

INTRADAY DYNAMICS OF ASSET RETURNS, TRADING ACTIVITIES, AND IMPLIED VOLATILITIES: A TRIVARIATE GARCH FRAMEWORK¹

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Abstract

This study investigates the intraday dynamic relationship among asset returns, trading volumes, and volatilities in index derivatives markets using an asymmetric trivariate BEKK-GARCH framework. We analyze the returns and trading activities of KOSPI200 futures and calculate the option-implied volatilities using the Black–Scholes model and a model-free approach (i.e., the VKOSPI). We find that more trading activity in the futures market leads to greater next-period returns and that the trading volume has a bi-directionally positive relationship with the volatility. We also find that greater market volatility increases asset returns but that greater returns decrease volatility, which is consistent with the asymmetric returns–volatility relationship and is explained by the risk-return trade-off and the leverage effect.

Keywords: asymmetric BEKK-GARCH; implied volatilities; intraday dynamics; KOSPI200 futures and options; VKOSPI

JEL Classification: C32, E44, F36, G17, G19

I. Introduction

Asset returns, trading volumes, and market volatilities are key financial variables that characterize the dynamics and behavior of financial markets. One strand of the previous literature examines the dynamic relationships between asset returns and volatilities and reports a significant but asymmetric relationship, which is represented by the

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asymmetric volatility effect. These studies insist that asset returns and volatilities are significantly and negatively related, which can be explained by the leverage effect, the volatility feedback effect, or both (Bekaert and Wu, 2000; Bollerslev, Litvinova, and Tauchen, 2006; Campbell and Hentschel, 1992; Christie, 1982; French, Schwert, and Stambaugh, 1987; Han, Guo, Ryu, and Webb, 2012; Hibbert, Daigler, and Dupoyet, 2008; Kim and Ryu, 2014; Lee and Ryu, 2013; Park, Ryu, and Song, 2017; Wu, 2001). Another strand of the previous literature examines the information role of trading volumes, considering that investor trading behavior reveals fundamental information and that the volume dynamics are related to the operational market efficiency and liquidity (Ahn, Kang, and Ryu, 2010; Chatrath, Ramchander, and Song, 1996; Clark, 1973; Copeland, 1976; Cornell, 1981; Crouch, 1970; Grammatikos and Saunders, 1986; Harris, 1986; Jennings, Starks, and Fellingham, 1981; Karpoff, 1987; Malliaris and Urrutia, 1998; Ryu, 2015b, 2016; Webb, Ryu, Ryu, and Han, 2016). Two representative hypotheses can explain the observed positive relationship between asset price changes and trading volumes. Each hypothesis interprets the relationship differently in terms of how market information is dispersed. Clark (1973) suggests the mixture of distribution (MD) hypothesis, which assumes that both price changes and trading volumes follow a joint probability distribution and share common underlying variables, so that returns and volumes tend to respond to market shocks simultaneously. Copeland (1976) develops the sequential information flow (SIF) hypothesis, which utilizes a different information arrival process from the MD hypothesis. The SIF hypothesis suggests that the dissemination of information is sequential and that the information arrival rate affects both trading volumes and price changes in the same direction, resulting in a positive returns-volume relationship.

A third strand of research examines the relationship between trading volumes and volatilities. The results of these studies may be used to improve the accuracy of forecasting models and to manage risky financial derivatives (Alizadeh and Tamvakis, 2016). Previous studies, including Chevallier and Sévi (2012), Fan, Yuan, Zhuang, and Jin (2017), Girma and Mougoue (2002), Grammatikos and Saunders (1986), Harris (1986), Herbert (1995), Moosa and Silvapulle (2000), Moosa, Silvapulle, and Silvapulle (2003), and Ripple and Moosa (2009), find a significantly positive relationship between the trading volume and volatility in global markets. Other studies, which investigate the return-volume and volume-volatility relationships separately, also report positive relationships (Bessembinder and Seguin, 1993; Chen, Firth, and Rui, 2001; Foster, 1995; Lamoureux and Lastrapes, 1990; Najand and Yung, 1991). In a recent study, Alizadeh and Tamvakis (2016) examine the asymmetric relationship between trading volumes and volatilities in energy commodity and futures markets under different market conditions (*i.e.*, backwardation or contango).

