset market return and financial market change. According to the Jarque-Bera statistic in Table 4, the null hypothesis that return (change) is a normal distribution is rejected, because probability is 0. On the other hand, leptokurtic and fat tail can be acknowledged by observing statistics for skewness and kurtosis. U.S., Japanese, and Korean stock returns show left-skewed tails (-1.037, -1.372, and -0.713, respectively), and changes in the CDS spread and two exchange rates have right-skewed tails (1.284, 0.863, and 0.843, respectively). Since kurtosis of normal

be applied to measurement of uncertainty as well as measurement of risk.

6 y_t^2 is regarded as a proxy of variance because variance is a mean of y_t^2 (Kim and Jang, 2006).

distribution is theoretically 3, all returns and changes are leptokurtic due to excess kurtosis over 3.

Under this circumstance, the assumption of constant variance (homoskedasticity) is inappropriate. When modelling with non-constant variance (heteroskedasticity), there is a way to model the changing variance due to the characteristics of leptokurtic and fat tail in data. ARCH- and GARCH-related models are useful to capture the nonlinear data.

3. Methodology

Hamilton (2008) argues that correctly modelling the conditional variance is important to capture the characteristics of time series. Following the initial GARCH model of Bollerslev (1986), various extensions from the original model have been proposed under different assumptions to overcome some limits. The multivariate GARCH (MGARCH) model has been commonly used to estimate the relationships between the volatilities of several financial markets since the studies by Bollerslev *et al*. (1988) and Engle and Kroner (1995). The latest research trend using the MGARCH model focuses on the persistence and transmission of volatility from one market to other markets, and now it is widely accepted that financial volatilities move together over time and across assets and markets (see Bauwens *et al*. (2006), Kim (2007), Silvennoinen and Terasvirta (2008), Karunanayake *et al*. (2009), and Meng *et al*. (2009)).

In this paper, the trivariate GARCH model is constructed to provide an insight into the nature of interaction among domestic and foreign financial markets on the basis of the Korean CDS market and the Korean stock market. There is a reason that the trivariate GARCH model is employed; MGARCH models have a well-known weak point that the number of parameters to estimate increases very rapidly as the number of variables increases. Thus, a trivariate GARCH model is suitable to analyse the return and volatility spillover effects among the Korean CDS market, Korean stock market, and one other financial market such as a foreign exchange market or another country's stock market.

The autoregressive stochastic process of financial market returns (changes) is given in the following conditional mean equation (2).

$$y_{i,t} = \mu_i + \sum_{j=1}^{3} \gamma_{ij} y_{j,t-1} + \varepsilon_{i,t} \quad \text{(For all } i = 1, 2, 3\text{)} \tag{2}$$

where $y_{i,t}$ is the return (change) of financial market *i* between time *t*-1 and *t*, μ_i is a long-term drift coefficient of financial market *i*, γ_{ij} indicates the coefficients for lagged own market returns (changes) and other financial market returns (changes), and $\varepsilon_{i,t}$ is the error term for the return (change) of financial market *i* at time *t*. Returns (changes) of each financial market ($y_{i,t}$) are specified as a function of their own innovations ($\varepsilon_{i,t}$), the lagged own return (change) ($y_{j,t-1}$, for all *j*=1,2,3 in case of $i = j$), and lagged other financial market returns (changes) ($y_{j,t-1}$, for all *j*=1,2,3 in case of $i \neq j$). Four cases of trivariate GARCH models are estimated for different asset and financial markets. In each case, $i = j = 1$ indicates won/dollar exchange rate change, U.S. stock return, won/yen exchange rate change, and Japanese stock return. These returns and changes are used one after another in order to consider four different cases in empirical tests along with the Korean CDS spread change ($i = j = 2$) and the Korean stock return ($i = j = 3$).

The following matrix form of conditional mean equation (3) has the same implication as equation (2).

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \\ y_{3,t} \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \end{bmatrix} + \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} \end{bmatrix} \begin{bmatrix} y_{1,t-1} \\ y_{2,t-1} \\ y_{3,t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \end{bmatrix} \tag{3}$$

The reason that this type of mean equation (3) is considered is that it is convenient to analyse the return spillover effects and dynamic relationships using the impulse response function between financial market returns and changes.[7]

The two common parameterizations for the MGARCH model used in previous research are the VECH model and BEKK model.[8] Since the traditional VECH model does not ensure a positive semi-definite conditional variance and covariance matrix, the BEKK model from Engle and Kroner (1995) is used to overcome the difficulties associated with the VECH parameterization (Kearney and Patton, 2000; Hassan and Malik, 2007). This model is designed in such a way that the estimated covariance matrix will be positive semi-definite, which is a requirement needed to guarantee non-negative estimated variances. The BEKK parameterization is written as follows:[9]

$$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B \tag{4}$$

The individual elements for *C*, *A*, *B*, H_t and ε_t matrices in equation (4) are given as follows:

[7] The vector form of the mean equation presented in equation (3) is equal to the three-variable unrestricted VAR (1) model. To be specific, the VAR (1) form of conditional mean equation is used to examine the return spillover effects between financial markets in this paper.
[8] The acronym BEKK model is used in the literature to refer to earlier unpublished work of Baba, Engle, Kraft, and Kroner (1990).
[9] According to the naming way of Dark *et al*. (2005), the multivariate GARCH model used in this paper is named as trivariate VAR BEKK GARCH (1,1) model.

$$C=\begin{bmatrix}\omega_{11} & 0 & 0\\ \omega_{21} & \omega_{22} & 0\\ \omega_{31} & \omega_{32} & \omega_{33}\end{bmatrix},\quad A=\begin{bmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13}\\ \alpha_{21} & \alpha_{22} & \alpha_{23}\\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{bmatrix},\quad B=\begin{bmatrix}\beta_{11} & \beta_{12} & \beta_{13}\\ \beta_{21} & \beta_{22} & \beta_{23}\\ \beta_{31} & \beta_{32} & \beta_{33}\end{bmatrix}$$

$$H_t=\begin{bmatrix}\sigma_{1,t}^2 & \sigma_{12,t} & \sigma_{13,t}\\ \sigma_{21,t} & \sigma_{2,t}^2 & \sigma_{23,t}\\ \sigma_{31,t} & \sigma_{32,t} & \sigma_{3,t}^2\end{bmatrix}=\begin{bmatrix}h_{11,t} & h_{12,t} & h_{13,t}\\ h_{21,t} & h_{22,t} & h_{23,t}\\ h_{31,t} & h_{32,t} & h_{33,t}\end{bmatrix},\quad \varepsilon_t=\begin{bmatrix}\varepsilon_{1,t}\\ \varepsilon_{2,t}\\ \varepsilon_{3,t}\end{bmatrix} \tag{5}$$

where ω_{ij} are elements of a 3×3 lower triangular matrix with six parameters of constants *C*. *A* is a 3×3 square matrix of parameters and shows how conditional variances are correlated with past squared errors. The elements (α_{ij}) of matrix *A* measure the degree of innovation from financial market *i* to another financial market *j*. *B* is also a 3×3 square matrix of parameters, and its elements (β_{ij}) indicate the persistence in conditional volatility between financial market *i* and market *j*. H_t is the 3×3 matrix composed of conditional variances ($\sigma_{i,t}^2$) and covariances ($\sigma_{ij,t}$). Hence, the total number of elements that should be estimated for variance equations of the trivariate GARCH model is 24. The conditional variance and covariance equations used to program are presented in Appendix A. The conditional variance equations show how volatilities are transmitted across financial markets over time.

The following log-likelihood function is maximized for the trivariate GARCH model with the assumption that errors are normally distributed:

$$L(\theta)=-\frac{TN}{2}\ln(2\pi)-\frac{1}{2}\sum_{t=1}^{T}(\ln|H_t|+\varepsilon'_t H_t^{-1}\varepsilon_t) \tag{6}$$

where θ is the vector of parameters to be estimated, *N* is the number of financial markets in the system being estimated, and *T* is the number of observations. Since the log-likelihood function in this case is non-linear, the Marquardt algorithm is used as an iterative algorithm to estimate the parameters.[10]

4. Empirical Results

To examine the return and volatility spillover effects between change in CDS spread underlying Korean government bonds and the Korean stock return, these return and change are commonly included in all four cases. In addition, the won/dollar exchange rate change, won/yen exchange rate change, U.S. stock return, and Japanese stock return are used one after another for the third financial market return or change in each case to investigate another spillover effect from the third financial market return or change to the Korean stock return and Korean CDS spread change.

Estimation for return and volatility spillover effects is conducted using a trivariate GARCH model, and analysis for dynamic interactions between returns and changes are performed using impulse response functions obtained from the unrestricted VAR (1) framework of conditional mean equation (3). The structure of the four cases is organized as follows:

Case I : Won/dollar exchange rate change – CDS spread change – Korean stock return

Case II : Won/yen exchange rate change – CDS spread change – Korean stock return

Case III : U.S. stock return – CDS spread change – Korean stock return

Case IV : Japanese stock return – CDS spread change – Korean stock return

4.1. Foreign Exchange Markets, the Korean CDS market, and the Korean

[10] The Berndt, Hall, Hall, and Hausman (BHHH) (1974) algorithm has been used in most previous studies. However, the Marquardt algorithm is used in this paper because of its better performance than the BHHH algorithm, which does not converge.

Stock Market

The estimated coefficients and standard errors of the conditional mean equations and conditional variance equations for Case I and Case II, which include foreign exchange markets as a third financial market, are reported in Table 5. Estimated coefficients of equations (3) and (5) which are based on computing the coefficients of ARCH term and GARCH term in Table 5 are also reported in Appendix B.1.

First, seeing the results of the conditional mean equation in Case I, which considers the Korean-U.S. foreign exchange market, Korean CDS market, and Korean stock market, all return spillover effects from the lagged change of the won/dollar exchange rate to the current own-market-change, current Korean CDS spread change, and current Korean stock return are significant. Each coefficient is 0.187(γ_{11}), 1.003(γ_{21}), and -0.193(γ_{31}), respectively, and they are significant at the 5%, 1%, and 5% levels, respectively. In particular, a positive cross-market return spillover effect exists from the Korean-U.S. foreign exchange market to the Korean CDS market. In contrast, a negative cross-market-return spillover effect exists from the Korean-U.S. foreign exchange market to the Korean stock market. Positive cross-market return spillover effect from the lagged Korean CDS spread change to the current Korean stock return is significant at the 5% level (0.027, γ_{32}). Conditional return spillover effects from the lagged Korean stock return to the current own-market-return and cross-market return do not exist, because the results are statistically insignificant. Thus, during the data period, conditional return spillover effect from the Korean-U.S. foreign exchange market to the Korean CDS market exists, and return spillover effects from the Korean-U.S. foreign exchange market and the Korean CDS market to the Korean stock market are significant.

