

Revisited Return and Volatility Spillover Effect in Korea*

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This paper investigates the price returns and volatility linkages between the foreign exchange (KRW) and stock (KOSPI) markets in Korea, using the cointegration test, and bivariate GJR-GARCH model. Our findings from empirical analysis are summarized as follows. First, there is no long-term equilibrium relationship between the KRW and KOSPI markets. Second, exogenous variables (yen/dollar exchange rate and S&P 500 index) have strong impact on the returns of both the KRW and KOSPI. Third, with regard to return spillover, a uni-directional volatility spillover exists from the KOSPI market to the KRW market. Fourth, our empirical results provide no evidence of volatility spillover effect in the pre-crisis, but an evidence of uni-directional volatility spillover effect from the KRW market to the KOSPI market in the post-crisis period, implying that financial crisis improves linkages between these two markets. Finally, we do not find the asymmetric volatility spillover effect between two markets. Thus, investors in the Korean stock market and/or the foreign exchange market need to consider the relationship between these two markets as part of their investment decisions.

JEL Classification: C32, C58, F31, G11

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1. INTRODUCTION

For theoretical and empirical reasons, the dynamic relationships between equity prices and foreign exchange rates have attracted the attention of numerous researchers and practitioners because these factors both play crucial roles in forecasting an economy and managing portfolios and risk. Due to the higher level of cross-border financial asset flows, domestic or international equity investors might be exposed to diverse currency risks. Thus, portfolio and risk managers must consider the linkages between equity and exchange rates in order to design appropriate investment strategies.

There are two traditional theories about the linkage between foreign exchange rates and stock prices. The first approach is the “flow-oriented” model of exchange rates (Dornbusch and Fisher, 1980). This model claims that changes in exchange rates alter the international competitiveness of a firm as well as the balance of trade position, and thus exchange rate changes affect real income and output in a country. Share prices of companies are influenced by exchange rate changes and future cash flows of firms. This implies that exchange rate changes lead to stock price returns, and that they are positively correlated.

In contrast, the alternative approach relates to “stock-oriented” models of exchange rates (Branson, 1983; Frankel, 1983). These models show exchange rates as serving the supply and demand for financial assets such as stocks and bonds. This approach suggests that an increase in stock prices induces investors to demand more domestic assets and thereby causes an appreciation in the domestic currency, implying that stock prices lead exchange rates and that they are negatively related. The appreciation of the domestic currency attracts more foreign capital and investments into the domestic market, which then leads to further currency appreciation.

The primary aim of this paper is to investigate the dynamic linkages between the Korean stock market (KOSPI) and the Korean exchange market (KRW) using a VAR(1)-biivariate GJR-GARCH model. The contribution of this study is threefold. First, although many studies have done the

dynamic relationship between two markets, there is no consensus on the relationship between two markets. In this context, we re-examine the volatility linkages to provide information on the complex volatility transmission, portfolio diversification and asset allocation.

Second, this study also considers the impact of exogenous variables (the yen/dollar exchange rates and the U.S stock returns) on the spillover effect of Korean financial markets. Lee (2010) suggested that foreign financial variables have a strong influence on volatility of domestic financial variables (stock returns and exchange rate). It would be interesting to indentify the impact of the U.S. stock returns on a causal relationship between KRW exchange rates and KOSPI returns.

Third, little attention has been paid to an asymmetric volatility spillover transmission between two markets, i.e., bad stock market news increases the volatility of exchange rate market. Such a feature offers the portfolio trading strategy. For example, the trading strategy consists of taking a position in stock following the signals given by the volatility of the exchange market. Thus, a good understanding of the asymmetric volatility spillover effect is an important ingredient for designing trading and hedging strategies and optimizing portfolios between two markets.

Finally, we examine how the financial crisis affected the dynamic relationship between stock returns and exchange rate changes. We assume the null hypothesis that the impact of a financial crisis leads to market contagion between KOSPI and KRW markets. Analyzing whether the transmission of price returns and volatility exists between the foreign exchange market and the equity market can help clarify the linkages between the two markets and the nature of risks that the participants in both markets have to cope with.

The rest of this paper is organized as follows. Section 2 discusses a brief overview of prior literature. Section 3 provides descriptive statistics of the sample data. Section 4 presents the econometric methodology used in this study. Section 5 discusses the empirical results. Section 6 presents our conclusions.

2. LITERATURE REVIEWS

Previous studies have placed emphasis on the first moments of the exchange rates and stock prices and have found a significant relationship between exchange rates and stock prices. However, the results have been mixed for the sign and causal direction between exchange rates and stock prices (Nieh and Lee, 2001; Phylaktis and Ravazzolo, 2005; Tabak, 2006; Pan, Fok, and Liu, 2007; Yau and Nieh, 2009).