Our study is motivated by the current status of the existing literature on the relationship among these key market variables. Many studies examine the dynamic relationship for each pair separately (*i.e.*, return-volatility, return-volume, or volume-volatility), but only a few simultaneously analyze the intraday dynamic relationship among returns, volumes, and volatilities within a high-frequency dataset. Furthermore, most studies analyze the dynamics of these variables in developed markets rather than focusing on emerging markets, where speculative trading prevails, information asymmetry is severe, and market friction and liquidity issues are important. Some empirical studies investigate

the return-volatility relationship in the Korean market, a representative and leading emerging market. An early study by Choe and Shin (1993) only analyzes opening and closing price data and does not use a high-frequency dataset that can yield rich trading and economic implications. Kim and Ryu (2015b) examine the return and volatility spillovers between the Korean market and overseas markets, but they also analyze a daily dataset. Although the recent studies of Han, Guo, Ryu, and Webb (2012) and Kim and Ryu (2014) investigate return-volatility dynamics using a one-minute intraday dataset, their scopes are limited to the relationship between these two variables. To the best of our knowledge, little research examines the relationships among returns, volumes, and volatilities in a unified multivariate GARCH framework.

Motivated by the lack of multivariate analyses and the paucity of studies on emerging markets, we analyze the intraday dynamics of KOSPI200 futures returns, KOSPI200 futures trading volumes, and market volatilities implied by KOSPI200 options prices in the Korean market. This study employs a modified multivariate version of the VAR(1)-asymmetric Baba-Engle-Kraft-Kroner (BEKK) GARCH model (Engle and Kroner, 1995). The KOSPI200 futures and options markets are highly liquid and, thus, have low transaction costs for market participants, and the information flows in both markets are fast and efficient. Thus, the relatively high-frequency KOSPI200 futures and options dataset is ideal for analyses investigating intraday dynamic relationships in a setting with less market friction and fewer biases. The information linkage between the futures and options markets further justifies our simultaneous investigation of returns and volumes derived from futures market trading and the implied volatility derived from options market trading (Lee, Kang, and Ryu, 2015; Lee and Ryu, 2016; Ryu, 2011, 2015a; Ryu and Yang, 2017).⁴

Our empirical results show that there is a significant intraday linkage among asset returns, trading volumes, and volatilities in Korea's index derivatives markets. First, active trading in the futures market increases the future returns of KOSPI200 prices, supporting the MD and SIF hypotheses. Second, we find bi-directional, positive relationships between trading volumes and volatilities, which is also consistent with the two hypotheses. Third, the significant lead-lag relationships between futures returns and volatilities are explained by leverage effects (*i.e.*, the negative relationship between current returns and future volatilities) or the risk-return trade-off (*i.e.*, the positive relationship between lagged volatilities and future returns). Fourth, the highly significant coefficient estimates in the variance equation of the VAR(1)-asymmetric BEKK-GARCH model support the selection of our model, which can effectively describe the asymmetric volatility phenomenon. Lastly, the somewhat different implications of implied volatilities calculated from options with different moneyness levels indicate that each option trade can affect the intraday dynamics differently. This result reflects that options with different moneyness levels exhibit varying degrees of sensitivity, leverage effects, and investor participation rates (Chung, Park, and Ryu, 2016; Ryu, Kang, and Suh, 2015; Sim, Ryu, and Yang, 2016; Yang, Choi, and Ryu, 2017).

The remainder of the paper is structured as follows. Section 2 introduces KOSPI200 futures, KOSPI200 options, and implied volatilities in the Korean market. Section 3

⁴ The details on the KOSPI200 futures and options markets are provided in Section 2. The characteristics and traits of the implied volatilities are also presented in that section.

explains the sample data and methodology used in the model. The empirical findings are provided in Section 4. Section 5 concludes the paper.

II. KOSPI200 Futures, KOSPI200 Options, and Implied Volatilities

The KOSPI200 futures and options markets are world-class index derivatives markets. Both markets exhibit high liquidity and active investor participation, which indicate less market friction, lower transaction costs, and faster information flows compared to spot and equity markets.⁵ The futures and options markets are highly correlated and there is a significant information linkage, issues that are grounds for conducting multivariate analyses with a unified model taking returns and trading volume dynamics from the futures market and calculating implied volatilities based on the options market. We use four implied volatility measures, all of which are estimated using KOSPI200 option prices, which incorporate the expectations, sentiments, and risk appetites of market participants. Our implied volatility measures are three model-dependent implied volatilities calculated with the Black-Scholes option pricing model and one model-free implied volatility computed with the fair-variance swap method (*i.e.*, the VKOSPI).