Second, seeing the result of the conditional variance equation in Case I, each persistence of volatility (see the significance of $h_{ij,t}$ and $h_{ij,t-1}$ for all i=j) for the Korean-U.S. foreign exchange market, the Korean CDS market, and the Korean stock market is 0.835, 0.799 and 0.228, respectively, and all of these coefficients are strongly significant at the 1% level. According to the size of each coefficient, the won/dollar exchange rate change has the highest volatility persistence. The volatility persistence of the Korean CDS spread change and Korean stock return follows in order. All three financial market returns and changes are significant at the 1% level of critical value in terms of own-market-volatility spillover effects (0.248, 0.173, and 0.279, respectively). Examining the cross-market volatility spillover effect, there are no significant volatility spillover effects from the Korean CDS spread change and the Korean stock return to the won/dollar exchange rate change. However, volatility spillover effects from the won/dollar exchange rate change and the Korean stock return to the Korean CDS spread change are significant at 0.902 (1%) and 0.135 (5%), respectively. On the other hand, the volatility spillover effect from the Korean CDS spread change to the Korean stock return is significant at 0.004 (1%). Thus, during the data period, there are bidirectional significant volatility spillover effects between the Korean CDS market and the Korean stock market, and there is a significant unidirectional volatility spillover effect from the Korean-U.S. foreign exchange market to the Korean CDS market.

Third, in comparison to Case I, seeing the result of the conditional mean equation in Case II, which considers the Korean-Japanese foreign exchange market, the Korean CDS market and the Korean stock market, return spillover effects from the lagged change of the won/yen exchange rate to the current own-market-return, the current Korean CDS spread change, and the current Korean stock return are -0.279 (γ_{11}), 0.244 (γ_{21}) and -0.134 (γ_{31}), respectively. They are all statistically significant at the 1% level.

In particular, a positive cross-market return spillover effect exists from the won/yen exchange rate change to the Korean CDS spread change, and a negative cross-market return spillover effect exists from the won/yen exchange rate change to the Korean stock return. As these results are consistent with the results of Case I, it can be concluded that there exist significant cross-market return spillover effects from both foreign exchange markets to the Korean CDS market and the Korean stock market. The lagged change of the Korean CDS spread has a negative conditional return spillover effect to the current Korean stock return at the 1% level of critical value, with the coefficient value of -0.017 (γ_{32}). The lagged Korean stock return has a conditional return spillover effect to the current Korean CDS spread change and current return of own market at the 1% level with coefficient values of 0.074 (γ_{23}) and -0.185 (γ_{33}), respectively. Thus, during the data period, there are bidirectional return spillover effects between the Korean CDS market and the Korean stock market, and there are unidirectional return spillover effects from the Korean-Japanese foreign exchange market to the Korean CDS market and the Korean stock market.

Fourth, seeing the result of the conditional variance equation in Case II, the persistence of volatility (see the significance of $h_{ij,t}$ and $h_{ij,t-1}$ for all *i*=*j*) for the Korean-Japanese foreign exchange market, the Korean CDS market, and the Korean stock market is 0.997, 0.487, and 0.522, respectively, and all of these coefficients are strongly significant at the 1% level. According to the size of each coefficient, the won/yen exchange rate change has the highest volatility persistence. The volatility persistence of the Korean stock returns and the Korean CDS spread change follows in order. All three financial market return and changes are significant at the 10%, 1% and 1% levels of critical value in terms of own-market-volatility spillover effects, respectively, and those estimates are 0.005, 0.215, and 0.652, respectively. Examining the cross-market volatility spillover effect, three significant volatility spillover effects, from the Korean stock return to the Won/Yen exchange rate change (0.020, 10%), from the won/yen exchange rate change to the Korean CDS spread change (0.004, 10%), and from the Korean stock return to the Korean CDS spread return (0.024, 1%), are statistically significant. Thus, during the data period, there are significant unidirectional volatility spillover effects from the Korean-Japanese foreign exchange market and the Korean stock market to the Korean CDS market. Another significant unidirectional volatility spillover effect is from the Korean stock market to the Korean-Japanese foreign exchange market.

For better understanding, simple figures for the results of return and volatility spillover effects for Case I and Case II are presented in Figure 5. Some empirical research provides evidence of return spillover effects between the stock market and the foreign exchange market (Roll, 1992; Dumas and Solnik, 1995; Choi *et al*., 1998; Phylaktis and Ravazzolo, 2005). They find the presence of bidirectional return spillover effects between the foreign exchange market and the stock market. In contrast to these results, during the data period for Korea, there is a unidirectional return spillover effect from foreign exchange markets to the Korean stock market.

In the meantime, although there are significant unidirectional volatility spillover effects from two foreign exchange markets to the Korean CDS market, there is no significant volatility spillover effect from two foreign exchange markets to the Korean stock market. Some empirical research provides different results of volatility spillover effects between the stock market and the foreign exchange market. Francis *et al*. (2002) and Wu (2005) find significant bidirectional volatility spillovers between the stock market and the foreign exchange market. Beer and Hebein (2008) find significant volatility spillovers from the foreign exchange market to the stock market for several countries. To the contrary, Kanas (2000) and Kim (2001) find the presence of unidirectional volatility spillover from the stock market to the foreign exchange market. Although there are no volatility spillover effects between the Korean-U.S. foreign exchange market and the Korean stock market, the significant unidirectional volatility spillover effect from the Korean stock market to the Korean-Japanese foreign exchange market is in line with the results of Kanas (2000) and Kim (2001).

In terms of the relationship among the CDS, foreign exchange, and stock markets, Nam and Byun (2006) claim a significant effect from the variations of stock prices and the exchange rate to the variation of the Korean CDS spread. Elmahadaoui and Dugas (2009) emphasize the effect from variations in the CDS spread to the variations in stock prices. Baum and Wan (2010) indicate the significant effect from the second moment of the stock index to the CDS spread. The results of this study are consistent with those of foregoing studies that there is a significant return spillover effect from the foreign exchange market to the CDS market, a return spillover effect from the CDS market to the stock market, and a volatility spillover effect from the stock market to the CDS market.

Considering the relationships in mean equations from a different angle, time varying impulse responses to positive one standard deviation of each return (change) shock are provided to illustrate the dynamics of the trivariate GARCH system for the conditional mean returns (changes) of financial markets. Impulse response functions are reported based on the mean equation (3). The errors ($\varepsilon_{i,t}$) are orthogonalized and then shocked to generate the impulse response functions. To observe the distinct response patterns of the system, the errors are transformed to orthogonalize the innovations using a Cholesky factorization. The impulse response functions for the trivariate GARCH process apply the same procedures to their standardized residuals series, which have been corrected for time varying conditional heteroskedasticity (Karolyi, 1995). Although the errors are conditionally heteroskedastic, it is valid to perform impulse response function analysis since this is a stationary GARCH which has unconditionally constant variance. The impulse responses of the return and change series to each positive financial market return and change shock with one standard error bands are presented in Figure 6 for Case I and in Figure 7 for Case II.

Figures 6 and 7 show similar impulse responses for each case. First, carrying out a thorough inspection of the results, the Korean CDS spread change increases immediately and returns to a steady-state level in one month to one standard deviation increasing shocks of the two exchange rate changes. Since increase in the exchange rate, which implies an increasing risk premium in foreign exchange market, is related to increasing country risk, the result of the increasing Korean CDS spread change is reasonable. This result is consistent with that of Kim (2009). To the contrary, the Korean stock return shows negative response immediately and recovers to the pre-shock level within one month to increasing shocks of the two exchange rate changes. This result is the same as previous research that draws the conclusion of a negative relationship between foreign exchange rate change and the Korean stock return (Chung, 2002).

The flow approach of Dornbusch and Fischer (1980) affirms that currency movements affect international competitiveness and the balance of trade position. As a result, the real output of the country is changed, and then this changed economic activity affects current and future cash flows of companies and stock prices. From this perspective, a depreciation in the Korean currency leads to increasing Korean exports, and consequently this will cause an increase in Korean stock prices due to increased output. In contrast, when the Korea currency is depreciated, prices rise because of increased import prices, and this will cause domestic interest rates to rise. The stock prices will fall because of higher interest rates. In addition, because of expected foreign-exchange loss stemming from the sudden rise in exchange rate, investment of foreign capital in the Korean asset market will not increase. Consequently, for the Korean economy during the data period, the Korean stock return responds negatively to the increasing exchange rate change shock.

Second, two exchange rate changes do not respond at first to the increasing Korean CDS spread change shock. However, they show delayed overshooting after the initial stage and return to the steady-state level in one month. The reason that the Korean currency depreciates is due to the increased country credit risk reflected by the increased CDS spread underlying Korean government bonds. In comparison to the exchange rate change responses, the impulse response in the Korean stock return to the increasing Korean CDS spread change shock displays immediate falling, and then afterward, the Korean stock return goes back to the pre-shock level in one month. Since investment is sensitively affected by the risk in assets, increased country risk due to increasing country credit spread causes decreasing foreign investment in the Korean asset market. It goes without saying that this condition makes the Korean stock return fall. This response pattern is very similar to the case of an increasing exchange rate change shock.

Third, impulse responses in the two exchange rate changes and the Korean CDS spread change to the increasing Korean stock return shock look similar. There are no responses at the initial stage, but they show delayed overshooting and return to the pre-shock level in one month. According to economic theory and previous empirical results, the change in the stock market has an influence on the change in the foreign exchange market negatively or positively (see Aggarwal (1981), Branson (1983), Phylaktis and Ravazzolo (2005), Pan *et al*. (2007), and Rahman and Uddin (2009)).

These conflicting results are explained by several economic theories related to the determinants of the exchange rate. According to the perspective of the flow approach, an increase in the Korean stock market conveys information about improved performance in the Korean economy, and it can be expected that imports in Korea will increase due to the better economic state. For this reason, demand for foreign currency leads to a depreciation in Korean currency. On the other hand, according to the monetary approach and portfolio balance approach, agents allocate their wealth among alternative assets such as foreign stocks and domestic money, bonds, and stocks. The role of the exchange rate is to balance the foreign and domestic asset demands and supplies. Hence, if there is a change in the demand and supply of Korean stock, this will change the equilibrium exchange rate. If the Korean stock price rises, it will persuade foreign investors to buy more Korean stock by selling foreign assets to obtain Korean currency. Increase in demand for Korean currency will lead to appreciation of the Korean currency (see Frankel, 1983). In addition, if the Korean stock price rises, this will lead to the growth of wealth, which will increase the demand for money. The excess demand for money will cause interest rates in Korea to rise, and in this situation, more foreign capital will be attracted and increase the foreign demand for the Korean currency (see Gavin, 1989). As a result, the Korean currency will appreciate. Thus, the overall effect on the exchange rate will depend on the relative strength of the various competing effects (Phylaktis and Ravazzolo, 2005). For the Korean economy during the data period, increase in the Korean stock return shock has a positive influence on exchange rate changes.