A number of studies have examined the volatility spillover between different assets or markets (Engle, Ito, and Lin, 1990; Baillie and Bollerslev, 1991; Ito, Engle, and Lin, 1992; Cheung and Ng, 1996; Hong, 2001; Bhar and Hamori, 2003; Inagaki, 2007). The existence of volatility spillover implies that one large shock increases the volatilities not only in its own asset or market but also in other assets or markets. Volatility is often related to the rate of information flow (Ross, 1989). If information comes in clusters, asset returns or prices may exhibit volatility even though the market perfectly and instantaneously adjusts to the news. Studies on volatility spillover can help clarify how information is transmitted across assets and markets.

Many empirical studies have focused on volatility spillover between exchange rates and equity markets. The evidence of volatility spillover indicates strong cross-market dependence in the volatility process. Three categories of research provide evidence of the volatility spillover effect. The first group of studies reports volatility spillovers from stock return changes to foreign currency fluctuations. Kanas (2000) first suggested evidence of a volatility spillover effect from stock returns to exchange rate changes in industrialized countries. Yang and Doong (2004) showed that movements of stock prices affect future exchange rate movements, but changes in exchange rates have less direct impact on future changes in stock prices in G-7 countries. Tai (2007) found evidence of volatility effects from stock to currency markets in some Asian markets.

The second group of studies supports volatility spillovers from exchange rate changes to stock returns. Apergis and Rezitis (2001) found a volatility

spillover effect from foreign exchange markets to stock markets, but the reverse effect is impossible. Yang and Chang (2008) concluded that foreign exchange markets play an important role in explaining domestic stock returns.

The final group of studies shows bi-directional volatility spillover between exchange rates and equity markets. Wu (2005) reported a bi-directional relationship between the volatility of stock prices and exchange rate changes during the recovery after the Asian financial crisis of 1997. Tasthan (2006) showed significant evidence of a bi-directional relationship between stock and foreign markets. Zhao (2010) found bi-directional volatility spillover effects between the Renminbi (RMB) and the Shanghai stock market index, indicating that past conditional variances in the stock market have a great impact on future volatility in foreign exchange markets, and vice versa.

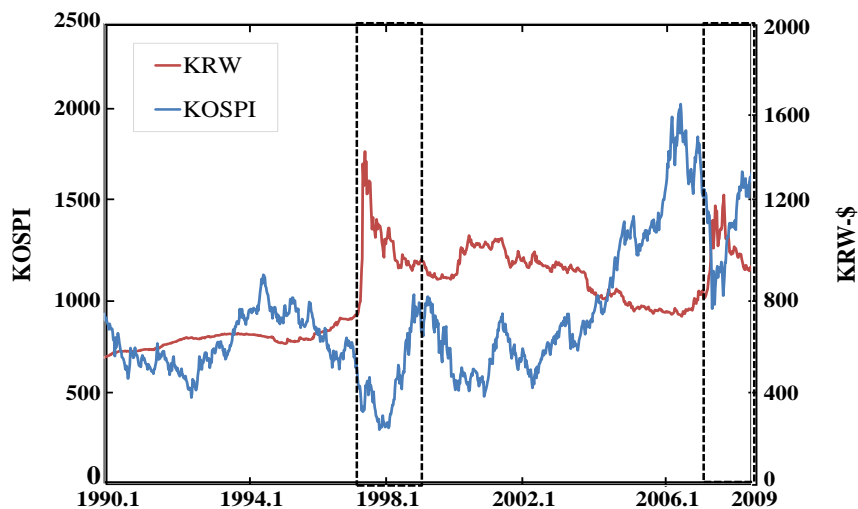
In the domestic case, many empirical studies have focused on a multivariate GARCH model in measuring the volatility spillover effect between the Korean stock market and won-dollar exchange market. Hahm (2004) examined the spillover effects in return and volatility between the S&P 500, KOSPI and won-dollar exchange rates during the financial crisis of 1997. This study empirically suggested that the Korean government has intervened in the won-dollar exchange market during the financial crisis. Park and Lee (2009) found that the expected stock returns are negatively related to the dynamic covariance with foreign exchange rate after the Asian currency crisis. Lee and Kim (2010) also reported a negative relationship between KOSPI and won-dollar exchange rates, but after the crisis this negative relationship becomes weaken. Lee (2010) investigated the impact of international financial shocks on the volatility of Korean financial markets and found that exogenous shocks (Dow Jones and yen/dollar exchange) have strong impact on the volatility of domestic markets. Cin (2011) examined asymmetric spillover effect between VIX and won-dollar exchange rates and suggested the existence of asymmetric volatility spillover effect in global market crisis. Kang and Yoon (2012) investigated the volatility spillover effect between stock prices and exchange rates in Asian markets using a bivariate GARCH model. They found strong bidirectional volatility

spillover between two markets in Asia.

