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The lead-lag relationship between stock index options and the stock index market

Model, moneyness, and news

Sol Kim
School of Business, Hankuk University of Foreign Studies, Seoul, South Korea
In Joon Kim
School of Business, Yonsei University, Seoul, South Korea, and
Seung Oh Nam
Department of Financial Management, Soonchunhyang University, Asan-si, South Korea

Abstract

Purpose – The purpose of this paper is to examine the price discovery role of the Korea Composite Stock Price Index 200 (KOSPI 200) stock index options market in contrast to other developed options markets.

Design/methodology/approach – The price discovery roles of the stock and options markets using the error-correction model derived from the co-integration relationship are examined. Various analyses are conducted. First, Heston's stochastic volatility option pricing model is employed to confirm its usefulness, and compare the results with the Black and Scholes (BS) model. Second, whether the out of the money (OTM) options purchased by individual investors have a stronger price discovery role than options with other moneyness is examined. Finally, whether options have a stronger price discovery role in bullish or bearish markets than in normal markets is tested.

Findings – It is found that stock index prices lead implied index prices estimated from option prices using both BS and Heston models. In regards to the OTM options, the lead-effect of real stock index to implied index prices holds. Also it is shown that there is a weak rise in the lead effect of the options to the stock index, but the lead effect of stock index market rules over that of the options market.

Originality/value – The paper examines the price discovery role of the KOSPI 200 stock index options market in contrast to other developed options markets and the results indicate that the consensus on the Korean financial markets may be incorrect.

Keywords Stochastic processes, Stock markets, Options markets, Stock prices

Paper type Research paper

1. Introduction

In a perfectly functioning capital market, there would be complete simultaneity across markets. That is, any new information disseminating into the markets would be reflected simultaneously in them all. However, such factors as lower transaction costs, higher liquidity, and higher financial leverage may make one market is more attractive than the others, and this one market may thus be able to absorb new information more quickly. In addition, if one market provides information more efficiently, then it should

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lead the others: price discovery may thus be interpreted as an indication of relative market efficiencies. Many traders take positions in inter-markets simultaneously. As a result, differences in reaction times, and the size of the differences in cross-sectional prices between markets, may have a crucial effect on profits. Thus, arbitrage opportunities may exist across markets.

This market efficiency has attracted the attention of researchers, and there have been several studies of the roles of price discovery in markets. Many researchers have examined the relationship between the stock market and its futures market, and have reported that the latter strongly leads the former[1]. However, although the majority of researchers has argued that the futures market leads the stock market, some conflicts have emerged in research on the relationship between the stock market and the options market.

Stephan and Whaley (1990) reported that price changes in the stock market tend to lead those in the option market for active Chicago Board Options Exchange call options by as much as 15 minutes, but according to Manaster and Rendleman (1982), Bhattacharya (1987) and Anthony (1988), Finucane (1991), and Diltz and Kim (1996), the options market leads the stock market. Moreover, recent studies have focused on the relationship between individual stocks and the corresponding options. Considering the results of the previous studies collectively, we can conclude that the lead-lag relationship between markets are different from one another depending on corresponding markets of the countries and methodologies.

Nam *et al.* (2006) argued that it is necessary to analyze the intraday patterns with a high frequency of derivatives markets with abundant liquidity to find out more apparent lead-lag relationship between markets. In this paper, we discuss the Korea Composite Stock Price Index 200 (KOSPI 200) stock index options market, which is one of the emerging options markets. It is ranked first in the world in terms of options trading volume, of which over 50 percent is by individual investors. In 2006, the combined trading volume reached 2.4 billion contracts, which accounted for 22.4 percent of total contracts in the world. The sufficient liquidity of the markets ensures that the KOSPI 200 stock index options market is an appropriate one in which to study the market microstructure of price discovery, and the pricing bias associated with stock index and options markets.

The object of this paper is to examine the price discovery role of the KOSPI 200 stock index options market in contrast to the other developed options markets. In addition to the difference in the sample market, we also examine several hypotheses that previous research has not addressed.

First, we examine whether the option pricing model gives different results for the lead-lag relationship between the stock index and options markets. The Black and Scholes (BS) model used in previous research is known to suffer from empirical deficiencies. From the several models that make up for the weak points of the BS model, we choose the stochastic volatility option pricing model. Several researchers have examined the importance of the stochastic volatility of the underlying asset in option valuation. For example, Bakshi *et al.* (1997) empirically tested the Standard & Poor’s 500 (S&P 500) market, and reported that it is significantly essential to consider stochastic volatility in option valuation. In addition, Kim and Kim (2004, 2005) documented the importance of stochastic volatility in option valuation, and empirically supported the argument within the Korean options market. Of course, we may estimate the model-free implied index price by using the put-call parity. In this case, only one option with specific moneyness is used. However, Ederington and Guan (2005) showed that the information content of options differs by the moneyness of options. Thus, we use the specific option pricing model to estimate the implied index price, by using the option prices with all moneyness. However, to prevent any distortion of the results based on the selected model, we employ both the BS and the Heston (1993) models to calculate the implied index prices from the options data.

Second, we focus on individual investors, who account for a considerable portion of options market trading volume. Accordingly, we can expect the Korean options market to show a greater lead effect with respect to the stock index market than any other options market, because individual traders are expected to enter the options market for speculative reasons rather than hedging purposes[2]. On the other hand, individual investors have less information on market movements than institutional investors, not because of informed trading that makes use of foresight, but because individual investors engage in speculative trading in the expectation of "winning the lottery." As a result, the options market may not lead the stock index market. In addition, options are known to be instruments for volatility rather than directional trading. What conclusion can be drawn from these two conflicting reasons?