4.2. U.S. and Japanese Stock Markets, the Korean CDS market, and the Korean Stock Market

The empirical results for Case III and Case IV, which include two large countries' stock returns, the Korean CDS spread change and the Korean stock return are reported in Table 6. Estimated coefficients of equations (3) and (5), which are based on computing the coefficients of ARCH term and GARCH term to examine the volatility spillover effect in Table 6, are also reported in Appendix B.2.

First, seeing the results of the conditional mean equation in Case III which considers the U.S. stock market, the Korean CDS market, and the Korean stock market, return spillover effects from the lagged U.S. stock return to the current CDS spread change and the current Korean stock return are -0.774 (γ_{21}) and 0.402 (γ_{31}), respectively, and they are both significant at the 1% level of critical value. In particular, a negative cross-market return spillover effect exists from the U.S. stock market to the Korean CDS market. In contrast, a positive cross-market return spillover effect exists from the U.S. stock market to the Korean stock market. Thus, it can be concluded that the U.S. stock market has a significant effect on the Korean CDS market and the Korean stock market during the data period. Although there is no significant return spillover effects from the lagged change of the Korean CDS spread to the current returns of the other two stock returns, the lagged return of the Korean stock market has a significant return spillover effect on the current Korean CDS spread change (0.565, γ_{23}) and its own market (-

0.347, γ_{33}) under the 5% and 1% levels of critical value, respectively.

Second, seeing the result of the conditional variance equation in Case III, the only significant persistence of volatility (see the significance of $h_{ij,t}$ and $h_{ij,t-1}$ for all i=j) is the Korean CDS spread change (0.728, 1%). Only the Korean CDS spread change is also significant at the 1% level in terms of the own-market-volatility spillover effect (0.379). Examining the cross-market volatility spillover effect, volatility spillover effects from the Korean CDS spread change to the other two stock returns (0.053, 0.013) are significant at the 1% level. Additionally, the volatility spillover effect from the Korean stock return to the Korean CDS spread change is significant at the 10% level of critical value (0.376).

Third, in comparison with Case III, the result of the conditional mean equation in Case IV, which considers the Japanese stock market, the Korean CDS market, and the Korean stock market, indicates that there is no meaningful return spillover effect among the three financial markets.

Fourth, as indicated by the result of the conditional variance equation in Case IV, the persistence of volatility (see the significance of $h_{ij,t}$ and $h_{ij,t-1}$ for all i=j) for the Japanese stock market, the Korean CDS market, and the Korean stock market are 1.056, 0.505, and 0.880, respectively. All of these coefficients are strongly significant at the 1% level. According to the size of each coefficient, the Japanese stock return has the highest volatility persistence. The volatility persistence of the Korean stock return and the Korean CDS spread change follow in order. The Korean CDS spread change and the Korean stock return are significant at the 10% and 1% levels of critical value in terms of own-market-volatility spillover effect, respectively (0.008 and 0.163, respectively).

Examining the cross-market volatility spillover effect, all three financial markets have significant bidirectional volatility spillover effects between markets in this case. The volatility spillover effects from the Japanese stock market and the Korean stock market to the Korean CDS market are statistically significant at 1.007 and 2.251, respectively, at the 1% significance level. The volatility spillover effects from the Japanese stock market and the Korean CDS market to the Korean stock market are significant at 0.085 and 0.003, respectively, at the 1% level.

For better understanding, simple figures for the results of return and volatility spillover effects for Case III and Case IV are presented in Figure 8. Considering synthetically Case IV together with Case III examining the return and volatility spillover effects among the Korean CDS market, the Korean stock market, and the U.S. or Japanese stock markets, there are significant cross-market return spillover effects from the U.S. stock market to the Korean CDS market and the Korean stock market. In contrast, there are significant cross-market volatility spillover effects from the Japanese stock market to the Korean CDS market and the Korean stock market. This result is consistent with Scheicher (2001), who shows that the regional influences are the cause of volatility in the markets, whereas international volatility has no impact on small stock markets. Beirne *et al*. (2010) conclude that return and volatility spillover effects exist from global or regional stock markets to local emerging markets. Studies by Karolyi (1995), Chou *et al*., (1999), Worthington and Higgs (2004), Harris and Pisedtasalasai (2006), and Sun and Zhang (2009) are also in line with this result. They show that there are return and volatility spillover effects from the advanced stock market to the smaller stock market.

Commonly in these two cases, although there is no significant bidirectional crossreturn-spillover effect between the Korean CDS market and the Korean stock market besides the significant effect from the Korean stock market to the Korean CDS market in Case III, bidirectional cross-market volatility spillover effects between two Korean financial markets are significant. Through the results of volatility spillover effects between the Korean CDS market and the Korean stock market from Case I to Case IV, there are significant bidirectional volatility spillover effects between two Korean financial markets except only one unidirectional effect. This can be interpreted that a decrease in the Korean CDS spread uncertainty, which implies that the country state is stable, leads to a decrease in the Korean stock market uncertainty and, as a result, there is a decrease in volatility and persistence in the Korean stock market. On the other hand, a decline in the Korean stock return uncertainty, which implies the stable state of asset markets, causes the volatility and persistence in the Korean CDS market to decrease because of the decreased Korean CDS spread uncertainty.

Although a study by Bala and Premaratne (2003) shows that the volatility spillover effect from the smaller stock market to the dominant stock market is plausible, most of the other earlier research concludes that spillover effects are significant only from the dominant market to the smaller market. Because the Korean stock market is relatively small, it is plausible that the influence from the Korean stock market and the Korean CDS market to global stock market such as that of the U.S. and a regional stock market such as that of Japan is insignificant, although some statistics indicate significance. Hence, only results are reported without further explanation.

To observe the time varying impulse responses of return and change series to positive financial market return and change shocks in the unrestricted VAR(1) model reported in equation (3), the results with one standard error bands are presented in Figure 9 for Case

III and in Figure 10 for Case IV. Figures 9 and 10 illustrate the impulse response functions of Case III and Case IV including U.S. and Japanese stock markets along with the Korean CDS market and the Korean stock market, which show similar responses in each case. Basically, impulse responses of the Korean CDS spread change and the Korean stock return to one standard deviation increasing U.S. and Japanese stock return shocks show similarities except for the different numerical values and the required periods to return to the steady-state level.

Describing the detailed results, the Korean CDS spread change falls immediately and returns to the pre-shock level to increasing U.S. and Japanese stock return shocks. In contrast, the Korean stock return rises immediately and returns to the pre-shock level to the same shocks. This result is consistent with the findings of Phylaktis and Ravazzolo (2005), who argue that an increase in the U.S. stock market causes the local stock market to rise as a result of the greater integration between Pacific Basin countries' markets and world markets. Compared to the required period to return to the steady-state level, responses in the Korean CDS spread change and the Korean stock return to increasing Japanese stock return shock are shorter by about one period (week) than responses in the Korean CDS spread change and the Korean stock return to the increasing U.S. stock return shock. This implies that change in the U.S. stock market has a longer effect on the movement in the Korean CDS market and the Korean stock market than change in the Japanese stock market does.

5. Conclusion

This study examines the return and volatility spillover effects among several domestic and foreign financial markets in Korea for the period from the first week of

January 2002 to the fourth week of February 2010. In particular, the relationship between the CDS underlying the Korean government bond market, which uses CDS spread as an indicator implying country risk, and the Korean stock market, which is a representative domestic asset market, is the main focus. Two kinds of financial markets − foreign exchange markets and global and regional stock markets − are added to investigate the relationships along with the Korean stock market and the Korean CDS market in a model. This study employs the trivariate GARCH model to capture the return and volatility transmission mechanism. In addition, to account for the dynamic interactions among financial market returns and changes, impulse response analysis is conducted.

The answers to questions presented in the introductory section 1 can be summarized as follows. First, the return spillover effects from the two foreign exchange markets, Korean-U.S. and Korean-Japanese foreign exchange markets, to the Korean stock market and the Korean CDS market are significant. In the case of including the Korean-U.S. foreign exchange market in the model, there is a significant unidirectional return spillover effect from the Korean CDS market to the Korean stock market. On the other hand, there is a significant bidirectional return spillover effect between the Korean CDS market and the Korean stock market in the case of including the Korean-Japanese foreign exchange market in the model. In the meantime, a significant unidirectional volatility spillover effect from the Korean-U.S. foreign exchange market to the Korean CDS market and a bidirectional volatility spillover effect between the Korean CDS market and the Korean stock market. On the other hand, there are three significant unidirectional volatility spillover effects: that from the Korean-Japanese foreign exchange market to the Korean CDS market, from the Korean stock market to the

Korean CDS market, and from the Korean stock market to the Korean-Japanese foreign exchange market.

Second, the return spillover effects from the U.S. stock market to the Korean stock market and the Korean CDS market are significant. In the case of including the U.S. stock market in the model, there is a significant unidirectional return spillover effect from the Korean stock market to the Korean CDS market. Meanwhile, a significant bidirectional volatility spillover effect exists between the Korean CDS market and the Korean stock market in the case of including the U.S. stock market in the model. On the other hand, the volatility spillover effects from the Japanese stock market to the Korean stock market and the Korean CDS market are significant. Additionally, there is a significant bidirectional volatility spillover effect between the Korean CDS market and the Korean stock market in the case of including the Japanese stock market in the model.

Third, the Korean stock return responds negatively, and the Korean CDS spread changes positively to increasing the two exchange rate change shocks. The Korean stock return responds negatively and the two exchange rate changes respond positively to the increasing Korean CDS spread change shock. Both the Korean CDS spread change and the two exchange rate changes respond positively to the increasing Korean stock return shock. Although there are some exceptions, it can generally be supposed that there is a negative relationship between the Korean CDS spread change and the Korean stock return, a positive relationship between exchange rate changes and the Korean CDS spread change, and a negative relationship between exchange rate changes and the Korean stock return.

Fourth, the Korean stock return responds positively and the Korean CDS spread change responds negatively to increasing U.S. and Japanese stock returns.

This study on return and volatility spillover effects among the CDS market, stock market, and foreign exchange market can provide useful information for risk analysis to domestic and foreign financial market participants. There is evidence that volatility transmission exists among these financial markets with some exceptions, increasing volatility in one financial market is a clear signal of increasing volatility in other financial markets.