3. DATA

This study mainly analyzes the dynamic relationship between stock prices and exchange rate in Korea. In this context, we consider two weekly Friday closing price data, Korea Composite Stock Price Index (KOSPI) and Korean won/US dollar (KRW), over the period from 8 January 1990 through 28 December 2009, respectively.¹⁾ Figure 1 shows the weekly prices of KOSPI

Figure 1 The Dynamics of Weekly Price Series of KOSPI and KRW

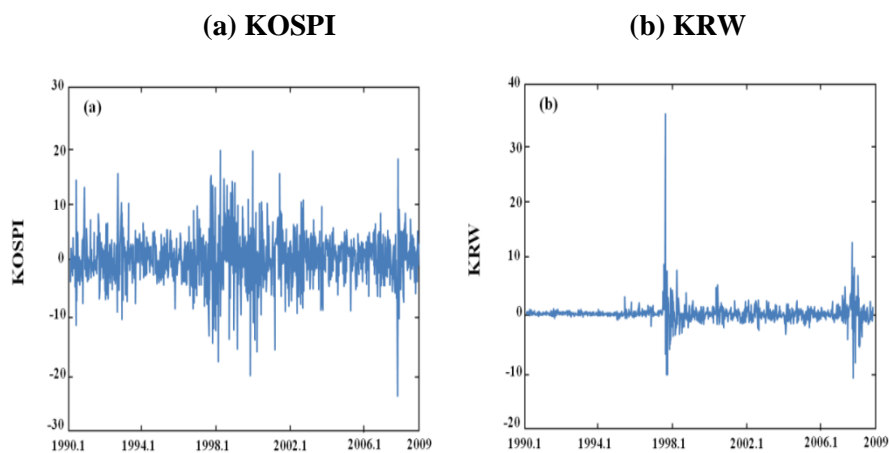


¹⁾ We obtained the KOSPI data from the Korean Exchange (KRX) and the KRW information from the database of the Bank of Korea (BOK). Weekly data were used in this study in an effort to minimize the possible distortion effects on time series such as seasonality, bid-ask bounce and non-synchronous trading, etc., which is common using daily returns. Following previous literature, the previous day of trading closing price was taken to calculate the return in those cases when a holiday occurred on Friday.

and KRW. Note that the dot line boxes indicate the 1997 Asian currency crisis period and the 2008 global financial crisis period. This selected period includes the 1997 Asian currency crisis, and thus we consider the impact of the currency crisis by dividing the full sample into two groups: pre-crisis (January 1990-September 1997) and post-crisis (January 1999-August 2008).²⁾ In the pre-crisis period, both prices show smooth movement, while the movements of both prices are volatile in the post-crisis period. Interestingly, their price direction often reverses after the crisis.

Both weekly price series are then converted into the logarithmic return series, i.e., $R_{i,t} = \ln(P_{i,t}/P_{i,t-1}) \times 100$, where $R_{i,t}$ denotes the continuously compounded percentage returns for index i at time t , and $P_{i,t}$ denotes the price level of index i at time t . The weekly return series are shown in figure 2.

Figure 2 The Dynamics of Weekly Return Series



²⁾ To avoid the impact of the crisis, we exclude the periods of Asian currency crisis and recent global crisis.

Table 1 Descriptive Statistics of Sample Return Series

Series		Whole	Pre-crisis	Post-crisis
		Jan. 1990- Dec. 2009	Jan. 1990- Sep. 1997	Jan. 1999- Aug. 2008
KRW	Mean	0.051	0.073	-0.019
	Std. Dev.	1.535	0.307	0.901
	Skewness	4.773	0.571	0.593
	Kurtosis	69.79	6.567	5.799
	J-B	198006 ^{***}	236.23 ^{***}	194.86 ^{***}
	$LB^2(24)$	352.95 ^{***}	125.69 ^{***}	139.08 ^{***}
KOSPI	Mean	0.058	-0.089	0.191
	Std. Dev.	4.159	2.972	4.121
	Skewness	-0.371	0.355	-0.245
	Kurtosis	6.729	3.932	4.231
	J-B	628.96 ^{***}	23.13 ^{***}	37.04 ^{***}
	$LB^2(24)$	333.75 ^{***}	18.56	165.19 ^{***}

Notes: The J-B corresponds to the test statistic for the null hypothesis of normality in sample returns distribution. The Ljung-Box statistic, $LB^2(24)$, checks for serial correlation of the squared returns up to the 20th order. ** and *** indicate rejection of the null hypothesis at the 5% and 1% significance levels, respectively.

Table 1 shows the descriptive statistics for the KRW returns and KOSPI returns in different sample periods, respectively. After the financial crisis, the standard deviation of both returns almost doubles or increases even more. The measures for skewness indicate that the return series are negatively skewed. Furthermore, the excess kurtosis measures show that the two series are leptokurtic. This evidence implies that both return series are not normally distributed, which is also supported by the results of Jarque-Bera normality test shown in the table. In addition, the null hypothesis of no serial correlation is statistically rejected at the 5% significance level by the Ljung-Box test statistic, $LB^2(24)$, with a lag of 24 for the squared return series, except for the pre-crisis period of KOSPI returns. This implies that the squared returns exhibit significant signs of serial correlation. These results are in favor of a model that incorporates ARCH/GARCH features.