We test whether the price discovery role of option prices is dependent on the moneyness of options. It is generally accepted that individual traders have a speculative rather than a hedging purpose, and use out-of-the-money (OTM) options. That is, individual traders intend to make a directional bet on the direction of the underlying stock index by purchasing cheap OTM options as a form of lottery ticket. These assumptions indicate that the OTM options that traders buy, with the intention of making a directional betting trade in a large stake, can be an instrument of informed trading. As a result, the index implied by OTM options can be expected to lead the stock index.

Finally, we test whether the price discovery role of option prices is dependent on the type of news. If investors receive good (bad) news in advance, they will hold call (put) options to obtain high leverage and a loss-limit effect. As a result, the options market is expected to lead the stock index market. In addition, in the case of bad news, profits from informed trading cannot be realized in the underlying stock index market because of the restriction on short selling. Therefore, in a declining market, the lead effect of the options market may become stronger. As a result, with a rising trend, call options are expected to lead the stock index, whereas in a declining trend put options would be expected to lead. We assume that it is easy for investors to receive information when the stock market moves on a large-scale, and that this enables them to examine the difference in the lead-lag relationship between the stock index and options markets.

The remainder of the paper is organized as follows. Section 2 explains in detail the empirical methodology adopted. Then, the data section describes the sample data, and the empirical results section presents the empirical results regarding several hypotheses. Finally, Section 4.6 presents the conclusions and a summary of the results.

2. Empirical methodology

2.1 Co-integration and error-correction model

Individual economic series may sometimes be nonstationary, but the linear combinations of the series are expected to be in equilibrium. For example, even though the difference between stock prices and implied index prices from options may increase temporarily, in the long-term they should mean revert to a long-run equilibrium. This is described as co-integration relationship in the time series perspective. The long-run relationship between the implied index price and the real index price series is explained by the following equation:

$$P_{o,t} - \hat{\beta}_0 - \hat{\beta}_1 P_{s,t} = \hat{e}_{o,t} \tag{1}$$

where $P_{s,t}$ and $P_{o,t}$ are the contemporaneous stock prices and implied index prices from options data at time t, respectively, $\hat{\beta}_0$ and $\hat{\beta}_1$ are parameters, and $\hat{e}_{o,t}$ is the deviation from parity. In equation (1), ordinary least squares is not appropriate if $P_{s,t}$ and $P_{o,t}$ are nonstationary, because standard errors are not consistent.

As Engle and Granger (1987) explained, if $P_{s,t}$ and $P_{o,t}$ are nonstationary, but the deviations, e_t, are stationary, then the two series, $P_{s,t}$ and $P_{o,t}$, are said to be co-integrated, and there exists an equilibrium relationship. In order for $P_{s,t}$ and $P_{o,t}$ to be co-integrated, they should be integrated of the same order, and the order of integration may be determined by conducting unit root tests. If each series is nonstationary but the first differences and the deviations are stationary, then the prices are considered to be co-integrated of the order (1, 1).

According to Granger and Newbold (1974), if the two series are covariance stationary without trends-in-mean and are co-integrated, then there exists an error-correction representation for each series that is not subject to spurious regression problems. In this paper, we follow the methodology of Wahab and Lashgari (1993), Diltz and Kim (1996), and Pizzi *et al.* (1998), and use the returns of the series rather than the first-order differences of the price series. There are four possible error-correction model specifications for the two series $P_{s,t}$ and $P_{o,t}$, as follows:

$$\begin{gathered}
r_{s,t} = \alpha_1 + \alpha_s \hat{e}_{s,t-1} + \sum_{k=1}^{n} \alpha_{11}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{12}(k) r_{o,t-k} + \varepsilon_{s,t} \\
r_{o,t} = \alpha_2 + \alpha_o \hat{e}_{o,t-1} + \sum_{k=1}^{n} \alpha_{21}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{22}(k) r_{o,t-k} + \varepsilon_{o,t} \\
P_{o,t} - \hat{\beta}_0 - \hat{\beta}_1 P_{s,t} = \hat{e}_{o,t} \\
r_{s,t} = \alpha_1' + \alpha_s' \hat{e}_{s,t-1} + \sum_{k=1}^{n} \alpha_{11}'(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{12}'(k) r_{o,t-k} + \varepsilon_{s,t}' \\
r_{o,t} = \alpha_2' + \alpha_o' \hat{e}_{o,t-1} + \sum_{k=1}^{n} \alpha_{21}'(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{22}'(k) r_{o,t-k} + \varepsilon_{o,t}' \\
P_{s,t} - \hat{\beta}_0 - \hat{\beta}_1 P_{o,t} = \hat{e}_{s,t}
\end{gathered} \tag{2}$$

where $P_{s,t}$ and $P_{o,t}$ are the contemporaneous stock prices and implied index prices from options data at time t, respectively, and $r_{s,t}$ and $r_{o,t}$ are the stock returns and implied index returns of options at time t, respectively.

According to Enders (1995), in a large sample the results are equivalent, regardless of whether the real index or implied index data are used as dependent variables in obtaining the standard error terms. Therefore, in our analysis we apply the first three equations from equations (2).

2.2 Implied index

We include the data of all types of moneyness – in-the-money (ITM), at-the-money (ATM), and OTM – in the calculation, though acknowledging some negative impacts that ITM and OTM options are often overvalued and thus the errors in volatility estimation tend to be larger than those for the ATM options. With respect to this volatility overestimation issue, we use the methodology with put-call parity, as in Finucane (1991). This methodology is effective because it offers a model-free approach.