Appendix A. The Conditional Variance and Covariance Equations

$$h_{11,t} = \omega_{11}^2 + \omega_{21}^2 + \omega_{31}^2 + \alpha_{11}^2\varepsilon_{1,t-1}^2 + \alpha_{21}^2\varepsilon_{2,t-1}^2 + \alpha_{31}^2\varepsilon_{3,t-1}^2 + \beta_{11}^2 h_{11,t-1} + \beta_{21}^2 h_{22,t-1} + \beta_{31}^2 h_{33,t-1}$$

$$+2(\alpha_{11}\alpha_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \alpha_{11}\alpha_{31}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + \alpha_{21}\alpha_{31}\varepsilon_{2,t-1}\varepsilon_{3,t-1} + \beta_{11}\beta_{21}h_{12,t-1} + \beta_{11}\beta_{31}h_{13,t-1}$$

$$+\beta_{21}\beta_{31}h_{23,t-1})$$

$$h_{22,t} = \omega_{22}^2 + \omega_{32}^2 + \alpha_{12}^2\varepsilon_{1,t-1}^2 + \alpha_{22}^2\varepsilon_{2,t-1}^2 + \alpha_{32}^2\varepsilon_{3,t-1}^2 + \beta_{12}^2 h_{11,t-1} + \beta_{22}^2 h_{22,t-1} + \beta_{32}^2 h_{33,t-1}$$

$$+2(\alpha_{12}\alpha_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \alpha_{12}\alpha_{32}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + \alpha_{22}\alpha_{32}\varepsilon_{2,t-1}\varepsilon_{3,t-1} + \beta_{12}\beta_{22}h_{12,t-1} + \beta_{12}\beta_{32}h_{13,t-1}$$

$$+\beta_{22}\beta_{32}h_{23,t-1})$$

$$h_{33,t} = \omega_{33}^2 + \alpha_{13}^2\varepsilon_{1,t-1}^2 + \alpha_{23}^2\varepsilon_{2,t-1}^2 + \alpha_{33}^2\varepsilon_{3,t-1}^2 + \beta_{13}^2 h_{11,t-1} + \beta_{23}^2 h_{22,t-1} + \beta_{33}^2 h_{33,t-1}$$

$$+2(\alpha_{13}\alpha_{23}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \alpha_{13}\alpha_{33}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + \alpha_{23}\alpha_{33}\varepsilon_{2,t-1}\varepsilon_{3,t-1} + \beta_{13}\beta_{23}h_{12,t-1} + \beta_{13}\beta_{33}h_{13,t-1}$$

$$+\beta_{23}\beta_{33}h_{23,t-1})$$

$$h_{12,t} = \omega_{21}\omega_{22} + \omega_{31}\omega_{32} + \alpha_{11}\alpha_{12}\varepsilon_{1,t-1}^2 + \alpha_{21}\alpha_{22}\varepsilon_{2,t-1}^2 + \alpha_{31}\alpha_{32}\varepsilon_{3,t-1}^2 + (\alpha_{12}\alpha_{21} + \alpha_{11}\alpha_{22})\varepsilon_{1,t-1}\varepsilon_{2,t-1}$$

$$+(\alpha_{12}\alpha_{31} + \alpha_{11}\alpha_{32})\varepsilon_{1,t-1}\varepsilon_{3,t-1} + (\alpha_{22}\alpha_{31} + \alpha_{21}\alpha_{32})\varepsilon_{2,t-1}\varepsilon_{3,t-1} + \beta_{11}\beta_{12}h_{11,t-1} + \beta_{21}\beta_{22}h_{22,t-1}$$

$$+\beta_{31}\beta_{32}h_{33,t-1} + (\beta_{21}\beta_{12} + \beta_{11}\beta_{22})h_{12,t-1} + (\beta_{31}\beta_{12} + \beta_{11}\beta_{32})h_{13,t-1} + (\beta_{31}\beta_{22} + \beta_{21}\beta_{32})h_{23,t-1}$$

$$h_{13,t} = \omega_{31}\omega_{33} + \alpha_{11}\alpha_{13}\varepsilon_{1,t-1}^2 + \alpha_{21}\alpha_{23}\varepsilon_{2,t-1}^2 + \alpha_{31}\alpha_{33}\varepsilon_{3,t-1}^2 + (\alpha_{13}\alpha_{21} + \alpha_{11}\alpha_{23})\varepsilon_{1,t-1}\varepsilon_{2,t-1}$$

$$+ (\alpha_{13}\alpha_{31} + \alpha_{11}\alpha_{33})\varepsilon_{1,t-1}\varepsilon_{3,t-1} + (\alpha_{23}\alpha_{31} + \alpha_{21}\alpha_{33})\varepsilon_{2,t-1}\varepsilon_{3,t-1} + \beta_{11}\beta_{13}h_{11,t-1} + \beta_{21}\beta_{23}h_{22,t-1}$$

$$+ \beta_{31}\beta_{33}h_{33,t-1} + (\beta_{21}\beta_{13} + \beta_{11}\beta_{23})h_{12,t-1} + (\beta_{31}\beta_{13} + \beta_{11}\beta_{33})h_{13,t-1} + (\beta_{31}\beta_{23} + \beta_{21}\beta_{33})h_{23,t-1}$$

$$h_{23,t} = \omega_{32}\omega_{33} + \alpha_{12}\alpha_{13}\varepsilon_{1,t-1}^2 + \alpha_{22}\alpha_{23}\varepsilon_{2,t-1}^2 + \alpha_{32}\alpha_{33}\varepsilon_{3,t-1}^2 + (\alpha_{13}\alpha_{22} + \alpha_{12}\alpha_{23})\varepsilon_{1,t-1}\varepsilon_{2,t-1}$$

$$+ (\alpha_{13}\alpha_{32} + \alpha_{12}\alpha_{33})\varepsilon_{1,t-1}\varepsilon_{3,t-1} + (\alpha_{23}\alpha_{32} + \alpha_{22}\alpha_{33})\varepsilon_{2,t-1}\varepsilon_{3,t-1} + \beta_{12}\beta_{13}h_{11,t-1} + \beta_{22}\beta_{23}h_{22,t-1}$$

$$+ \beta_{32}\beta_{33}h_{33,t-1} + (\beta_{22}\beta_{13} + \beta_{12}\beta_{23})h_{12,t-1} + (\beta_{32}\beta_{13} + \beta_{12}\beta_{33})h_{13,t-1} + (\beta_{32}\beta_{23} + \beta_{22}\beta_{33})h_{23,t-1}$$

Appendix B. Coefficients of Trivariate GARCH Model

Table B.1: Coefficients of Multivariate GARCH Model for Case I and Case II

	Case I			Case II		
	$i=1$	$i=2$	$i=3$	$i=1$	$i=2$	$i=3$
μ_i	-0.002***	-0.008**	0.005***	0.002	-0.005***	0.006***
	(-2.710)	(-2.362)	(4.247)	(0.734)	(-7.346)	(16.31)
γ_{i1}	0.187**	1.003***	-0.193**	-0.279***	0.244***	-0.134***
	(2.470)	(3.761)	(-2.031)	(-4.068)	(6.869)	(-6.194)
γ_{i2}	0.004	-0.041	0.027**	0.036	0.013	-0.017***
	(0.649)	(-0.793)	(2.024)	(1.306)	(0.939)	(-3.586)
γ_{i3}	0.018	0.090	-0.051	0.039	0.074***	-0.185***
	(0.862)	(0.775)	(-1.134)	(0.460)	(3.165)	(-8.652)
ω_{1i}	-0.000			0.000		
	(-0.000)			(0.000)		
ω_{2i}	0.002	-0.008		0.001	0.006	
	(0.222)	(-0.341)		(0.014)	(0.142)	
ω_{3i}	-0.001	0.012	0.018***	0.000	0.012	-0.001
	(-1.458)	(1.611)	(10.12)	(0.014)	(0.620)	(-0.637)
α_{1i}	0.498***	0.950***	-0.145	0.068*	0.062*	-0.009
	(6.852)	(3.545)	(-1.529)	(1.684)	(1.763)	(-0.367)
α_{2i}	0.002	0.416***	-0.064***	0.010	0.463***	0.005
	(0.142)	(7.747)	(-3.573)	(0.442)	(39.78)	(0.740)
α_{3i}	-0.047	-0.367**	0.528***	-0.143*	-0.154***	0.807***
	(-1.118)	(-2.482)	(8.127)	(-1.793)	(-6.539)	(30.88)

β_{1i}	0.914***	-0.130	-0.055	0.998***	0.023	0.014
	(29.78)	(-0.932)	(-0.707)	(107.6)	(0.383)	(0.392)
β_{2i}	0.009	0.894***	-0.058*	-0.009	0.698***	-0.007
	(0.739)	(15.94)	(-1.838)	(-0.385)	(86.47)	(-1.484)
β_{3i}	0.070	0.210	0.477***	0.055	0.069***	0.723***
	1.295)	0.857)	(3.869)	(1.471)	(5.067)	(80.77)

Note: (Case I) *i*=1: Won/dollar exchange rate change, *i*=2: Korean CDS spread change, *i*=3: Korean stock return. (Case II) *i*=1: Won/yen exchange rate change, *i*=2: Korean CDS spread change, *i*=3: Korean stock return. The values in parentheses are standard errors. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

Table B.2: Coefficients of Multivariate GARCH Model for Case III and Case IV

	Case III			Case IV		
	i = 1	*i* = 2	*i* = 3	*i* = 1	*i* = 2	*i* = 3
μ_i	-0.005	-0.004	0.002	0.001	-0.001	0.003
	(-0.928)	(-0.549)	(1.026)	(0.587)	(-0.201)	(1.498)
γ_{i1}	0.094	-0.774***	0.402***	0.032	-0.021	-0.003
	(0.473)	(-2.588)	(5.002)	(0.469)	(-0.088)	(-0.053)
γ_{i2}	-0.001	0.061	-0.012	-0.037*	0.128**	-0.033
	(-0.012)	(0.678)	(-0.464)	(-1.759)	(2.382)	(-1.428)
γ_{i3}	-0.236	0.565**	-0.347***	-0.101	0.166	-0.116
	(-1.537)	(2.380)	(-5.019)	(-1.487)	(0.580)	(-1.627)
ω_{1i}	0.000			0.000		
	(0.000)			(0.000)		
ω_{2i}	-0.036	0.027		-0.003	-0.025	
	(-0.203)	(0.193)		(-0.061)	(-0.180)	
ω_{3i}	-0.006	-0.044	0.024***	0.004	-0.031	0.003
	(-0.285)	(-1.151)	(2.623)	(0.342)	(-0.277)	(0.211)
α_{1i}	0.281	0.047	0.060	0.078	1.003***	-0.291***
	(1.102)	(0.090)	(0.496)	(1.136)	(3.774)	(-4.513)
α_{2i}	-0.231***	0.615***	-0.145***	-0.045***	0.090*	-0.057***
	(-3.145)	(4.355)	(-2.715)	(-3.691)	(1.813)	(-3.038)
α_{3i}	-0.054	0.613*	0.103	0.182**	-1.500***	0.404***
	(-0.236)	(1.800)	(0.918)	(2.550)	(-8.345)	(5.823)

β_{1i}	0.473 (0.582)	-0.498 (-0.374)	0.037 (0.105)	1.207*** (24.45)	-0.070 (-0.391)	0.180*** (3.099)
β_{2i}	0.111 (0.818)	0.853*** (3.750)	-0.012 (-0.233)	0.038*** (2.609)	0.711*** (12.14)	0.108*** (6.867)
β_{3i}	0.246 (0.221)	1.206 (0.572)	0.509 (0.963)	-0.064 (-0.985)	-0.720*** (-2.987)	0.938*** (11.07)

Note: (Case III) i=1: U.S. stock return, i=2: Korean CDS spread change, i=3: Korean stock return. (Case IV) i=1: Japanese stock return, i=2: Korean CDS spread change, i=3: Korean stock return. The values in parentheses are standard errors. *** indicates significance at the 1% level, ** indicates significance at the 5% level and * indicates significance at the 10% level.