Table 2 Results of Unit Root Tests for Log Price and Returns

	Whole		Pre-crisis		Post-crisis	
	Log Price	Returns	Log Price	Returns	Log Price	Returns
KRW						
ADF	-2.170 [0.218]	-10.41 [0.000]	-0.025 [0.954]	-20.02 [0.000]	-0.991 [0.757]	-20.57 [0.000]
PP	-1.993 [0.289]	-32.76 [0.000]	-0.093 [0.947]	-20.04 [0.000]	-1.047 [0.737]	-20.55 [0.000]
KOSPI						
ADF	-1.491 [0.538]	-34.42 [0.000]	-2.005 [0.284]	-21.41 [0.000]	-0.674 [0.850]	-24.16 [0.000]
PP	-1.455 [0.555]	-34.43 [0.000]	-1.883 [0.340]	-21.46 [0.000]	-0.779 [0.823]	-24.18 [0.000]

Notes: MacKinnon's (1991) 1% critical value is -3.435 for the ADF and PP tests. The numbers in brackets are *p*-values.

Table 2 provides the results of augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests for the log price series and the return series. The null hypothesis of the ADF and PP tests is that a time series contains a unit root. As shown in table 2, both the ADF and PP test statistics indicate that the log price series contain a single unit root at the 1% significance level, implying that the log prices series are non-stationary. However, both these test statistics reject the null hypothesis of a unit root at the 1% significance level, implying that the return series are stationary in all samples.

4. MODEL FRAMEWORK

4.1. Cointegration Test and Granger Causality Test

Cointegration is an econometric property of time series variables. If two or more series are themselves non-stationary, but a linear combination of them is stationary, then the series are said to be cointegrated. In practice, cointegration is a means for correctly testing those hypotheses concerning the

relationship between two variables having unit roots. In the literature, the Johansen (1991) cointegration test is the most popular approach for testing cointegration. This cointegration test is based on maximum likelihood estimators of a vector auto regressive (VAR) process, and the likelihood ratio-test statistic for the hypothesis of the at most r cointegrated relationship and at least $m = n - r$ common trend is given by

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^n \ln(1 - \hat{\lambda}_i), \quad (1)$$

$$\lambda_{max}(r, r+1) = -T \ln(1 - \hat{\lambda}_{r+1}), \quad (2)$$

where $\lambda_{trace}(r)$ is the trace statistic, $\lambda_{max}(r, r+1)$ is the eigen-max statistics, $\hat{\lambda}_i$ denotes the estimated eigenvalue, and T is the sample size. The null hypothesis tested in $\lambda_{trace}(r)$ is no cointegration. In fact, for bivariate cointegration tests, up to two null hypotheses can be tested. If the null that $r=0$ is rejected, at least one cointegrating vector may exist and the second hypothesis that $r \leq 1$ is subsequently tested.

4.2. Bivariate GJR-GARCH Model

Much attention has focused on how news from one market affects the volatility process of another market. The univariate GARCH model of Bollerslev (1986) has been extended to the multivariate GARCH model with a cross conditional variance equation. Bauwens, Laurent and Rombouts (2006) provide a comprehensive survey on the multivariate GARCH approach. Many multivariate GARCH model has been introduced in measuring the volatility linkages cross countries and assets, such as VEC, CCC and DCC. Such models can only be estimated by imposing specific restrictions on the conditional variance-covariance matrix (e.g., positive definiteness).

Moreover, it does not allow cross-equation conditional variances and

covariances to affect each other due to its oversimplifying restrictions. To overcome these problems, Engle and Kroner (1995) introduced the BEKK (Baba, Engle, Kraft, and Kroner) parameterization, which complies with the hypothesis of constant correlation and permits for volatility spillover across markets. However, there is increasing computational difficulty with high dimensional systems in the BEKK approach.³⁾

In this study, we analyze the volatility spillovers effect between the KOSPI market and KRW market by using a VAR(1)-bivariate GARCH(1,1) model based on the BEKK approach.