Here, an option of a particular moneyness type is used, and often the ATM or near-the-money option with the largest trading volume is selected. However, some of the information implied in the options data of other types of moneyness may be overlooked. Ederington and Guan (2005) stated that the information implied in the prices of options with respect to moneyness differs, and thus we assume that the inclusion in the calculation of implied index prices of all types of options regarding moneyness may indeed be useful in obtaining all of the information in available options data.

We choose the closed-form option pricing model. A non-linear least squares procedure is thus a natural candidate for the estimation of parameters, spot volatility, and the implied cum-dividend index in the pricing formula, which involves minimizing the sum of squared errors between the model and the market prices. Following Bakshi *et al.* (1997, 2000) and Bates (1995, 1996), we estimate the structural parameters together with the spot volatility of each model in the sample. Estimating parameters and spot volatility from the asset returns can be an alternative method, but historical data reflect only what has happened in the past. Furthermore, the procedure using historical data is not capable of identifying risk premiums, which must be estimated from options data that are conditional on the estimates of other parameters. The important advantage of using option prices to estimate parameters is that this approach allows the use of the forward-looking information contained in the option prices.

Let $O_i^*(t, \tau; K)$ denote the model price of option i with time to maturity τ on day t, and let $O_i(t, \tau; K)$ denote the market price of option i with time to maturity τ on day t. We estimate the parameters for calls and puts[3]. That is, there are two sets of parameters for calls and puts, day after day. To estimate the parameters, spot volatility, and implied index for each model, we minimize the sum of squared percentage errors between the model and the market prices, as follows:

$$\min_{\phi_t, V_t} \sum_{i=1}^{N} \left[\frac{O_i^*(t, \tau; K) - O_i(t, \tau; K)}{O_i(t, \tau; K)} \right]^2 \quad t = 1, \ldots, T \tag{3}$$

where ϕ_t and V_t denote the vector consisting of structural parameters and spot volatility on day t, respectively. N denotes the number of options on day t and T denotes the number of days in the sample[4]. The estimated index price is the ex-dividend index, and it can be identified as the implied forward price. In this paper, we define this price as the implied index price, to satisfy the above condition.

3. Data

KOSPI 200 stock index options are based on the KOSPI 200 stock index, which consists of 200 constituent blue-chip stocks of the Korea Stock Exchange (KSE) and European-style options. The KOSPI 200 stock index options market, which was opened on July 7, 1997, began with unprecedented enthusiasm. During the five-year period from 1999 to 2003, the KSE options market ranked, in terms of trading volume, as the most heavily traded options market in the world, and annual trading volume reached almost 1890 million contracts in 2002. Obviously, the main explanation for this extraordinary growth was the interest and enthusiasm of the investors in the market. In addition, the exercise style of the KOSPI 200 stock index options market is European, and thus contracts can be exercised only on the expiration date. Hence, our test results are unaffected by the complications that result from the early exercise feature of American options.

The sample period includes data from January 2002 to July 2004. Minute-by-minute transaction prices for the KOSPI 200 stock index options were obtained from the KSE. The 91-day certificate of deposit yields are used as the risk-free interest rates, and were obtained from the Korea Bond Pricing and Korea Rating Co. In the following section, we explain the criteria that were employed to filter the data used in the empirical tests:

- To eliminate any liquidity-related biases, options with less than six days or more than 60 days to expiration were excluded.
- Five-minute data were sorted from the minute-by-minute data of options prices[5].
- The following condition of no arbitrage had to be satisfied for inclusion in the test:

$$\begin{aligned} C_{t,\tau} &\geq S_t - KB_{t,\tau} \\ P_{t,\tau} &\geq KB_{t,\tau} - S_t \end{aligned} \tag{4}$$

  where $C_{t,\tau}$ and $P_{t,\tau}$ are the call and put option-price data in τ periods from time, respectively, and $B_{t,\tau}$ denotes a zero-coupon bond that pays 1 in τ periods from time t.
- As simultaneous bids and offers start from 2:50 p.m., only transactions from 9:00 a.m. to 2:50 p.m. were employed in the test.
- As it was necessary to use actual traded options data only, we adopted only those data where an actual transaction occurred. This option volume was not equal to that occurring five minutes previously.
- To mitigate the impact of price discreteness in option valuation, prices lower than 0.2 were excluded from the sample.

4. Empirical results

4.1 Market microstructure effects

In this section, we consider the infrequent trading and bid-ask spread effects that are generally produced in intraday data. To factor out these effects, Stoll and Whaley (1990) and Pizzi *et al.* (1998) assumed that the residuals from the estimation of the autoregressive moving average (ARMA) model are the genuine returns purified of the infrequent trading and bid-ask spread effects, and they used those in the error-correction model. This method is derived from Stoll and Whaley's (1990) assumption that the infrequent trading effect produces the AR term, and that the bid-ask spread effect produces the MA term of returns. However, we do not artificially distort the returns of the implied index and real index prices. First, the ARMA model itself is time varying. Thus, we use the returns themselves in the error-correction model, and focus more on the factual lead-lag relationship of the returns of the stock and options data.