The information conveyed by options trades can vary significantly by option moneyness and leverage in the KOSPI200 options market (Ahn, Kang, and Ryu, 2008, 2010; Ryu, 2013b; Yang, Kutan, and Ryu, 2017); as such, we calculate and examine the implied volatility separately for each moneyness group. The moneyness of a call (put) option is calculated as the ratio of the underlying asset price (strike price) to the strike price (underlying asset price). Options contracts are categorized as out of the money (OTM) if their moneyness values are less than 0.975 and as in the money (ITM) if their moneyness values are greater than 1.025. The remaining options are categorized as at-the-money (ATM) options. We calculate the Black-Scholes implied volatilities for the three moneyness groups (*i.e.*, ITM, ATM, and OTM) for each intraday sampling interval. These implied volatilities can reflect the characteristics of the different moneyness types, but they are still dependent on the specific option pricing model, so model bias may exist. Thus, we simultaneously examine the model-free implied volatility index, which is the VKOSPI.

The Korea Exchange announced its first model-free options-implied volatility index in 2009 and named it the VKOSPI. The launch of the VKOSPI is motivated by the great success and influence of the US volatility index (*i.e.*, the VIX). Given the high liquidity and large trading volume of KOSPI200 options, the VKOSPI is a meaningful trading indicator and fear gauge measure and provides trading and policy implications to market practitioners and regulators.

The VKOSPI captures the one-month-ahead volatility of the KOSPI200 spot price. By benchmarking the VIX, the VKOSPI is calculated using the fair-variance-swap approach suggested by Britten-Jones and Neuberger (2000) and Jiang and Tian (2007).

⁵ Many existing studies document the traits of the KOSPI200 futures and options markets (Guo, Han, and Ryu, 2013; Han, Hwang, and Ryu, 2015; Hwang, Kang, and Ryu, 2010; Kang, Park, Ryu, and Song, 2015; Kang, Ryu, and Ryu, 2014; Kim and Ryu, 2012; Kim and Ryu, 2015a; Kim, Ryu, and Seo, 2015; Ryu, 2013a, 2017).

Specifically, the VKOSPI is derived from the market prices of the two consecutive nearest-maturity KOSPI200 options contracts and from other market values, including underlying asset prices and risk-free rates (Lee and Ryu, 2014b; Song, Ryu, and Webb, 2016). Equations (1)-(4) show how to calculate the VKOSPI given this market information and may be used to construct the VKOSPI time series before its initial publication date (Ryu, 2012).

$$\text{Volatility} = 100 \times \sqrt{\left\{ T_1 \sigma_1^2 \left[\frac{N_{T_2} - N_{30}}{N_{T_2} - N_{T_1}} \right] + T_2 \sigma_2^2 \left[\frac{N_{30} - N_{T_1}}{N_{T_2} - N_{T_1}} \right] \right\} \times \frac{N_{365}}{N_{30}}}, \quad (1)$$

$$\sigma_1^2 = \frac{2}{T_1} \sum_i^n \frac{\Delta K_i}{K_i^2} e^{rT_1} Q(K_i) - \frac{1}{T_1} \left[\frac{F_1}{K_0} - 1 \right]^2, \sigma_2^2 = \frac{2}{T_2} \sum_i^n \frac{\Delta K_i}{K_i^2} e^{rT_2} Q(K_i) - \frac{1}{T_2} \left[\frac{F_2}{K_0} - 1 \right]^2, \quad (2)$$

$$F_1 = S_1 + e^{rT_1} \times [C_1 - P_1], F_2 = S_2 + e^{rT_2} \times [C_2 - P_2], \quad (3)$$

$$T_1 = \frac{N_{T_1}}{N_{365}}, \text{ and } T_2 = \frac{N_{T_2}}{N_{365}}. \quad (4)$$