Firstly we consider the first order of VAR process, namely VAR(1) process:

$$\begin{bmatrix} R_{1,t} \\ R_{2,t} \end{bmatrix} = \begin{bmatrix} \beta_{10} \\ \beta_{20} \end{bmatrix} + \begin{bmatrix} \beta_{11} & \beta_{12} \\ \beta_{21} & \beta_{22} \end{bmatrix} \begin{bmatrix} R_{1,t-1} \\ R_{2,t-2} \end{bmatrix} + Yen \begin{bmatrix} \gamma_{1,t} \\ \gamma_{2,t} \end{bmatrix} + SP \begin{bmatrix} \delta_{1,t} \\ \delta_{2,t} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}, \quad (3)$$

where

$$\begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix} | \Omega_{t-1} \sim N(0, H_t), \quad (4)$$

where $R_{1,t}$ is returns of KRW and $R_{2,t}$ is returns of KOSPI at time t . H_t is a 2×2 corresponding conditional variance-covariance matrix. The market information available at time $t-1$ is represented by the information Ω_{t-1} . The parameter β_{ij} implies the mean spillover effects. For example, both β_{11} and β_{22} indicate that the returns of KRW and KOSPI is affected

³⁾ Bauwens, Laurent and Rombouts (2006) provided a comprehensive survey on the multivariate GARCH approach. Some papers introduce the Constant Conditional Correlation (CCC) of Bollerslev (1990) and the Dynamic Constant Correlation (DCC) of Engle (2002) specification incorporating time-varying correlation between two markets. This paper focuses on the direction of volatility spillover effect with sudden changes, so that the BEEK approach provides more relevant information about information transmission. Following anonymous reviewer's comment, our future study will consider the DCC approach with dummy variables in measuring the time-varying correlation between other markets.

by their own lag values, whereas β_{12} and β_{21} represent the mean spillover effects across two markets. To investigate proper relationship between the KRW and KOSPI, we consider exogenous variables, such as yen/dollar exchange rates (Yen) and S&P 500 index (SP) in equation (3).

This bivariate structure thus facilitates the measurement of the effects of innovations in the mean returns of one market on its own lagged returns and those of the lagged returns of the other market (Kang and Yoon, 2011). The standard BEKK parameterization for the bivariate GARCH model is written as:

$$H_t = C' C + A' \varepsilon_{t-1} \varepsilon'_{t-1} A + B' H_{t-1} B, \quad (5)$$

where H_t is a 2×2 matrix of conditional variance-covariance at time t , and C is a 2×2 lower triangular matrix with three parameters. A is a 2×2 square matrix of coefficients and measures the extent to which conditional variances are correlated past squared errors. B is a 2×2 squared matrix of coefficients and shows the extent to which current levels of conditional variances are related to past conditional variances.

$$\begin{aligned} \begin{bmatrix} h_{11,t} & h_{12,t} \\ h_{21,t} & h_{22,t} \end{bmatrix} &= \begin{bmatrix} c_{11} & \\ c_{21} & c_{22} \end{bmatrix}' \begin{bmatrix} c_{11} & \\ c_{21} & c_{22} \end{bmatrix} \\ &+ \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' \begin{bmatrix} \varepsilon_{1,t-1}^2 & \varepsilon_{1,t-1} \varepsilon_{2,t-1} \\ \varepsilon_{2,t-1} \varepsilon_{1,t-1} & \varepsilon_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \\ &+ \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}' \begin{bmatrix} h_{11,t-1} & h_{12,t-1} \\ h_{21,t-1} & h_{22,t-1} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}, \end{aligned} \quad (6)$$

where $h_{11,t}$ denotes the variance of the KRW market returns, $h_{12,t}$ and $h_{21,t}$ denote the covariance of the KRW market returns and the KOSPI market returns, and $h_{22,t}$ denotes the variance of the KOSPI market returns.⁴⁾

⁴⁾ Saleem (2009) explained the H_t matrix, which is further expended by matrix multiplication.

The significance of diagonal coefficients $a_{11}(a_{22})$ suggests that the current conditional variance of $h_{1,t}(h_{2,t})$ is correlated with its own past squared errors, while the significance of lagged variance $b_{11}(b_{22})$ indicates that the current conditional variance of $h_{1,t}(h_{2,t})$ is affected by its own past conditional variance. In addition, the significance of the off-diagonal coefficients a_{12} and b_{12} indicates evidence of a volatility spillover effect from the KOSPI market to the KRW market, whereas the significance of off-diagonal coefficients a_{21} and b_{21} suggests evidence of a volatility spillover effect from the KRW market to the KOSPI market.

The standard BEKK model implies that only the magnitude of past return innovations is important in determining current conditional variances and covariances. However, it has been well observed that volatility responds asymmetrically to positive and negative innovations of equal magnitude, i.e., volatility tends to rise more in response to negative shocks (bad news) than to positive shocks (good news) (Engle and Ng, 1993; Glosten, Jagannathan, and Runkle, 1993; Kroner and Ng, 1998).