Second, in Table I, we examine the correlogram of the returns of the implied and real index prices, to assess the necessity of considering the market microstructure effects. The results indicate that the real index returns show a negative autocorrelation, but are generally close to white noise. The implied index returns show strong negative autocorrelation at order 1, which proves that they are influenced by the bid-ask spread effects. If the lead-lag relationship comes into existence because of market microstructure effects, the price discovery role between the two markets will be biased, as in the options market, in which prices change frequently, because the bid-ask spread effect leads the stock index market. Conversely, if real index prices lead the implied index prices, and even though the returns with these market microstructure effects are used in this research, our results are more concrete despite the bias that rejects our results. Therefore, in this paper, we use pure returns instead of the residuals from the ARMA filtering.

4.2 Co-integration test results

We employ Johansen's (1991, 1992) co-integration test to examine the relationship between the stock price and the implied index price series. In doing so, we examine all cases of computing implied index prices using calls and puts estimated from the BS model. We conduct a co-integration test to examine whether there is a long-run equilibrium relationship between the real and implied index price series.

	Real index return		Implied index return	
	AC	PAC	AC	PAC
Panel A: calls				
1	−0.026*	−0.026*	−0.181*	−0.181*
2	−0.022*	−0.023*	−0.018*	−0.053*
3	−0.010*	−0.011*	0.001*	−0.012*
4	0.001*	0.000*	0.005*	0.002*
5	−0.005*	−0.006*	−0.009*	−0.008*
6	−0.001*	−0.001*	0.003*	0.001*
7	0.009*	0.009*	0.013*	0.013*
8	−0.003*	−0.002*	0.001*	0.006*
9	0.007*	0.007*	0.008*	0.010*
10	−0.007*	−0.007*	−0.011*	−0.008*
Panel B: puts				
1	−0.025*	−0.025*	−0.278*	−0.278*
2	−0.022*	−0.023*	−0.005*	−0.090*
3	−0.011*	−0.012*	−0.005*	−0.035*
4	0.004*	0.003*	0.013*	0.002*
5	−0.005*	−0.006*	0.001*	0.006*
6	−0.001*	−0.001*	0.003*	0.007*
7	0.009*	0.009*	0.009*	0.014*
8	−0.002*	−0.002*	−0.003*	0.005*
9	0.008*	0.008*	−0.008*	−0.007*
10	−0.005*	−0.004*	0.002*	−0.003*

Notes: *Statistically significant at 1 percent level; the correlogram of real index returns and implied index returns estimated from Black and Scholes (1973) model; AC and PAC denote the coefficients of autocorrelation and partial autocorrelation, respectively

Table I. Correlogram of real index and implied index returns

As Table II shows, the hypothesis that there is no co-integration between the two time series is strongly rejected, with high Likelihood ratio (LR) statistic values. Thus, the price relationship between the stock and options markets reverts to the equilibrium level because these two series are closely related by the arbitrage opportunities. In addition, the LR statistic value of call options (68,080.7109) is higher than that of put options (1783.6848): this result indicates that call options show a stronger relationship with the stock index market than put options. As a result, we showed that there exists a co-integration relationship, and so the error-correction model can be applied to the series.

4.3 Error-correction model results

Next, we examine the price discovery roles of the stock and options markets using the error-correction model derived from the co-integration relationship.

Table III describes the results of the lead-lag relationship between the stock and options markets when the implied index prices are calculated using the BS model[6].

First, the real index returns strongly lead the index returns implied by option prices. When the real index returns are used as the dependent variable, the implied index return series estimated from call options, r_c', is significant at the 1 percent level up to order 9, which indicates that the implied index returns lead the real index returns by 45 minutes. In addition, the implied index returns from put options lead the real index returns by 20 minutes. On the other hand, the real index returns lead the implied index returns by 75 minutes and 110 minutes for calls and puts, respectively. As mentioned in Section 4.1, this is a concrete result that overcomes the bias from bid-ask spread effects.

Second, from the lead-lag time between the options and stock index markets, we may conclude that the lead-lag relationship between the two markets is bidirectional. However, the coefficients of the lead-lag variables show large differences. For example, when the variables of the first lag are examined, the options-lead values when the dependent variable is current stock index returns are 0.1069 and 0.0392 for call and put options, respectively. On the other hand, the stock-lead values when the dependent

Table II.
Johansen's co-integration test results

			Critical value	
	Eigenvalue	Likelihood ratio	5%	1%
Panel A: calls				
H_0	0.9974	68,080.7109	12.53	16.31
Normalized co-integrating coefficients				
P_s	P_o			
1.0000	−0.9976	Log likelihood	209.1173	
Panel B: puts				
H_0	0.1933	1,783.6848	12.53	16.31
Normalized co-integrating coefficients				
P_s	P_o			
1.0000	−0.9974	Log likelihood	5,231.1068	

Notes: The Johansen's co-integration test results between real index price and implied index price estimated from option prices; implied index prices are calculated from call and put options data using the Black and Scholes (1973) model; Panel A describes the Johansen's co-integration test results between real index price and implied index price estimated from calls and Panel B does from puts; H_0 is the hypothesis that there are no co-integration vectors between the series. P_s and P_o are contemporaneous real index prices and implied index prices from options data, respectively