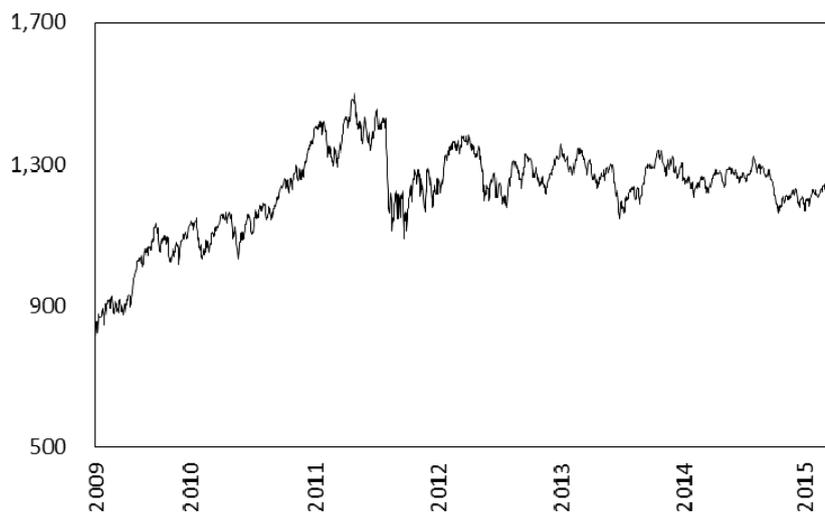
In Equation (1), *Volatility* denotes the annualized VKOSPI value, which is calculated from the observed market prices of the two consecutive nearest-maturity KOSPI200 options contracts. In Equations (2)-(4), N_{30} and N_{365} are the number of days in a month and a year, respectively. N_{T_1} and N_{T_2} denote the number of days remaining until the nearest and next-nearest maturity dates (*i.e.*, two consecutive maturity dates), respectively. r represents the continuously compounded risk-free interest rate. K_0 denotes the exercise price closest to the KOSPI200 underlying spot index among all exercise prices equal to or lower than the spot index. S_1 (S_2) means the strike price with the least difference between the nearest-maturity (next-nearest-maturity) call and put prices. C_1 (P_1) denotes the nearest-maturity call (put) price, and C_2 (P_2) denotes the next-nearest-maturity call (put) price.

Figure 1 shows the time trends of the KOSPI200 futures price and trading volume (Panels A and B, respectively) and the VKOSPI (Panel C) from 2009 to 2015. The futures prices are measured in points (one point indicates 500,000 Korean won in the KOSPI200 futures market) and the trading volume is given as the number of contracts. The VKOSPI, shown as a percentage value, is greater during periods of recession and crisis.

Figure 1

Time Trends of the KOSPI200 Futures Price and Trading Volume and of the VKOSPI

Panel A: KOSPI200 Futures Price (In Points)



Panel B: KOSPI200 Futures Trading Volume (In Number of Contracts)

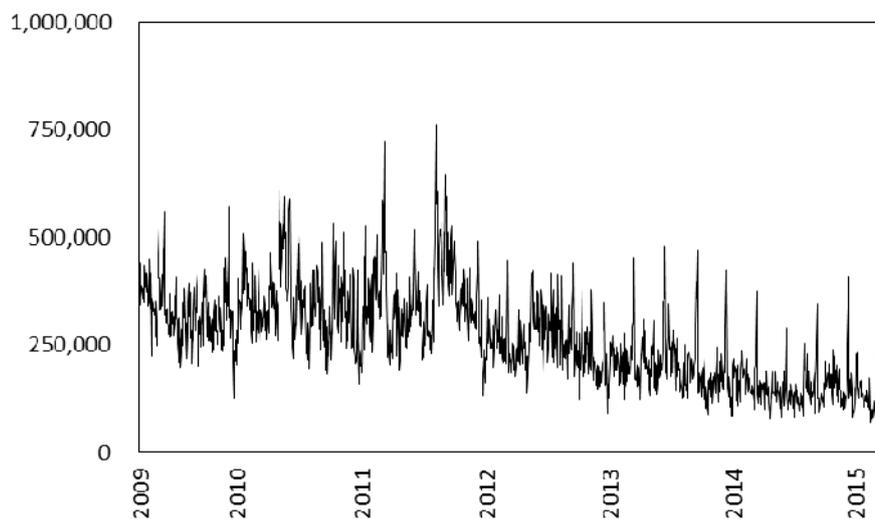
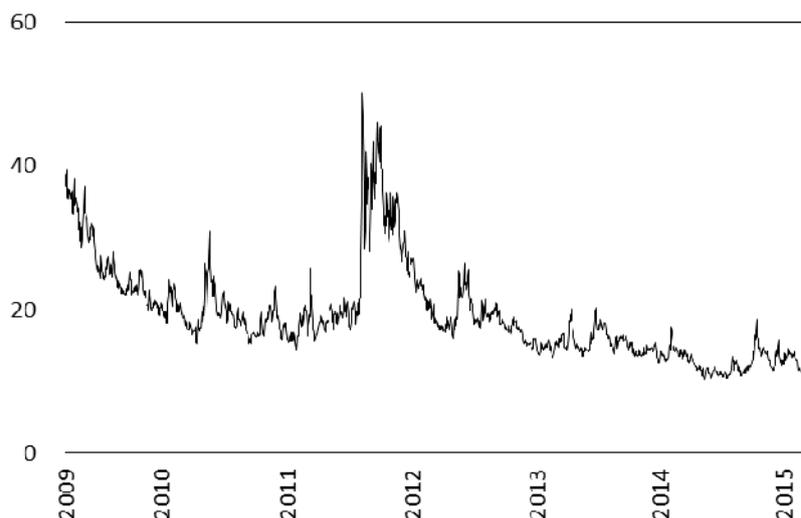