To circumvent this problem, Kroner and Ng (1998) extended the GJR-GARCH approach to a multivariate setting capturing the asymmetric response to news on volatility. The asymmetric BEKK model is written as:

$$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B + D'\eta_{t-1}\eta'D, \quad (7)$$

$$\begin{aligned} \begin{bmatrix} h_{11,t} & h_{12,t} \\ h_{21,t} & h_{22,t} \end{bmatrix} &= \begin{bmatrix} c_{11} & \\ & c_{22} \end{bmatrix}' \begin{bmatrix} c_{11} & \\ & c_{22} \end{bmatrix} \\ &+ \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' \begin{bmatrix} \varepsilon_{1,t-1}^2 & \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon_{2,t-1}\varepsilon_{1,t-1} & \varepsilon_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \\ &+ \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}' \begin{bmatrix} h_{11,t-1} & h_{12,t-1} \\ h_{21,t-1} & h_{22,t-1} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \\ &+ \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix}' \begin{bmatrix} \eta_{1,t-1}^2 & \eta_{1,t-1}\eta_{2,t-1} \\ \eta_{2,t-1}\eta_{1,t-1} & \eta_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix}, \end{aligned} \quad (8)$$

where $\eta_{t-1} = \begin{bmatrix} \max(0, -\varepsilon_{1,t-1}) \\ \max(0, -\varepsilon_{2,t-1}) \end{bmatrix}$, D is a 2×2 squared matrix of parameters

and captures any asymmetry in variances and covariance through the definition of η_{t-1} . If the off-diagonal coefficient $d_{12}(d_{21})$ is positive and significant, the bad news volatility of the KOSPI market (the KRW market) causes a larger volatility of the KRW market (the KOSPI market) than the good news volatility of the KOSPI market (the KRW market).

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:

$$L(\theta) = -T \log 2\pi - 0.5 \sum_{t=1}^T \log |H_t(\theta)| - 0.5 \sum_{t=1}^T \varepsilon_t(\theta)' H_t^{-1} \varepsilon_t(\theta), \quad (9)$$

where T is number of observations and θ denotes the vector of all the unknown parameters.

5. EMPIRICAL RESULTS

5.1. Results of the Cointegration Test and Granger Causality Test

Table 3 shows the results of the Johansen cointegration test for the KRW and KOSPI series. The null hypothesis that two log price series are not cointegrated ($r=0$) against the alternative of one cointegrating vector ($r>0$) is not rejected because the $\lambda_{trace}(0)$ and $\lambda_{max}(0)$ statistics do not exceed their critical values at the 5% significant level. Thus, we conclude that there is no evidence of cointegration between the KRW and KOSPI series. In other words, there is no long-term relationship between the KRW and KOSPI series.

Table 3 Results of the Johansen Cointegration Test

Series	Null Hypothesis	Whole	Pre-crisis	Post-crisis	0.05 Critical Value
Trace Statistic					
	$r = 0$	6.156	5.567	7.700	15.49
	$r \leq 0$	1.744	0.014	0.374	3.841
Max-eigen Statistic					
	$r = 0$	4.412	5.553	7.325	14.28
	$r \leq 0$	1.744	0.015	0.374	3.841

Notes: A one-sided test of the null hypothesis shows that the variables are not cointegrated. The reported critical values are from Osterwald-Lenum (1992).

5.2. Volatility Spillover Effect between KOSPI and KRW Markets

In order to examine the spillover effect, we employ the bivariate GJR-GARCH(1, 1) (asymmetric) model. Table 4 reports the estimation results of the VAR(1)-bivariate GJR-GARCH model for the whole sample periods. To check the accuracy of the model specifications, we employ the Ljung-Box statistic, $LB_i^2(24)$ for squared standardized residuals. Note that the $LB_i^2(24)$ test statistic checks for the serial correlation of squared standardized residuals. The insignificance of $LB_1^2(24)$ and $LB_2^2(24)$ indicates the appropriateness of the bivariate GJR-GARCH model.

In addition, we consider the impact of exogenous variables on the spillover effect between two markets. Both exogenous variables, Yen and SP, affect both the KRW and KOSPI returns due to the significance of coefficients (γ_i) and (δ_i). More specifically, the yen/dollar exchange rates positively affect the KRW returns, but negatively affect the KOSPI returns. However, the S&P 500 has a negative influence on the KRW exchange rates, but positive influence on the KOSPI returns.

We compare the accuracy of two restricted and unrestricted models using the LR statistics. The large value of LR test statistics indicates that the unrestricted model is superior to the restricted model. This means that considering the exogenous variables, Yen and SP, improves the spillover effect between the KRW and the KOSPI.