Table III. Error-correction model results

	Options lead stocks					Stocks lead options			
	Calls		Puts			Calls		Puts	
	r_s	*t*-stat.	r_s	*t*-stat.		r_c	*t*-stat.	r_D	*t*-stat.
c	0.0000	−0.3569	0.0000	−0.1567	c	0.0000	−0.8398	0.0000**	−1.1700
$\hat{e}_j(-1)$	0.0000	0.1232	0.0000	1.0151	$\hat{e}_j(-1)$	0.0001**	5.0435	−0.0002**	−11.1637
$r_j(-1)$	0.1069**	20.0138	0.0392**	13.2237	$r_s(-1)$	0.4622**	53.1180	0.6081**	58.7409
$r_j(-2)$	0.0804**	13.5707	0.0329**	9.7395	$r_s(-2)$	0.3458**	36.9210	0.5037**	46.1194
$r_j(-3)$	0.0618**	9.9205	0.0250**	6.8882	$r_s(-3)$	0.2655**	27.3313	0.4237**	37.5080
$r_j(-4)$	0.0472**	7.3884	0.0156**	4.1148	–	–	–	–	–
$r_j(-5)$	0.0346**	5.3276	0.008	2.0604	$r_s(-14)$	0.0396**	3.8838	0.0823**	6.9104
$r_j(-6)$	0.0380**	5.8107	0.0090*	2.2693	$r_s(-15)$	0.0384**	3.7622	0.0716**	6.0032
$r_j(-7)$	0.0297**	4.5153	0.0051	1.2902	$r_s(-16)$	0.0195	1.9200	0.0574**	4.8310
$r_j(-8)$	0.0236**	3.5834	−0.0028	−0.6871	$r_s(-17)$	0.0185	1.8171	0.0599**	5.0538
$r_j(-9)$	0.0197**	2.9911	−0.0007	−0.1772	$r_s(-18)$	0.0142	1.4006	0.0541**	4.5759
$r_j(-10)$	0.0135*	2.0455	−0.0037	−0.9254	$r_s(-19)$	0.0210*	2.0766	0.0391**	3.3169
$r_j(-11)$	0.0137*	2.0785	−0.0059	−1.4700	$r_s(-20)$	0.0033	0.3297	0.0399**	3.4121
$r_j(-12)$	−0.0010	−0.1536	−0.0082*	−2.0347	$r_s(-21)$	0.0065	0.6503	0.0439**	3.7829
$r_j(-13)$	0.0015	0.2308	−0.0044	−1.0943	$r_s(-22)$	0.0106	1.0881	0.0321**	2.8167
–	–	–	–	–	$r_s(-23)$	0.0141	1.4796	0.0186	1.6821
$r_j(-23)$	0.0010	0.1681	−0.0042	−1.2075	$r_s(-25)$	0.0037	0.4678	0.0191*	1.9748

Notes: ** and * are statistically significant at 5% and 1% levels; the error-correction model results between real index price and implied index price from the options using Black and Scholes (1973) model; the error-correction model is as follows:

$$r_{s,t} = \alpha_1 + \alpha_s \hat{e}_{j,t-1} + \sum_{k=1}^{n} \alpha_{11}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{12}(k) r_{j,t-k} + \varepsilon_{s,t}$$

$$r_{j,t} = \alpha_2 + \alpha_j \hat{e}_{j,t-1} + \sum_{k=1}^{n} \alpha_{21}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{22}(k) r_{j,t-k} + \varepsilon_{j,t}$$

$$P_{j,t} - \hat{\beta}_0 - \hat{\beta}_1 P_{s,t} = \hat{e}_{j,t} (j = c, p)$$

$r_s$and r_j are log returns of real index price and implied index price from calls or puts, respectively variable is current option returns are 0.4622 and 0.6081 for call and put options, respectively. That is, the lead effect of real index prices on implied index prices estimated from the options market is stronger than in the opposite case.

Third, we consider the significance of the error-correction term $\hat{e}_c$. In the equation in which the implied index return from the prices of options is the dependent variable, only the error-correction term is significant. This indicates that the implied index returns estimated from call and put options have corrected the errors from the long-term equilibrium five minutes previously. This result is also consistent with the idea that the stock index leads the options market. If the stock index market leads the options market, option prices will reflect the information that arrives after the passage of a sufficient amount of time since the news enters the capital market. If this is the case, errors from the long-term equilibrium between the two markets will be generated, and they will be mediated, after some time, by the option prices. As a result, the implied index from option prices is expected to correct the errors from the long-term equilibrium five minutes previously.

Finally, the real index shows that the price discovery role of the implied index from put options is stronger than that of the implied index from call options. This result is connected with that of the co-integration test discussed previously. As mentioned earlier, the co-integration relationship between real and implied index prices that is estimated from call options is stronger than that from the estimation using put options. That is, call options have a stickier long-term equilibrium with the underlying stock index than put options. This shows that the interrelationship between the two markets is strong, and it confirms that the lead-lag relationship between the implied index prices from call options and the real index is stronger than that from put options.

4.4 Price discovery under the type of model

Until now, we have assumed the use of a specific option pricing model, the BS model, to estimate the implied index price. However, the lead-lag relationship between stock index and options markets may change, according to the option pricing model selected. To clarify this possibility, we examine the price discovery role of the implied index prices, as estimated using another option pricing model. Several researchers have derived option pricing models that complement the empirical deficiency of the BS model, and others have examined the empirical performance of various option pricing models. Among them, Bakshi *et al.* (1997, 2000) and Kim and Kim (2004, 2005) showed that the stochastic volatility term is the most important factor for the S&P 500, Long-Term Equity Anticipation Securities, and KOSPI 200 stock index options markets. Indeed, adding jumps may improve the explanatory power regarding option prices. However, the stochastic volatility with the jumps model requires more parameters than the stochastic volatility model, and it also has the potential problem of over-fitting with the data. In the light of these points, we choose the stochastic volatility option pricing model as a benchmark of the BS model. In addition, from several models, we choose Heston's (1993) model, which has a closed-form solution, and reflects a non-zero correlation between the returns and volatility.

First, we examine the co-integration test, to determine whether the error-correction model can be used.