Figure 1 (cont.)

Panel C: VKOSPI (In Percentage Value)



III. Models and Sample Data

To examine the intraday dynamic relationship among asset returns, trading volumes, and volatilities, we employ the VAR(1)-asymmetric trivariate BEKK-GARCH model framework with Student's t innovations, which can capture volatility clustering, asymmetric and time-varying volatilities, and interactions among market variables. The most important advantage of the multivariate framework is that it accounts for the co-movements and interdependency of the variables. Equation (5) presents the system of mean equations of the model. The mean equation describes how the key variables intertemporally affect one another and determines which variables Granger-cause other variables.

$$Y_t = \alpha + \gamma Y_{t-1} + \varepsilon_t, \text{ where } Y_t = \begin{bmatrix} R_t \\ T_t \\ V_t \end{bmatrix}, \alpha = \begin{bmatrix} \alpha_R \\ \alpha_T \\ \alpha_V \end{bmatrix}, \gamma = \begin{bmatrix} \gamma_{RR} & \gamma_{RT} & \gamma_{RV} \\ \gamma_{TR} & \gamma_{TT} & \gamma_{TV} \\ \gamma_{VR} & \gamma_{VT} & \gamma_{VV} \end{bmatrix}, \text{ and } \varepsilon_t = \begin{bmatrix} \varepsilon_{R_t} \\ \varepsilon_{T_t} \\ \varepsilon_{V_t} \end{bmatrix} | \psi_{t-1} \sim t(0, H_t, \nu) \quad (5)$$

In Equation (5), Y_t is a 3×1 vector consisting of KOSPI200 futures returns (R_t), the trading volume of the futures (T_t), and an option-implied volatility measure (V_t) at time t . α denotes a 3×1 vector consisting of constants. γ_{ij} denotes each element of the matrix γ and measures how the variable j at time $t-1$ affects the variable i at time t . ε_t represents a 3×1 error term vector following a multivariate Student's t -distribution with mean 0. H_t denotes a 3×3 conditional variance-covariance matrix. ν indicates the degrees of freedom. To capture the fat-tailed distributions of the standardized residuals, we use the Student's t -distribution rather than the standard normal distribution to model the error term.

Equation (6) presents the system of variance equations, which describe the interrelatedness and dynamics of the volatility and covariance structures. Essentially, the variance equation system shows that the current conditional variance-covariance matrix (H_t) is determined by the error term ($A\varepsilon_{t-1}\varepsilon_{t-1}^T A^T$), the conditional variance term ($BH_{t-1}B^T$), and the remaining error term capturing the covariance asymmetry in the volatility ($C\xi_{t-1}\xi_{t-1}^T C^T$).

$$H_t = W + A\varepsilon_{t-1}\varepsilon_{t-1}^T A^T + BH_{t-1}B^T + C\xi_{t-1}\xi_{t-1}^T C^T,$$

where $H_t = \begin{bmatrix} H_{RR,t} & H_{RT,t} & H_{RV,t} \\ H_{RT,t} & H_{TT,t} & H_{TV,t} \\ H_{RV,t} & H_{TV,t} & H_{VV,t} \end{bmatrix}$, $W = \begin{bmatrix} \omega_{RR} & \omega_{RT} & \omega_{RV} \\ \omega_{RT} & \omega_{TT} & \omega_{TV} \\ \omega_{RV} & \omega_{TV} & \omega_{VV} \end{bmatrix}$, $A_t = \begin{bmatrix} \alpha_{RR} & 0 & 0 \\ 0 & \alpha_{TT} & 0 \\ 0 & 0 & \alpha_{VV} \end{bmatrix}$,

$$B_t = \begin{bmatrix} \beta_{RR} & 0 & 0 \\ 0 & \beta_{TT} & 0 \\ 0 & 0 & \beta_{VV} \end{bmatrix}, \text{ and } C_t = \begin{bmatrix} C_{RR} & 0 & 0 \\ 0 & C_{TT} & 0 \\ 0 & 0 & C_{VV} \end{bmatrix}. \quad (6)$$