Table 4 Estimation Results for Volatility Spillovers (Whole Period)

Variable	Restricted Model		Unrestricted Model	
	KRW ($i = 1$)	KOSPI ($i = 2$)	KRW ($i = 1$)	KOSPI ($i = 2$)
Mean Equation				
β_i	0.048 (0.047)	0.052 (0.041)	0.074 (0.045)	-0.025 (0.120)
β_{i1}	0.090*** (0.032)	0.165 (0.088)	0.094*** (0.030)	0.143 (0.082)
β_{i2}	-0.031** (0.011)	-0.045 (0.032)	-0.035*** (0.011)	-0.026 (0.030)
Yen (γ_i)	-	-	0.149*** (0.036)	-0.214** (0.097)
SP (δ_i)	-	-	-0.175*** (0.019)	0.625*** (0.051)
Variance Equation				
c_{i1}	-0.053*** (0.017)	-0.011 (0.346)	0.101*** (0.024)	-0.122 (0.201)
c_{i2}	0.000 (0.000)	-0.413*** (0.127)	0.000 (0.000)	0.324*** (0.061)
a_{i1}	0.539*** (0.031)	-0.009 (0.005)	0.464*** (0.032)	-0.004 (0.007)
a_{i2}	-0.406*** (0.094)	0.088 (0.053)	-0.285*** (0.073)	0.045 (0.046)
b_{i1}	0.858*** (0.013)	0.003 (0.002)	0.875*** (0.014)	0.002 (0.002)
b_{i2}	0.108*** (0.033)	0.971*** (0.011)	0.080*** (0.026)	0.982*** (0.004)
d_{i1}	-0.019 (0.085)	-0.039*** (0.007)	0.074 (0.105)	-0.053*** (0.009)
d_{i2}	-0.001 (0.131)	0.271*** (0.033)	-0.050 (0.112)	0.236*** (0.023)
Diagnostic Tests				
$LB_1^2(24)$	34.10 [0.083]		25.21 [0.508]	
$LB_2^2(24)$	10.04 [0.994]		24.84 [0.414]	
Log-likelihood	-3,841.96		-3,953.21	
LR Test	222.50 [0.000]			

Notes: P -values are in brackets and standard errors are in parenthesis. The $LB_i^2(24)$ test statistic checks for the serial correlation of squared standardized residuals. The LR test statistics, $LR = -2 \cdot [ML_u - ML_r]$, where ML_u and ML_r denote the maximum log-likelihood values of the unrestricted model and restricted model, respectively. ** and *** indicate significance at the 5% and 1% levels, respectively.

In table 4, we first consider the return spillover effects between two markets. The important coefficients are β_{12} and β_{21} , where $i=1$ stands for the KRW and $i=2$ for the KOSPI. Due to the significance of the only coefficient of β_{12} , we conclude that there is uni-directional return transmission from the KOSPI market to the KRW market. This evidence support the “stock-oriented” approach, suggesting that an increase in stock prices induces investors to demand more domestic assets and thereby causes an appreciation in the domestic currency, implying that stock prices lead exchange rates and that they are negatively related.

As for the volatility spillover effect in the variance equation, the off-diagonal elements of matrices A and B capture cross-market effects, such as shock spillover and volatility spillover between KRW and KOSPI markets. We find evidence of uni-directional shock and volatility spillover from the KOSPI market to the KRW market because of the significance of off-diagnostic coefficient a_{21} and b_{21} . In fact, past shocks in the KOSPI market affect the present volatility of KOSPI, and the opposite direction is impossible. Thus, we conclude that evidence exists of uni-directional volatility spillover between the KOSPI and KRW markets.

As far as matrix D is concerned, we find evidence of an asymmetric response to negative shocks (bad news) of own market for KOSPI returns because the only positively significance of coefficient d_{22} . This evidence suggests that the own negative shocks have more effect than own positive shocks on the volatility of KOSPI market. However, there is no cross asymmetric volatility spillover effect between two markets due to the negatively significance of coefficient d_{12} and the insignificance of coefficient

5.3. The Impact of Financial Crisis

There is strong consensus in the existing literature that a financial crisis leads to linkages among financial markets. Table 5 shows the estimation results of bivariate GJR-GARCH model in the pre-crisis and post-crisis periods.