As Table IV shows, there is a co-integration relationship between the implied index price estimated from the stochastic volatility option pricing model and the real index price. This is similar to the results of the BS model. As Table V shows, we followed the

	Eigenvalue	Likelihood ratio	Critical value 5%	1%
Panel A: calls				
H_0	0.3427	6,290.1770	12.53	16.31
Normalized co-integrating coefficients				
P_s	P_o			
1.0000	− 1.0002	Log likelihood	8,999.6050	
Panel B: puts				
H_0	0.9935	73097.2560	12.53	16.31
Normalized co-integrating coefficients				
P_s	P_o			
1.0000	− 0.9990	Log likelihood	1,578.2369	

Notes: The Johansen's co-integration test results between real index price and implied index price estimated from option prices; implied index prices are calculated from call and put options data using Heston (1993) model; Panel A describes the Johansen's co-integration test results between real index price and implied index price estimated from calls and Panel B does from puts; H_0 is the hypothesis that there are no co-integration vectors between the series; P_s and P_o are contemporaneous real index prices and implied index prices from options data, respectively

Table IV. Johansen's co-integration test results in use of Heston model

same methodology in estimating the error-correcting regression, and obtained the following results.

First, stock returns lead option returns by 210 and 180 minutes for call and put options data, respectively. On the other hand, call and put options returns lead the stock returns by 0 and 40 minutes, respectively. That is, when using the Heston (1993) model there exists a stronger lead effect of the stock index market on the options market than when using the BS model. This interesting result may be interpreted as follows. If Heston's (1993) model, which captures stochastic volatility, explains the options market better, as reported by Bakshi *et al.* (1997, 2000) and Kim and Kim (2004, 2005), we may conclude that stock returns do indeed lead options returns, and that Heston's (1993) model presents these results more precisely. That is, the Heston (1993) model can be expected to provide a better representation of the options market[7].

On the other hand, real index prices lead the implied index prices from call options more strongly than the implied index prices from put options. As with the results using the BS model, this comes from the co-integration result. Using Heston's (1993) model, the LR value of the co-integration relationship between implied and real index prices is larger for put options than for call options. This is consistent with the unidirectional relationship in call options.

Next the significance of the co-integration error term, $\hat{e}_c$, indicates that the implied index prices estimated from the Heston (1993) model reconcile the errors in the long-term equilibrium five minutes previously. This result is identical to that obtained using the BS model.

Thus, both the BS and Heston (1993) models agree that the stock index market leads the options market. To validate this argument, as Table VI shows, we carried out the Wald test on the variables of the lead effects. With use of both the Heston (1993) and BS models, the hypothesis that stock returns do not lead implied index returns was strongly rejected for both calls and puts. By comparison, the hypothesis that implied index returns do not lead stock index returns was also rejected, but the F-statistics'

Table V.
Error-correction model results in use of Heston model

	Options lead stocks					Stocks lead options			
	Calls		Puts			Calls		Puts	
	r_s	*t*-stat.	r_s	*t*-stat.		r_c	*t*-stat.	r_p	*t*-stat.
c	0.0000	−0.2350	0.0000	0.6215	c	0.0002**	9.7044	−0.0004**	−11.3317
$\hat{e}_j(-1)$	0.0000	−0.5558	0.0000	−2.3325	$\hat{e}_j(-1)$	0.0019**	40.2914	0.0044**	95.4986
$r_j(-1)$	−0.0006	−0.2259	0.0024**	3.0893	$r_s(-1)$	0.5883**	49.7446	0.2218**	14.2023
$r_j(-2)$	−0.0005	−0.2097	0.0025**	3.1901	$r_s(-2)$	0.5489**	45.3057	0.1233**	8.1705
$r_j(-3)$	−0.0013	−0.4890	0.0019**	2.4645	$r_s(-3)$	0.5116**	41.6432	0.1359**	8.9902
$r_j(-4)$	−0.0028	−0.9967	0.0019**	2.5060	$r_s(-4)$	0.4663**	37.6381	0.1265**	8.3252
$r_j(-5)$	−0.0010	−0.3675	0.0018**	2.4082	$r_s(-5)$	0.4516**	36.2390	0.1152**	7.4898
$r_j(-6)$	−0.0002	−0.0739	0.0020**	2.6956	$r_s(-6)$	0.4411**	35.1407	0.1422**	9.2618
$r_j(-7)$	0.0015	0.4968	0.0019**	2.5410	$r_s(-7)$	0.3938**	31.2001	0.1574**	10.3860
…	…	…	…	…	…	…	…	…	…
$r_j(-38)$	−0.0001	−0.0455	0.0010*	2.4155	$r_s(-36)$	0.0689**	5.6700	0.0527**	3.5265
$r_j(-39)$	0.0002	0.0820	0.0007	1.8991	$r_s(-37)$	0.0901**	7.4730	0.0168	1.1253
$r_j(-40)$	0.0017	0.7543	0.0007*	1.9785	$r_s(-38)$	0.0682**	5.7033	0.0388**	2.5895
$r_j(-41)$	0.0005	0.2366	0.0007*	2.0036	$r_s(-39)$	0.0581**	4.9025	0.0356*	2.3828
$r_j(-42)$	−0.0001	−0.0608	0.0007*	2.4242	$r_s(-40)$	0.0406**	3.4537	0.0090	0.6025
$r_j(-43)$	−0.0004	−0.2286	0.0006*	2.0790	$r_s(-41)$	0.0488**	4.1932	0.0318*	2.1282
$r_j(-44)$	−0.0011	−0.7438	0.0005*	2.1548	$r_s(-42)$	0.0364**	3.1683	0.0060	0.4014
$r_j(-45)$	−0.0016	−1.3335	0.0001	0.4291	$r_s(-43)$	0.0167**	1.4761	0.0211	1.4161