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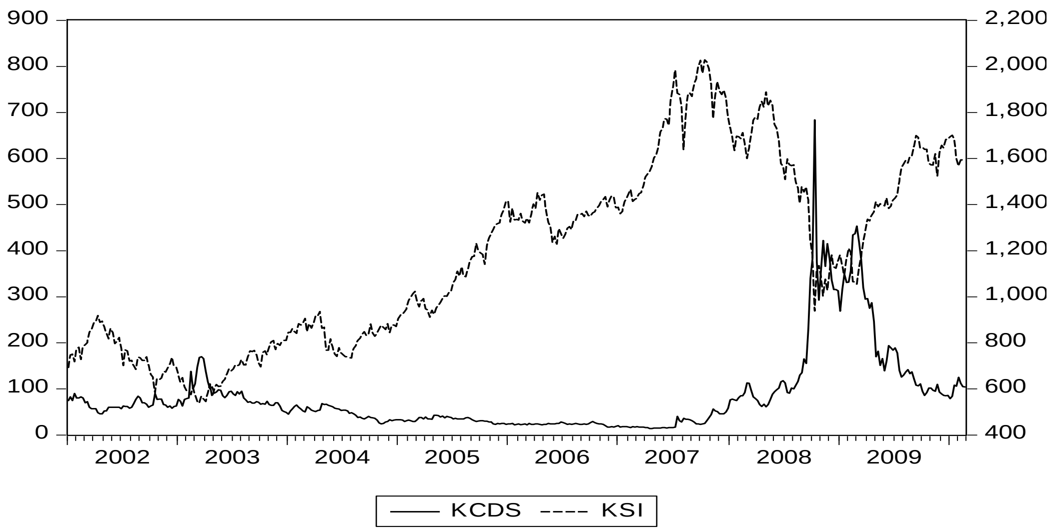
Figure 1: Korean CDS Spread and Korean Stock Market Index (KOSPI)

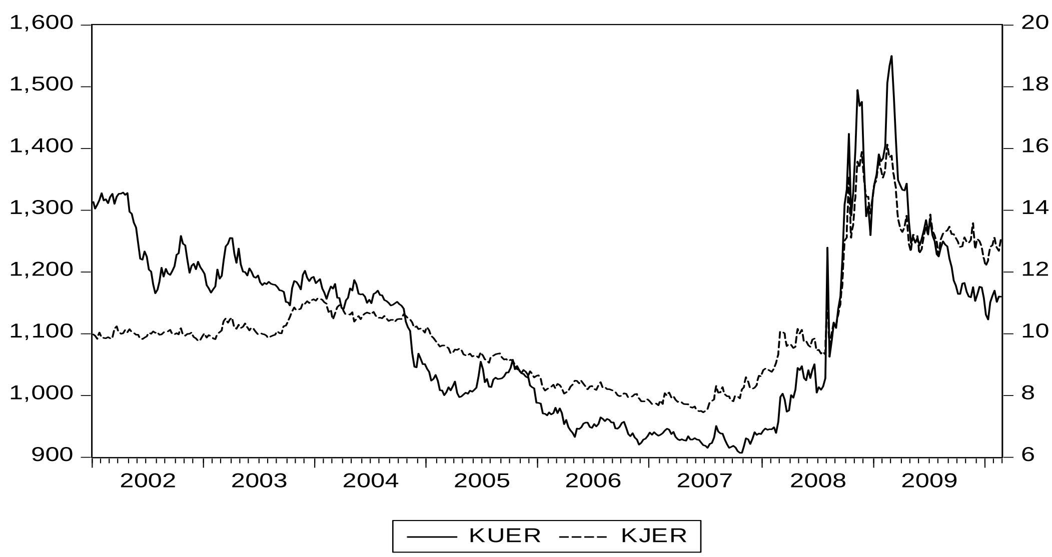


Note: Solid line of KCDS denotes the CDS spread underlying Korean government bonds. Dotted line of KSI denotes the Korean stock market index (KOSPI). Numerical values on the left side are KCDS, and numerical values on the right side are KSI. The data period is from Jan. 2002 W1 to Feb. 2010 W4. The data source is the Korea Centre for International Finance (KCIF).

Figure 2: U.S. Stock Market Index (S&P 500) and Japanese Stock Market Index (NIKKEI 225)

Note: Solid line of USI denotes the U.S. stock market index (S&P 500). Dotted line of JSI denotes the Japanese stock market index (NIKKEI 225). Numerical values on the left side are USI, and numerical values on the right side are JSI. The data period is from Jan. 2002 W1 to Feb. 2010 W4. The data source is the Korea Centre for International Finance (KCIF).

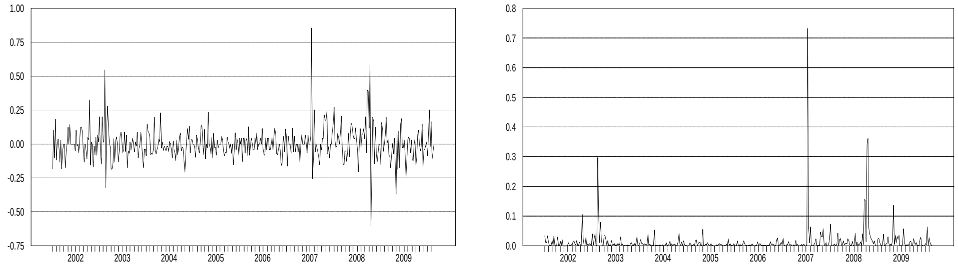
Figure 3: Won/Dollar Exchange Rate and Won/Yen Exchange Rate



Note: Solid line of KUER denotes the won/dollar exchange rate. Dotted line of KJER denotes the won/yen exchange rate. Numerical values on the left side are KUER, and numerical values on the right side are KJER. The data period is from Jan. 2002 W1 to Feb. 2010 W4. The data source is the Bank of Korea.

Figure 4: Time Plots of Returns (Changes) and Squared Series

(a) Korean CDS Spread Change



(b) Won/Dollar Exchange Rate Change

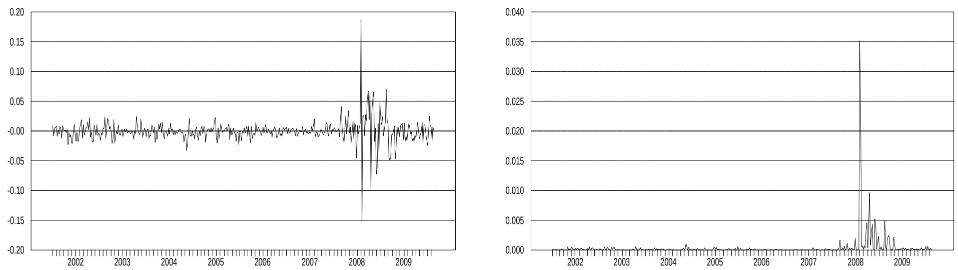
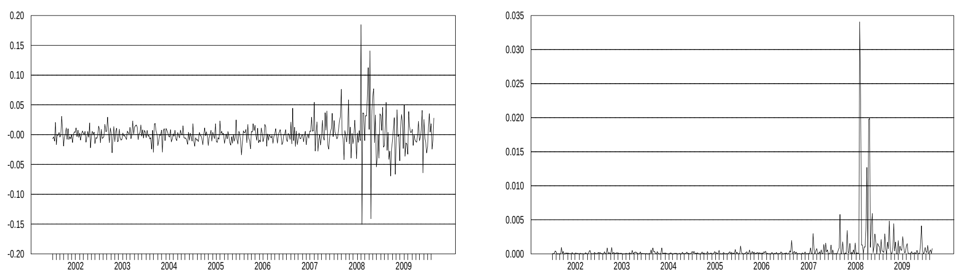
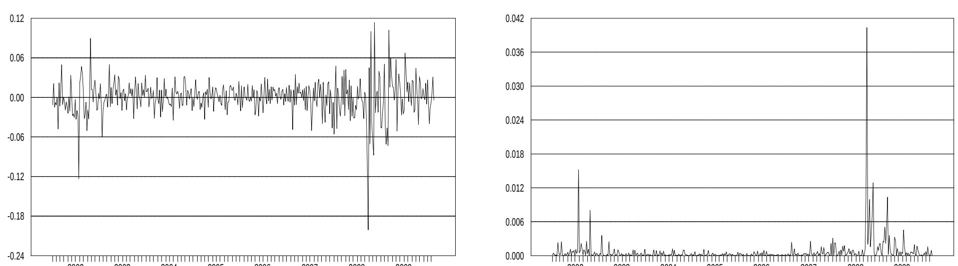


Figure 4 (continued)