**Table 5 Estimation results for Volatility Spillovers
(pre- and post-crisis periods)**

Variable	Pre-crisis		Post-crisis	
	KRW ($i = 1$)	KOSPI ($i = 2$)	KRW ($i = 1$)	KOSPI ($i = 2$)
Mean Equation				
β_i	0.060 (0.015)	-0.088 (0.152)	0.002 (0.037)	0.197 (0.169)
β_{i1}	0.241*** (0.048)	-0.889 (0.481)	0.172*** (0.042)	0.296 (0.193)
β_{i2}	-0.008 (0.005)	0.058 (0.050)	-0.033*** (0.009)	-0.030 (0.042)
Yen (γ_i)	0.028** (0.012)	-0.211 (0.123)	0.238*** (0.034)	0.073 (0.153)
SP (δ_i)	-0.016 (0.009)	0.234*** (0.090)	-0.036 (0.016)**	0.657 (0.073)***
Variance Equation				
c_{i1}	0.082 (0.057)	-1.060 (0.684)	0.610** (0.032)	0.251 (0.259)
c_{i2}	0.000 (0.000)	0.000 (2.772)	0.000 (0.000)	-0.001 (0.559)
a_{i1}	0.158** (0.072)	0.003 (0.009)	0.569*** (0.060)	-0.056*** (0.019)
a_{i2}	0.703 (0.547)	0.152 (0.100)	-0.177 (0.179)	0.284*** (0.054)
b_{i1}	0.940*** (0.028)	-0.001 (0.007)	0.037 (0.114)	-0.045** (0.019)
b_{i2}	0.481 (0.352)	0.925*** (0.098)	0.247 (0.358)	0.962*** (0.026)
d_{i1}	-0.115 (0.070)	-0.040 (0.010)***	0.299 (0.177)	-0.102*** (0.027)
d_{i2}	-0.702 (0.732)	0.073 (0.121)	-0.404 (0.438)	-0.081 (0.082)
Diagnostic Tests				
$LB_1^2(24)$	17.24 [0.838]		33.15 [0.101]	
$LB_2^2(24)$	10.75 [0.990]		15.17 [0.915]	
Log-likelihood	-1,221.96		-3,953.21	

Notes: P -values are in brackets and standard errors are in parenthesis. The $LB_i^2(24)$ test statistic checks for the serial correlation of squared standardized residuals. ** and *** indicate significance at the 5% and 1% levels, respectively.

In the pre-crisis period, we find that yen/dollar exchange rates positively affect only the KRW exchange rates and the S&P 500 returns have a positive impact on the KOSPI returns. However, after the crisis, the S&P 500 returns have an influence on both the KRW exchange rates and the KOSPI returns, but the yen/dollar exchange rate only affect the KRW exchange rates. In addition, we find no return spillover in the pre-crisis period because of the insignificance of β_{12} and β_{21} , but in the post-crisis period, the unidirectional return spillover effect from the KOSPI market to the KRW market due to the significance of the coefficient $\beta_{12}(-0.038)$.

In the conditional equation, the off-diagonal elements of matrices A and B capture cross-market effects, such as shock spillover and volatility spillover between KOSPI and KRW markets. In the pre-crisis period, we find no shock spillover and volatility spillover due to the insignificance of coefficients a_{12} , a_{21} , b_{12} and b_{21} . However, after the crisis, the unidirectional shock and volatility spillover effect from the KRW market to the KOSPI market due to the significance of coefficients $a_{21}(-0.056)$ and $b_{21}(-0.045)$. This evidence indicates that the financial crisis might improve linkages between the KRW and KOSPI markets. After the Asian currency crisis, the Korean financial system was deregulated by the IMF bailout and then both markets were opened to foreign investors. It seems that common information is transmitted from the KRW market to the KOSPI market.

Considering the cross asymmetric volatility feature, we do not find clear evidence on cross asymmetric volatility feature in the pre- and post-crisis. Despite of the negatively significance of coefficient d_{21} , there is no clear consensus on the cross-asymmetric volatility feature between two markets.

Consequently, the financial crisis plays an important role on the improvement of the information transmission between two markets. It seems that the financial crisis, as refereed to a systematic risk, has impact on both markets and enhances the integration of both markets. These findings have important implications for portfolio and risk management. For example, for portfolio management, the relationship between exchange rates and stock prices may be used to hedge portfolios against currency

movements. Additionally, risk management must consider that these markets are correlated.

6. CONCLUSIONS

This paper investigates the price returns and volatility linkages between the Korean stock (KOSPI) and the foreign exchange (KRW) markets using the VAR(1)-bivariate GJR-GARCH model. In addition, we examined how the financial crisis affected the dynamic relationship between these two markets.

Our empirical results are summarized as follows. First, there is no long-term equilibrium relationship between the KRW and KOSPI markets. Second, exogenous variables (yen/dollar exchange rate and S&P 500 index) have strong impact on the returns of both the KRW and KOSPI. Third, with regard to return spillover, a uni-directional volatility spillover exists from the KOSPI market to the KRW market. This evidence supports the “stock-oriented” approach, implying that stock prices lead exchange rates and that they are negatively related. Fourth, our empirical results provide no evidence of volatility spillover effect in the pre-crisis, but an evidence of uni-directional volatility spillover effect from the KRW market to the KOSPI market in the post-crisis period, implying that financial crisis improves linkages between these two markets. Finally, we do not find the asymmetric volatility spillover effect between two markets.

These findings have important implications for portfolio and risk management. For example, for portfolio management, the relationship between exchange rates and stock prices may be used to hedge portfolios against currency movements. Additionally, risk management must consider that these markets are correlated.

A limitation of this paper is that we neglected the movements of interest rates, which may exert considerable influence on stock prices. In general, stock prices inversely move with interest rates, while exchange rates move in

the same direction as interest rates. We suggest that this research may be extended in a future study to investigate the linkages and causal relationships among the three variables of stock prices, foreign exchange rates, and interest rates.

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