Notes: *and **are statistically significant at 5 and 1 percent levels; the error-correction model results between real index price and implied index price from the options using Heston (1993) model; the error-correction model is as follows:

$$r_{s,t} = \alpha_1 + \alpha_s \hat{e}_{j,t-1} + \sum_{k=1}^{n} \alpha_{11}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{12}(k) r_{j,t-k} + \varepsilon_{s,t}$$

$$r_{j,t} = \alpha_2 + \alpha_j \hat{e}_{j,t-1} + \sum_{k=1}^{n} \alpha_{21}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{22}(k) r_{j,t-k} + \varepsilon_{j,t}$$

$$P_{j,t} - \hat{\beta}_0 - \hat{\beta}_1 P_{s,t} = \hat{e}_{j,t} (j = c, p)$$

r_s and r_j are log returns of real index price and implied index price from calls or puts, respectively

	Heston		BS	
	Calls	Puts	Calls	Puts
H_o	1.2086	1.0417	17.0440	8.8904
H_s	115.4633	23.9207	125.0359	190.2874

Notes: The Wald test results for the error-correction model between real index price and implied index price from option prices using Heston (1993) and Black and Scholes (1973) Models; the error-correction model is as follows:

$$r_{s,t} = \alpha_1 + \alpha_s \hat{e}_{j,t-1} + \sum_{k=1}^{n} \alpha_{11}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{12}(k) r_{j,t-k} + \varepsilon_{s,t};$$

$$r_{j,t} = \alpha_2 + \alpha_j \hat{e}_{j,t-1} + \sum_{k=1}^{n} \alpha_{21}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{22}(k) r_{j,t-k} + \varepsilon_{j,t};$$

$$P_{j,t} - \hat{\beta}_0 - \hat{\beta}_1 P_{s,t} = \hat{e}_{o,t};$$

r_s and r_o are log returns of stock price and implied index price, respectively; (i) Dependent variable: r_s; F-statistic value for $H_o : \forall a_{12}(-k) = 0$ (Implied index returns do not lead stock returns.); (ii) Dependent variable: r_o; F-statistic value for $H_s : \forall a_{21}(-k) = 0$ (Stock returns do not lead implied index returns)

Table VI.
Wald test results

values were smaller than those of the former hypothesis for calls and puts. We concluded that stock index returns tend to lead options returns, regardless of the model used to compute the implied index prices. However, in the case of the Heston model, we found a stronger lead effect of stock returns on options returns.

4.5 Price discovery under the moneyness of options

Ederington and Guan (2005) showed that the information content of options differs by moneyness. This results from differences in investors' preferences regarding option moneyness and the trading volume of each option. In the KOSPI 200 stock index options market, the trading volume of OTM options is large in comparison to other options markets, because individual investors tend to trade OTM options as though they were trying to win a prize in a lottery (http://english.fss.or.kr). Based on this conjecture, the OTM options that individual investors trade frequently for the purpose of directional betting are expected to have a lead effect on the stock index market. We define the OTM options as call (put) options for which the ratio of the stock index price to the strike price is less than 0.97 (more than 1.03), and we estimate separately the implied index price from the OTM options.

As Table VII shows, stock returns lead option returns by 115 and 90 minutes for call and put options data, respectively. On the other hand, call and put option returns lead stock returns by 50 and 30 minutes, respectively. Compared to using the implied index prices estimated from the options with all moneyness, the lead effect of both call and put options on the stock index becomes weaker, and that of the stock index on options becomes stronger. Contrary to our expectations, the OTM option does not significantly improve the price discovery role of options. This result agrees with the common view that individual investors do not hold OTM options based on information on the direction of the underlying index, but think of OTM options as a lottery. That is, this result is brought about not by informed trading according to foresight, but by speculative trading according to individual investors' hopes of winning the lottery.

Table VII.
Error-correction model results for OTM options

	Options lead stocks					Stocks lead options			
	Calls		Puts			Calls		Puts	
	r_s	t-stat.	r_s	t-stat.		r_c	t-stat.	r_p	t-stat.
c	0.0000	−0.0160	0.0000	−0.2173	c	0.0000*	−2.3501	−0.0001**	−3.3776
$\hat{e}_j$ (−1)	0.0000	0.1573	0.0000	1.3616	$\hat{e}_j$ (−1)	0.0002**	9.5355	−0.0003**	−15.1927
r_j (−1)	0.0402**	14.6599	0.0185**	11.0106	r_s (−1)	0.5100**	48.3190	0.6034**	37.7627
r_j (−2)	0.0309**	10.0522	0.0149**	7.5600	r_s (−2)	0.4205**	38.6638	0.5078**	31.2954
r_j (−3)	0.0245**	7.5111	0.0122**	5.7579	r_s (−3)	0.3423**	30.8765	0.4058**	24.6836
r_j (−4)	0.0223**	6.5877	0.0094**	4.2598	r_s (−4)	0.2914**	25.8996	0.3247**	19.5626
r_j (−5)	0.0198**	5.7188	0.0045*	2.0104	…	…	…	…	…
r_j (−6)	0.0188**	5.3760	0.0046*	2.0010	r_s (−15)	0.0610**	5.3027	0.0953**	5.6979
r_j (−7)	0.0163**	4.6201	0.0017	0.7591	r_s (−16)	0.0267*	2.3276	0.0495**	2.9550
r_j (−8)	0.0135**	3.8107	−0.0007	−0.2837	r_s (−17)	0.0277*	2.4177	0.0616**	3.6813
r_j (−9)	0.0137**	3.8586	−0.0003	−0.1234	r_s (−18)	0.0384**	3.3513	0.0591**	3.5506
r_j (−10)	0.0105**	2.9614	−0.0004	−0.1701	r_s (−19)	0.0293*	2.5682	0.0256	1.5421
r_j (−11)	0.0069	1.9292	−0.0028	−1.2147	r_s (−20)	0.0266*	2.3498	0.0167	1.0104
…	…	…	…	…	r_s (−21)	0.0281*	2.4972	0.0611**	3.7040
r_j (−21)	0.0019	0.5623	−0.0002	−0.0929	r_s (−22)	0.0197	1.7704	0.0553**	3.3882
r_j (−22)	0.0014	0.4308	−0.0031	−1.4544	r_s (−23)	0.0247*	2.2678	0.0221	1.3703
r_j (−23)	0.0001	0.0436	−0.0031	−1.5318	r_s (−24)	0.0088	0.8380	0.0165	1.0450
r_j (−24)	−0.0045	−1.5892	−0.0029	−1.5418	r_s (−25)	0.0041	0.4125	0.0381*	2.5101