In Equation (6), W is a positive-definite symmetric matrix consisting of constant elements. ξ_t is an additional error term capturing the phenomenon of asymmetric volatility as in the GJR-GARCH model (Glosten, Jagannathan, and Runkle, 1993). If ε_t is less than zero, then ξ_t equals ε_t ; otherwise, ξ_t equals zero. A , B , and C are diagonal matrices.

Our sample is the one-minute intraday dataset for the futures and options markets from April 29, 2009 to June 30, 2014. We only include the transactions from 9:15 AM to 2:50 PM to mitigate the systematic biases possibly caused by intraday trading patterns (Ryu 2011; Yang, Choi, and Ryu, 2017). In order to investigate the intertemporal, dynamic intraday relationship among futures returns, futures trading volumes, and implied volatilities, we use the processed intraday dataset of the nearest-maturity KOSPI200 futures and options,⁶ yielding 429,072 observations. Table 1 reports summary statistics of the key market variables. The KOSPI200 futures prices ($Price$) are presented in points. The futures returns are calculated as the log-difference of the prices ($\Delta \ln(Price)$). $Volume$ denotes the KOSPI200 futures trading volume in terms of the number of contracts. Trading activities in financial markets normally exhibit a U-shaped or downward sloping intraday pattern, which reflects higher turnover rates in the early part of each trading day (Admati and Pfleiderer, 1988; Chan, Christie, and Schultz, 1995; Foster and Viswanathan, 1990; Hwang, Kang, and Ryu, 2010; McInish and Wood, 1992). Thus, to eliminate these intraday patterns, we use the standardized trading volume ($Volume_{std}$) by adjusting its average and standard deviation. We consider four types of option-implied volatilities (IV), the three Black-Scholes implied volatilities and the VKOSPI. The Black-Scholes implied volatilities are calculated using the ITM (IV_{ITM}), ATM (IV_{ATM}), and OTM (IV_{OTM}) option prices. The model-free implied volatility index, the VKOSPI ($VKOSPI$), is calculated by the fair-variance swap method using options of all moneyness levels (Lee and Ryu, 2014a; Han, Kutan, and Ryu, 2015). The implied volatilities are given in percentage values. We conduct the augmented Dickey-Fuller (ADF) test to examine whether the variables are stationary and find that we can reject

⁶ There is one exception: the second-nearest-maturity options contracts are used to construct the intraday VKOSPI.

the null hypothesis that all the variables have unit roots. Thus, the variables are suitable for our study.

Table 1

Summary Statistics								
	Price	$\Delta \ln(\text{Price})$	Volume	Volume _{std}	IV _{ITM}	IV _{ATM}	IV _{OTM}	VKOSPI
Mean	244.9	1.E-06	642.2	0.086	21.34	18.58	20.55	19.86
Median	251.2	0.0000	458.0	-0.231	19.60	17.75	19.48	18.43
Maximum	296.8	0.0392	12,777	17.888	291.60	107.02	75.73	69.88
Minimum	168.2	-0.0637	1.0	-1.505	3.65	6.60	8.39	9.74
Std. Dev.	24.8	0.0007	636.7	1.111	8.42	5.50	5.66	6.16
Skewness	-0.8	-3.5764	2.5	2.524	3.06	2.20	1.13	1.61
Kurtosis	3.3	817.682	14.3	13.812	28.44	17.25	4.85	6.52

IV. Empirical Findings

Table 2 shows the estimation results of the VAR(1)-asymmetric BEKK-GARCH models with different implied volatility measures.⁷ Models M_{ITM} , M_{ATM} , and M_{OTM} employ the Black-Scholes implied volatilities calculated from the ITM, ATM, and OTM option prices, respectively. Model M_{VKOSPI} employs the VKOSPI, which is the model-free implied volatility index calculated from options of all moneyness levels. The models are estimated by the numerical maximization of log-likelihood functions using the Marquardt (Marquardt, 1963) or the BHHH (Berndt, Hall, Hall, and Hausman, 1974) algorithm.