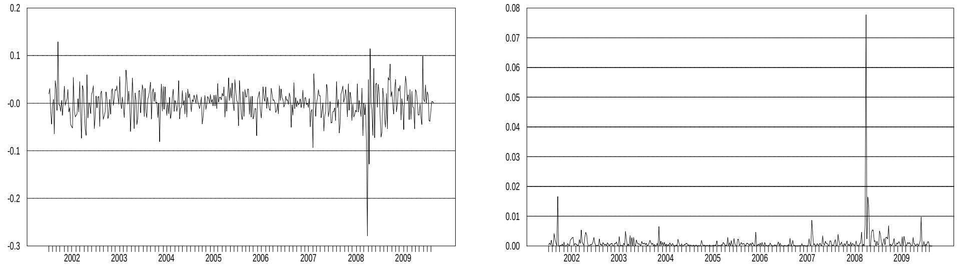
(c) Won/Yen Exchange Rate Change



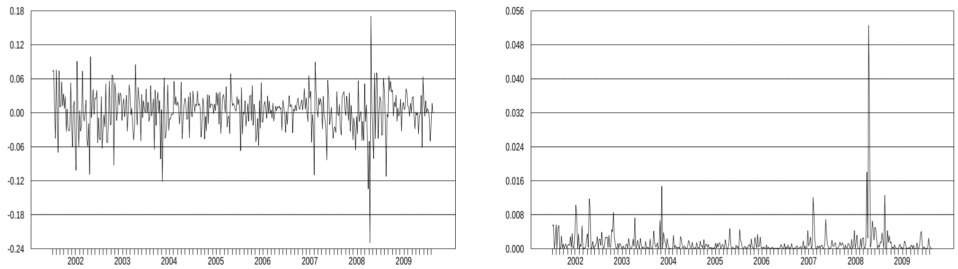
(d) U.S. Stock Return



(e) Japanese Stock Return



(f) Korean Stock Return

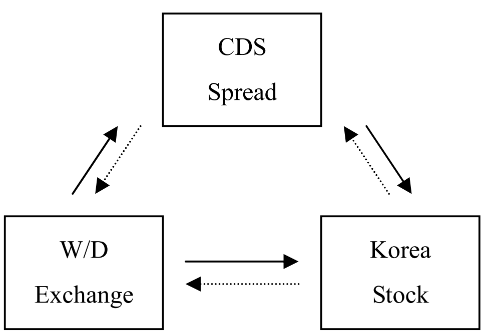


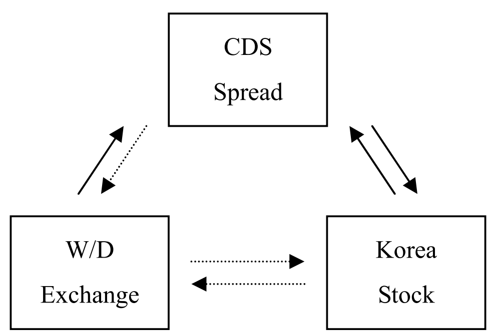
Note: Left column displays the time plots of returns and changes. Right column displays the squared series from original returns and changes. The data period is from Jan. 2002 W1 to Feb. 2010 W4.

Figure 5: Return and Volatility Spillover Effects for Case I and Case II

(Case I) Won/dollar exchange rate change – CDS spread change – Korean stock return

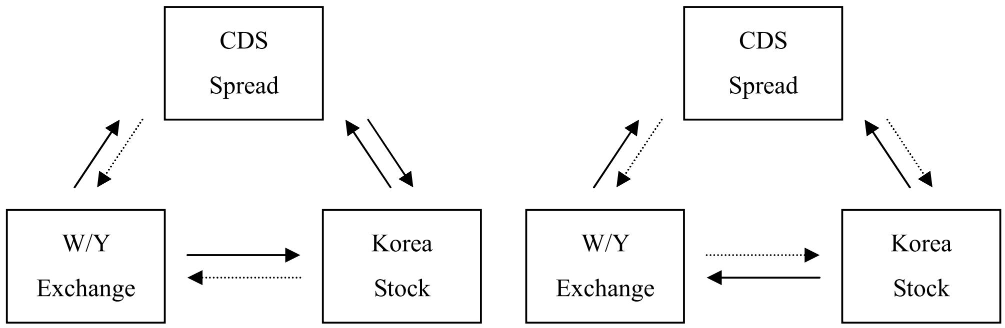
(a) Return Spillover Effect (b)Volatility Spillover Effect





(Case II) Won/yen exchange rate change – CDS spread change – Korean stock return

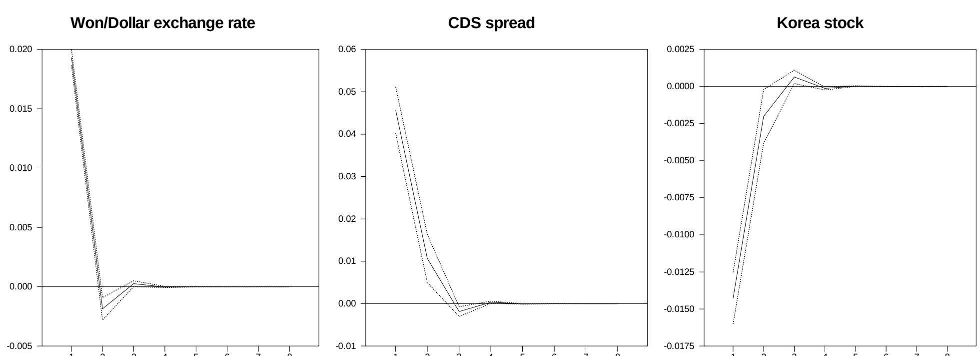
(a) Return Spillover Effect (b)Volatility Spillover Effect



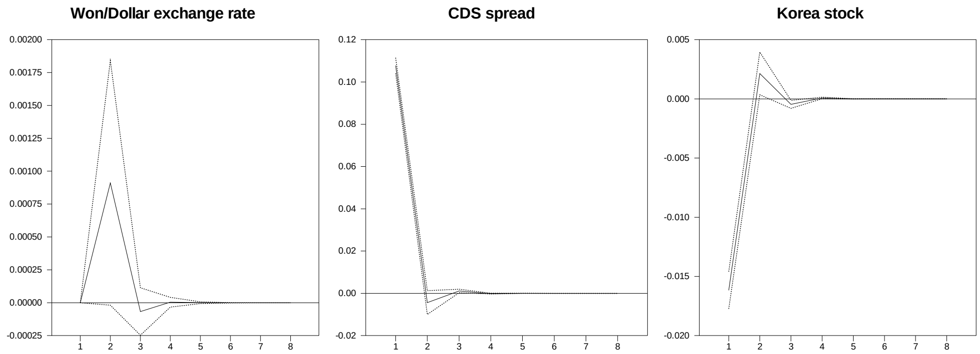
Note: —— denotes significant spillover effect, and ········ denotes insignificant spillover effect

Figure 6: Impulse Response Functions for Case I

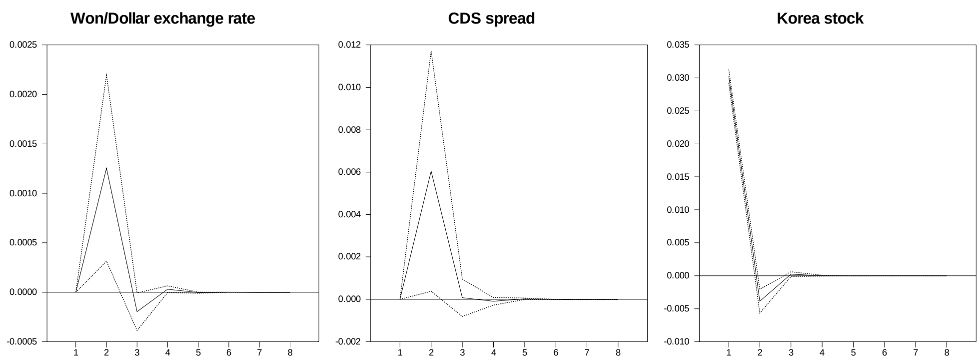
(a) Responses to Won/Dollar Exchange Rate Change Shock



(b) Responses to CDS Spread Change Shock



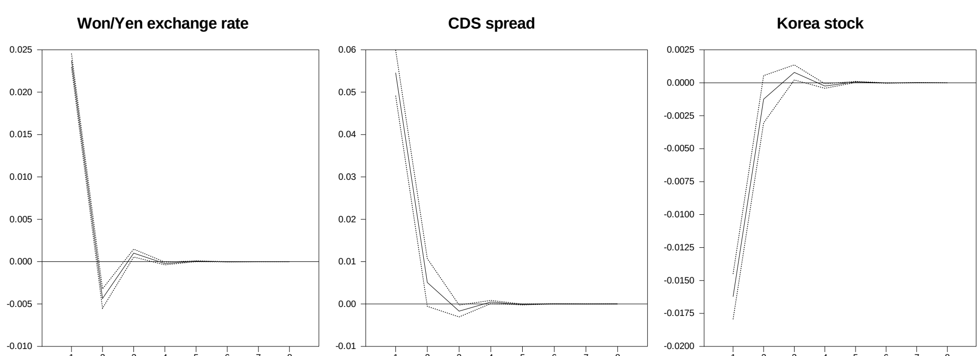
(c) Responses to Korean Stock Return Shock



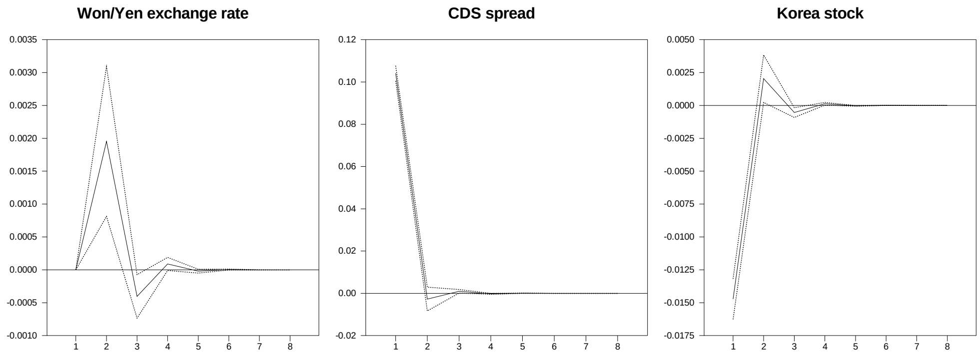
Note: Solid lines depict impulse responses of each one standard deviation increasing shock, and broken lines depict the upper and lower one standard error bands.

Figure 7: Impulse Response Functions for Case II

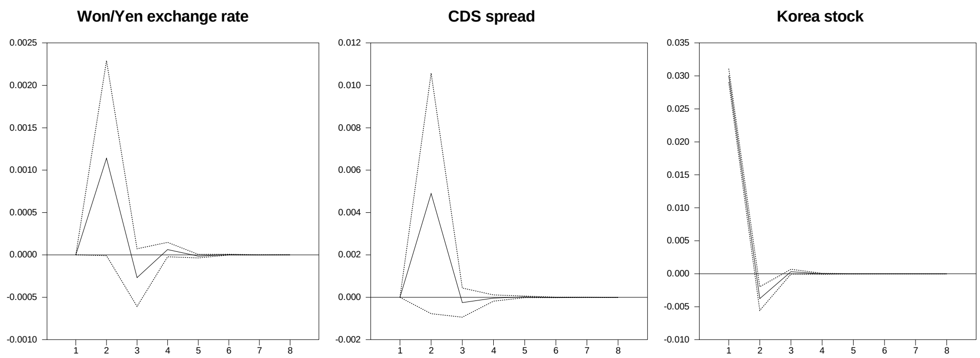
(a) Responses to Won/Yen Exchange Rate Change Shock



(b) Responses to CDS Spread Change Shock



(c) Responses to a Korean Stock Return Shock

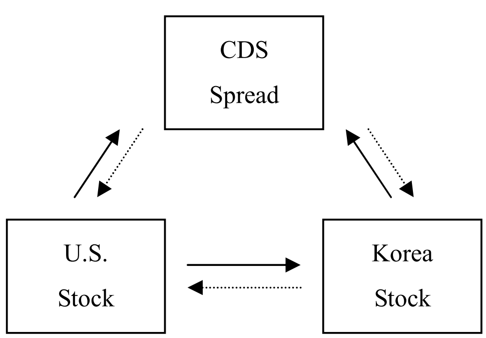


Note: Solid lines depict impulse responses of each one standard deviation increasing shock, and broken lines depict the upper and lower one standard error bands.