Table 2

Intraday Estimation Results of the VAR(1)-asymmetric BEKK-GARCH Model				
	M_{ITM}	M_{ATM}	M_{OTM}	M_{VKOSPI}
γ_{RR}	-0.124979***	-0.124365***	-0.131345***	-0.144377***
γ_{RT}	5.80E-06***	3.10E-06***	3.97E-06***	6.88E-07
γ_{RV}	4.25E-07***	1.88E-06***	1.58E-06***	1.08E-06***
γ_{TR}	-0.967502	-1.202282	-3.446295**	-0.434607
γ_{TT}	0.458526***	0.409174***	0.416777***	0.399740***
γ_{TV}	0.010730***	0.030798***	0.026648***	0.026545***
γ_{VR}	3.559993	-17.48809***	-34.83082***	-0.734034***
γ_{VT}	0.046347***	0.001920***	0.067056***	0.000233***
γ_{VV}	0.954736***	0.997882***	0.956976***	0.999942***
α_{RR}	0.068467***	0.088230***	0.065259***	0.189553***
α_{TT}	0.154195***	0.158511***	0.171009***	0.113795***
α_{VV}	0.855482***	0.458077***	0.423330***	0.303137***
β_{RR}	0.974011***	0.970193***	0.972888***	0.964546***
β_{TT}	0.984681***	0.980307***	0.978240***	0.990989***
β_{VV}	0.794082***	0.927570***	0.932786***	0.950284***
C_{RR}	0.265039***	0.251261***	0.256258***	0.184626***
C_{TT}	-0.142479***	-0.223206***	-0.225423***	0.191568***
C_{VV}	-0.060270***	-0.009792	0.001288	0.137096***

** Significant at 5%. *** Significant at 1%.

⁷ The estimates for the constant terms are not presented for the sake of brevity.

Overall, the estimated results show that most of the coefficients are highly significant in all models, suggesting that there are significant intraday linkages among asset returns, trading volumes, and volatilities and that meaningful statistical mechanics exist in Korea's index derivatives markets. We present the detailed findings and interpretations of the estimated coefficients as follows. First, the three diagonal terms of the γ matrix (γ_{RR} , γ_{TT} , and γ_{VV}) are highly significant, which implies strong autocorrelation in each variable. Although the estimated γ_{TT} and γ_{VV} coefficients are positive, the estimated γ_{RR} coefficients are negative in all models, reflecting the short-term reversal of futures returns. All of the γ_{VV} coefficients are greater than 0.95, suggesting that the volatilities are highly persistent irrespective of whether they are calculated using the model-based (*i.e.*, the Black-Scholes option pricing model) or the model-free (*i.e.*, the fair-variance swap approach) methodology. We also find that the volatility-related coefficient estimates of M_{VKOSPI} model are generally smaller than those of the other models, partially reflecting the relatively lower performance of the VKOSPI compared to the Black-Scholes implied volatilities reported in this emerging market (Kim and Ryu, 2015c).

Second, information flows from trading volumes to asset returns are more significant than flows in the opposite direction. Although the estimated γ_{TR} coefficient is significant only in the M_{OTM} model, the estimated γ_{RT} coefficients are significant and positive in the M_{ITM} , M_{ATM} , and M_{OTM} models, indicating that trading activities in the futures market increase future asset returns. The finding that an increase in the futures trading volume raises futures returns in the next period is consistent with the previous literature (Board and Sutcliffe, 1990; Hiemstra and Jones, 1994; Jain and Joh, 1988; Jennings, Starks, and Fellingham, 1981; Smirlock and Starks, 1988). The intraday positive relationship between the volume and returns is generally consistent with the MD and SIF hypotheses, both of which predict such a relationship. However, the observed lead-lag relationship between the trading volume and returns indicates that asset returns might be predicted by trading volume changes, which is evidence against the efficient market hypothesis and indicates that the arrival of information can be described by a sequential process, not by a simultaneous process (*i.e.*, this result supports the SIF hypothesis to a greater extent; Chen, Qiu, Jiang, Zhong, and Wu, 2015; Copeland, 1976; Epps, 1975; Jennings, Starks, and Fellingham, 1981; Moosa, Silvapulle, and Silvapulle, 2003; Zhang, Bi, and Shen, 2017). Across the models, the γ_{RT} estimate in the M_{ITM} model is greater than the corresponding estimates in the M_{ATM} , M_{OTM} , and M_{VKOSPI} models, which partially reflects the relative information superiority of ITM options trading.⁸