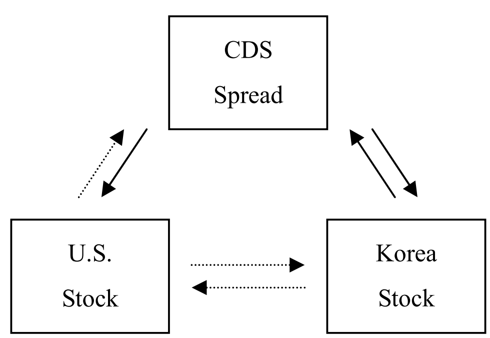
Figure 8: Return and Volatility Spillover Effects for Case III and Case IV

(Case III) U.S. stock return – CDS spread change – Korean stock return

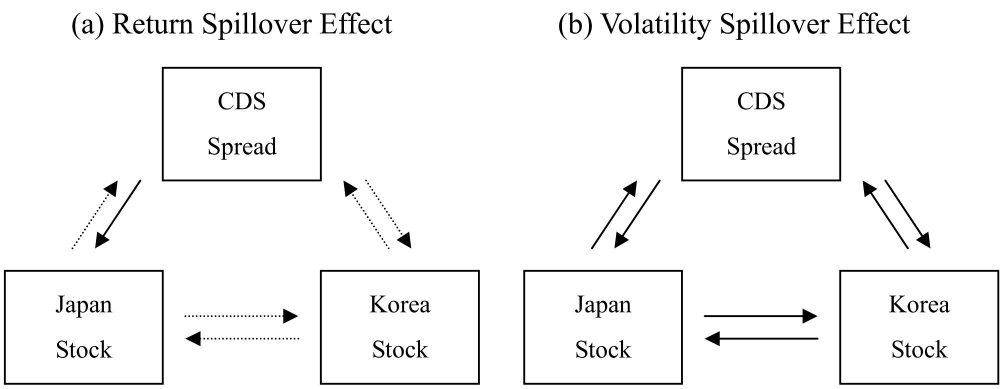
(a) Return Spillover Effect



(b) Volatility Spillover Effect



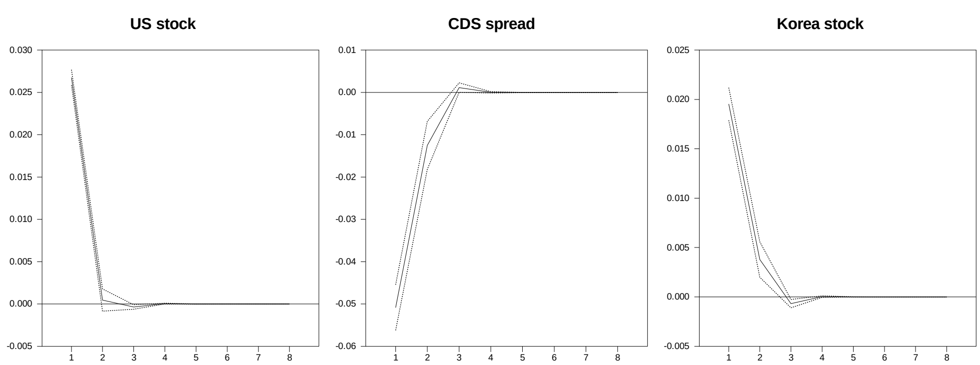
(Case IV) Japanese stock return – CDS spread change – Korean stock return



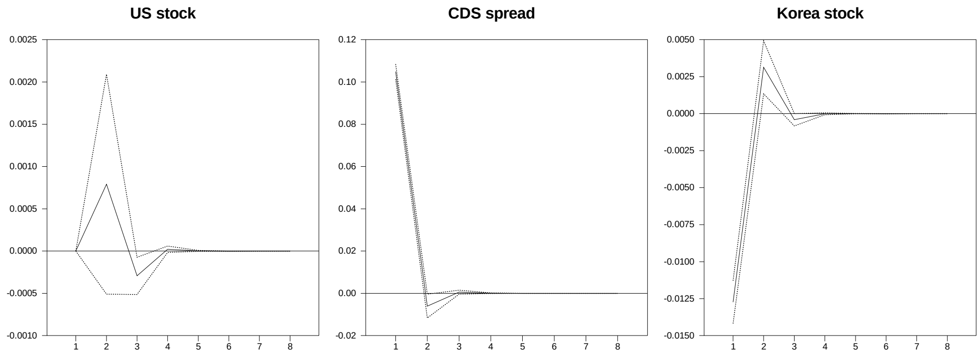
Note: —— denotes significant spillover effect, and ········ denotes insignificant spillover effect

Figure 9: Impulse Response Functions for Case III

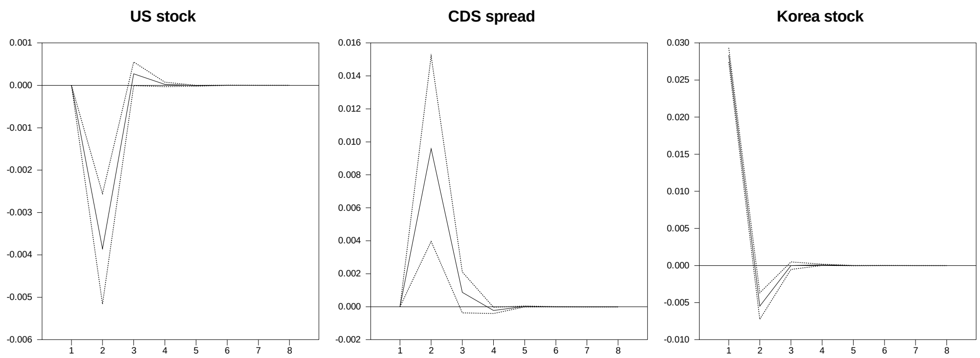
(a) Responses to U.S. Stock Return Shock



(b) Responses to CDS Spread Change Shock



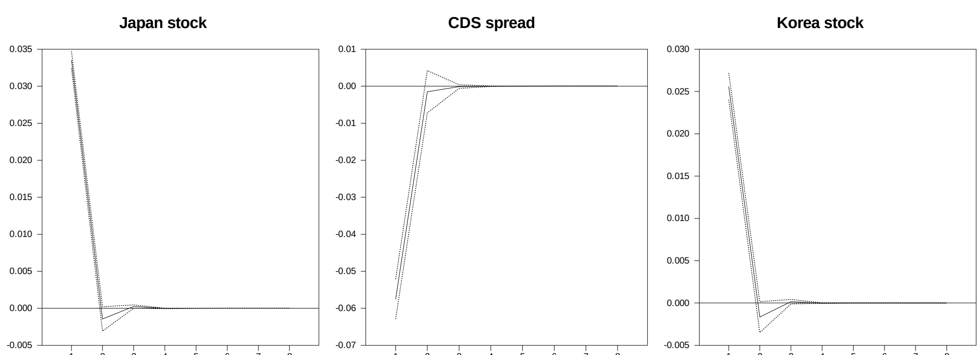
(c) Responses to Korean Stock Return Shock



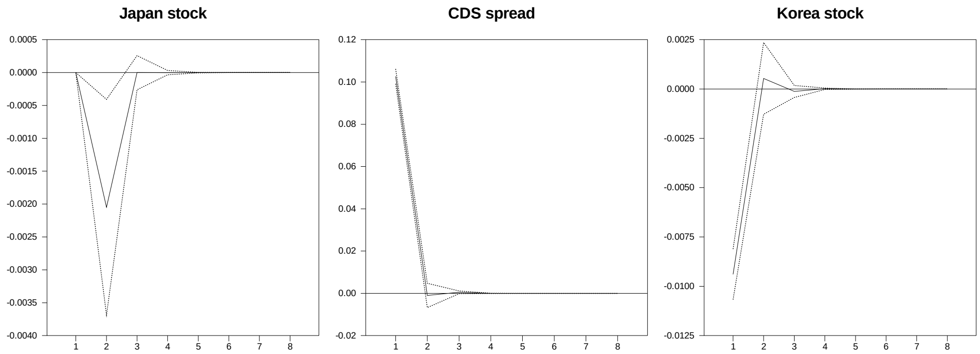
Note: Solid lines depict impulse responses of each one standard deviation increasing shock, and broken lines depict the upper and lower one standard error bands.

Figure 10: Impulse Response Functions for Case IV

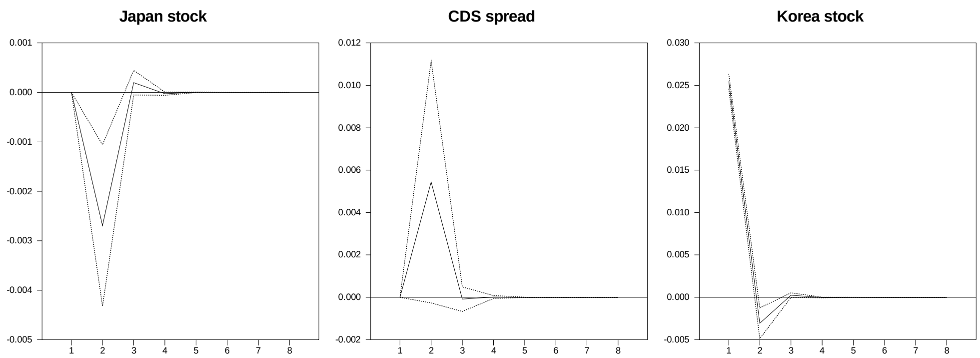
(a) Responses to Japanese Stock Return Shock



(b) Responses to CDS Spread Change Shock



(c) Responses to Korean Stock Return Shock



Note: Solid lines depict impulse responses of each one standard deviation increasing shock, and broken lines depict the upper and lower one standard error bands.