Third, we find a bi-directionally significant and positive intertemporal relationship between trading volumes and volatilities, which is consistent with previous studies analyzing the relationship between trading activities and volatilities (*e.g.*, Chevallier and Sévi, 2012; Foster, 1995; Lamoureux and Lastrapes, 1990; Moosa and Silvapulle, 2000; Moosa, Silvapulle, and Silvapulle, 2003; Najand and Yung, 1991). These studies report a positive relationship between trading volume and volatility and explain this relationship

⁸ Ahn, Kang, and Ryu (2008, 2010), and Chung, Park, and Ryu (2016) find that ITM options trading is more informative than OTM options trading in the KOSPI200 options market. They attribute this finding to the relatively high participation of domestic and foreign institutional investors, who are generally informed and experienced, in ITM options trading.

within the existing hypotheses. Clark (1973), Harris (1982), and Tauchen and Pitts (1983), who favor the MD hypothesis, claim that the arrival of new information generates simultaneous increases in the trading volume and the volatility, resulting in a positive association between them. Epps and Epps (1976), who support the SIF hypothesis, also argue that an increase in investor disagreement on asset valuation causes substantial increases in trading volume and volatility. Admati and Pfleiderer (1988) explain that strategic investors choose to trade when markets are more active and liquid, resulting in a positive association between the volume and the volatility. Our estimation results confirm that this positive association still holds within an intraday dynamic system consisting of returns, volumes, and volatilities.

Fourth, we detect a bi-directionally significant intertemporal relationship between returns and volatilities. In all models except M_{ITM} , all estimated γ_{VR} coefficients are significant and negative, meaning that an increase (decrease) in asset returns causes a decrease (increase) in volatility in the next period. This finding is consistent with the asymmetric volatility effect explained by the leverage effect hypothesis (Bekaert and Wu, 2000; Black, 1976; Lee and Ryu, 2013; Wu, 2001). We confirm that the negative relationship between returns and volatilities is also observed in an intraday high-frequency dataset when the dynamic relationship among returns, volumes, and volatilities is analyzed. The substantially greater magnitude of the estimated γ_{VR} in the M_{OTM} model relative to the estimates in the other models further supports the leverage effect hypothesis because OTM options provide a higher leverage effect than other options.

The γ_{RV} coefficient estimates are highly significant and positive in all models, meaning that the change in volatility in the current period is positively correlated with the asset returns in the next period. We can interpret this positive relationship between the lagged volatility (V_{t-1}) and the current returns (R_t) in the framework of the risk–return trade-off. The rise in the market volatility indicates increased systematic risk, which should result in greater compensation in the form of higher returns for risk-averse investors. The magnitude of the γ_{RV} coefficient estimate in the M_{ITM} model is much greater than the corresponding values in the other models, which is consistent with previous studies that observe a greater information quality of ITM options trading and a strong linkage between KOSPI200 ITM options and the underlying spot market (Ryu, 2011).

Fifth, although only two of the C_{VV} estimates (excluding those in the M_{ATM} and M_{OTM} models) are significant, all of the estimates of C_{RR} and C_{TT} are statically significant. The result that most of the elements of matrix C are statistically significant indicates the existence of covariance asymmetry in the volatilities and supports our selection of a GJR-GARCH-type model to capture this asymmetric volatility.

■ ■ ■ V. Conclusion

We examine the dynamics and the statistical relationship among returns, trading volumes, and volatilities in the Korean futures and options market using an asymmetric multivariate BEKK-GARCH model based on an intraday dataset. This study distinguishes from previous work in that it uses a multivariate model based on an intraday dataset of the KOSPI200 derivatives markets, which has rarely received attention in the literature in spite of its importance and influence.

The implications from the empirical results are as follows. We note the intertemporal intraday linkages among asset returns, trading volumes, and volatilities. The findings that an increase in the futures trading volume leads to greater returns in the next period and that trading volumes and volatilities are positively and bi-directionally correlated both support the MD and SIF hypotheses. There is a significant relationship between returns and volatilities, which is explained by the risk–return trade-off and the asymmetric volatility effect. We also associate the differences in coefficient estimates across the M_{ITM} , M_{ATM} , M_{OTM} , and M_{VKOSPI} models with the different option moneyness levels to determine the degree of the leverage effect and the sensitivity level.

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