Table 1: ADF Test and PP Test

Prices and Rates	Model I		Model II		Model III	
	ADF	PP	ADF	PP	ADF	PP
Korean CDS Spread	-2.61*	-2.68*	-2.87*	-2.96*	-1.87*	-1.73*
	(-20.63)	(-20.63)	(-20.63)	(-20.62)	(-20.65)	(-20.65)
Korean-U.S. Exchange Rate	-2.00*	-1.91*	-1.88*	-1.73*	-0.56*	-0.59*
	(-22.65)	(-22.64)	(-22.68)	(-22.75)	(-22.67)	(-22.66)
U.S. Stock	-1.45*	-1.47*	-1.46*	-1.48*	-0.32*	-0.32*
	(-20.23)	(-20.23)	(-20.21)	(-20.21)	(-20.26)	(-20.26)

Korean-Japanese Exchange Rate	-0.88* (-24.74)	-1.01* (-24.62)	-1.24* (-24.77)	-1.37* (-24.62)	0.44* (-24.75)	0.36* (-24.62)
Japanese Stock	-1.27* (-21.45)	-1.30* (-21.45)	-1.11* (-21.45)	-1.14* (-21.45)	-0.35* (-21.48)	-0.36* (-21.48)
Korean Stock	-1.20* (-22.59)	-1.19* (-22.59)	-1.90* (-22.56)	-1.91* (-22.57)	0.59* (-22.55)	0.62* (-22.55)

Note: Model I represents the case of no constant and trend. The case with constant is in Model II, and the case with both constant and trend is in Model III. * denotes that there is a unit root in the data under the 5% level of critical value. Parentheses located on the second line denote the statistics of ADF test and PP test for returns and changes corresponding to each level series of variables.

Table 2: Ljung-Box *Q*-statistics of returns and changes

Returns and changes	1	2	3	5	10	15	20
Korean CDS Spread	0.001 (0.98)	0.024 (0.99)	1.488 (0.69)	3.635 (0.60)	5.016 (0.89)	15.17 (0.44)	18.86 (0.53)
Korean-U.S. Exchange rate	4.021 (0.04)	5.082 (0.07)	5.448 (0.14)	10.06 (0.07)	17.47 (0.06)	65.86 (0.00)	86.24 (0.00)
U.S. Stock	0.100 (0.75)	1.616 (0.44)	6.212 (0.10)	8.723 (0.12)	21.50 (0.01)	33.10 (0.00)	49.40 (0.00)
Korean-Japanese Exchange rate	14.59 (0.00)	18.95 (0.00)	19.14 (0.00)	19.68 (0.00)	43.91 (0.00)	80.53 (0.00)	92.93 (0.00)
Japanese Stock	0.791	2.074	2.282	2.316	3.091	6.345	11.81

	(0.37)	(0.36)	(0.51)	(0.80)	(0.97)	(0.97)	(0.92)
Korean Stock	3.493	3.634	5.301	5.748	14.22	22.77	24.80
	(0.06)	(0.16)	(0.15)	(0.33)	(0.16)	(0.08)	(0.20)

Note: The numbers in parentheses denote *P*-value.

Table 3: Cross-Correlation between Two Financial Markets

(A)	(B)	Shift	0	1	2	5	10	15	20
Korean CDS Spread	Won/ Dollar	Lag	0.374	0.007	-0.019	0.086	-0.087	0.005	0.105
		lead	0.374	0.092	0.042	0.031	0.164	-0.083	0.024
	U.S. Stock	Lag	-0.439	0.023	0.031	0.030	0.069	-0.074	-0.187
		lead	-0.439	-0.106	-0.143	-0.009	0.044	-0.062	-0.053
	Won/ Yen	Lag	0.445	-0.010	-0.000	0.020	-0.064	-0.002	0.071
		lead	0.445	0.045	0.041	0.007	0.147	-0.057	0.034
	Japanese Stock	Lag	-0.489	-0.032	-0.029	0.021	-0.004	-0.014	-0.093
		lead	-0.489	-0.013	-0.099	-0.028	-0.005	-0.052	-0.000
	Korean	Lag	-0.558	0.025	-0.025	-0.015	0.037	-0.012	-0.003

	Stock	lead	-0.558	0.035	-0.080	0.023	-0.012	0.018	-0.108
Korean Stock Return	Won/ Dollar	Lag	-0.373	-0.056	-0.024	0.010	-0.208	0.039	-0.056
		lead	-0.373	0.068	-0.028	-0.058	0.123	-0.016	-0.078
	U.S. Stock	Lag	0.537	0.099	0.220	-0.031	-0.030	0.090	0.056
		lead	0.537	-0.114	-0.034	-0.008	-0.043	0.022	0.156
	Won/ Yen	Lag	-0.417	-0.037	-0.058	0.023	-0.146	0.034	-0.096
		lead	-0.417	0.082	-0.036	-0.012	0.084	0.020	-0.061
	Japanese Stock	Lag	0.686	-0.045	0.147	0.007	-0.015	0.045	0.069
		lead	0.686	-0.069	-0.024	-0.015	0.016	0.043	0.076

Note: (A) and (B) are target returns or changes to be tested for cross-correlation.

Table 4: Descriptive Statistics for the Financial Series

Statistics	CDS Spread	Won /Dollar	U.S. Stock	Won /Yen	Japanese Stock	Korean Stock
Mean	0.001	-0.001	-0.001	0.001	-0.001	0.002
Maximum	0.856	0.187	0.114	0.185	0.129	0.170
Minimum	-0.601	-0.154	-0.201	-0.151	-0.279	-0.229
Std.Dev.	0.118	0.019	0.027	0.024	0.034	0.037
Skewness	1.284	0.863	-1.037	0.843	-1.372	-0.713
Kurtosis	13.056	34.894	12.522	20.01	14.358	7.489
Jarque-Bera	1907.5	18066.1	1681.9	5173.9	2417.9	392.8
Probability	0.000	0.000	0.000	0.000	0.000	0.000

Table 5: Estimates of Trivariate GARCH Model for Case I and Case II

	Case I			Case II		
Return Spillover Effect (Mean Equation)						
γ_{ij}	$i = 1$	$i = 2$	$i = 3$	$i = 1$	$i = 2$	$i = 3$
γ_{i1}	0.187** (0.076)	1.003*** (0.267)	-0.193** (0.095)	-0.279*** (0.069)	0.244*** (0.035)	-0.134*** (0.022)
γ_{i2}	0.004 (0.007)	-0.041 (0.052)	0.027** (0.013)	0.036 (0.027)	0.013 (0.014)	-0.017*** (0.005)
γ_{i3}	0.018	0.090	-0.051	0.039	0.074***	-0.185***

	(0.021)	(0.116)	(0.045)	(0.085)	(0.023)	(0.021)
Volatility Spillover Effect (Variance Equation)						
h_{ij}	$h_{11,t}$	$h_{22,t}$	$h_{33,t}$	$h_{11,t}$	$h_{22,t}$	$h_{33,t}$
$\varepsilon^2_{1,t-1}$	0.248***	0.902***	0.021	0.005*	0.004*	8.21e-5
	(0.073)	(0.268)	(0.095)	(0.040)	(0.035)	(0.025)
$\varepsilon^2_{2,t-1}$	2.44e-6	0.173***	0.004***	1.06e-4	0.215***	2.79e-5
	(0.011)	(0.054)	(0.018)	(0.023)	(0.012)	(0.007)
$\varepsilon^2_{3,t-1}$	0.002	0.135**	0.279***	0.020*	0.024***	0.652***
	(0.042)	(0.148)	(0.065)	(0.079)	(0.024)	(0.026)
$h_{11,t-1}$	0.835***	0.017	0.003	0.997***	0.001	2.02e-4
	(0.031)	(0.140)	(0.078)	(0.009)	(0.059)	(0.036)
$h_{22,t-1}$	8.98e-5	0.799***	0.003*	7.24e-5	0.487***	5.47e-5
	(0.013)	(0.056)	(0.032)	(0.022)	(0.008)	(0.005)
$h_{33,t-1}$	0.005	0.044	0.228***	0.003	0.005***	0.522***
	(0.054)	(0.245)	(0.123)	(0.038)	(0.014)	(0.009)

Note: (Case I) i=1: Won/dollar exchange rate change, i=2: Korean CDS spread change, i=3: Korean stock return. (Case II) i=1: Won/yen exchange rate change, i=2: Korean CDS spread change, i=3: Korean stock return. The values in parentheses are standard errors. *** indicates significance at the 1% level, ** indicates significance at the 5% level, and * indicates significance at the 10% level.

Table 6: Estimates of Trivariate GARCH Model for Case III and Case IV

	Case III			Case IV		
Return Spillover Effect (Mean Equation)						
γ_{ij}	$i = 1$	$i = 2$	$i = 3$	$i = 1$	$i = 2$	$i = 3$
γ_{i1}	0.094	-0.774***	0.402***	0.032	-0.021	-0.003
	(0.199)	(0.299)	(0.080)	(0.068)	(0.235)	(0.058)
γ_{i2}	-0.001	0.061	-0.012	-0.037*	0.128**	-0.033
	(0.057)	(0.090)	(0.027)	(0.021)	(0.054)	(0.023)

γ_{i3}	-0.236 (0.153)	0.565** (0.237)	-0.347*** (0.069)	-0.101 (0.068)	0.166 (0.286)	-0.116 (0.071)
Volatility Spillover Effect (Variance Equation)						
h_{ij}	$h_{11,t}$	$h_{22,t}$	$h_{33,t}$	$h_{11,t}$	$h_{22,t}$	$h_{33,t}$
$\varepsilon^2_{1,t-1}$	0.079 (0.255)	0.002 (0.523)	0.004 (0.122)	0.006 (0.069)	1.007*** (0.266)	0.085*** (0.064)
$\varepsilon^2_{2,t-1}$	0.053*** (0.073)	0.379*** (0.141)	0.013*** (0.053)	0.002*** (0.012)	0.008* (0.050)	0.003*** (0.019)
$\varepsilon^2_{3,t-1}$	0.003 (0.228)	0.376* (0.341)	0.011 (0.112)	0.033** (0.072)	2.251*** (0.180)	0.163*** (0.069)
$h_{11,t-1}$	0.223 (0.812)	0.248 (1.331)	0.001 (0.351)	1.056*** (0.042)	0.005 (0.179)	0.033*** (0.058)
$h_{22,t-1}$	0.012 (0.135)	0.728*** (0.228)	1.52e-4 (0.053)	0.001*** (0.015)	0.505*** (0.059)	0.012*** (0.016)
$h_{33,t-1}$	0.061 (1.117)	1.455 (2.108)	0.259 (0.529)	0.004 (0.064)	0.518*** (0.241)	0.880*** (0.085)

Note: (Case III) *i*=1: U.S. stock return, *i*=2: Korean CDS spread change, *i*=3: Korean stock return. (Case IV) *i*=1: Japanese stock return, *i*=2: Korean CDS spread change, *i*=3: Korean stock return. The values in parentheses are standard errors. *** indicates significance at the 1% level, ** indicates significance at the 5% level, and * indicates significance at the 10% level.