Notes: * and ** are statistically significant at 5 and 1 percent levels; the error-correction model results between real index price and implied index price from the OTM options using Black and Scholes (1973) model; the error-correction model is as follows:

$$r_{s,t} = \alpha_1 + \alpha_s \hat{e}_{j,t-1} + \sum_{k=1}^{n} \alpha_{11}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{12}(k) r_{j,t-k} + \varepsilon_{s,t};$$

$$r_{j,t} = \alpha_2 + \alpha_j \hat{e}_{j,t-1} + \sum_{k=1}^{n} \alpha_{21}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{22}(k) r_{j,t-k} + \varepsilon_{j,t};$$

$$P_{j,t} - \hat{\beta}_0 - \hat{\beta}_1 P_{s,t} = \hat{e}_{j,t} (j = c, p);$$

r_s and r_j are log returns of real index price and implied index price from calls or puts, respectively

4.6 Price discovery under the type of news

We showed above that stock market returns lead options market returns. However, if the stock market moves significantly up or down depending on the type of news, whether good or bad, then speculative investors may alter the role of the options market extensively. When investors have good knowledge of the direction of the underlying index, options can be a useful instrument because of their high leverage and their loss-limiting effects.

In this section, we discuss whether price discovery roles differ, depending on the type of news, and specifically whether the news is good or bad. The Korean options market is well known as a market for individual investors. Thus, it is expected that a large number of transactions will be speculative, rather than for hedging purposes. In this case, if the market is bullish, there will be more profits from call options, whereas, if the market is bearish, more profits will be realized from put options. We now examine whether the price discovery functions react differently to the whole market, under bullish and bearish markets. Based on the assumptions outlined below, we continue our empirical tests:

H1. In bullish markets with good news, there will be more price discoveries from the call options market to the stock market.

H2. In bearish markets with bad news, there will be more price discoveries from the put options market to the stock market.

We adopt the method of Chan (1992) and analyze whether the results differ depending on the type of news. We define bullish and bearish markets as follows. Following Chan (1992), the observations are sorted by the size of KOSPI 200 stock index returns in descending order. To do so, trading hours are partitioned into one-hour intervals, and the stock returns for each interval are calculated. The one-hour intervals are stratified into five subsections, and the top 20 percent and the bottom 20 percent are called Quintiles 1 and 5, respectively. Quintile 1 is the good-news group, which contains the highest returns and upward price movements, while Quintile 5 is the bad-news group, which contains the smallest returns and downward price movements.

Next, we create two dummy variables for Quintiles 1 and 5, and these are included in the regressions. For example, the first dummy variable is set to 1 if the data are in Quintile 1, and otherwise it is set to 0. This dummy variable is used for error-corrected regression to test the lead-lag relationship between the stock returns and the implied index returns obtained from the call options data. Likewise, another dummy variable is set to 1 if the data are in Quintile 5, and otherwise it is set to 0. This variable is included in the error-corrected regression for testing the lead-lag relationship between the stock returns and the implied index returns obtained from the put options data. The estimated equation is as follows:

$$\begin{aligned} r_{s,t} &= \alpha_1 + \alpha_j \hat{e}_{j,t-1} + \sum_{k=1}^{n} \alpha_{11}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{12}(k) r_{j,t-k} + \sum_{k=1}^{n} \alpha_{13}(k) r_{j,t-k} \cdot D_j + \varepsilon_{s,t} \\ r_{j,t} &= \alpha_2 + \alpha_j \hat{e}_{j,t-1} + \sum_{k=1}^{n} \alpha_{21}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{22}(k) r_{j,t-k} + \sum_{k=1}^{n} \alpha_{23}(k) r_{s,t-k} \cdot D_j + \varepsilon_{j,t} \\ & P_{j,t} - \hat{\beta}_0 - \hat{\beta}_1 P_{s,t} = \hat{e}_{j,t} \, (j = c, p) \end{aligned} \tag{5}$$

As Tables VIII and IX show, the lead times of call and put options are 45 and 20 minutes, respectively, and the dummy variables are significant to 30 and 25 minutes, respectively. The sum of the estimates of the option-lead and dummy variables is larger than the previous estimates of the option-lead variables, as Table III shows. That is, both call and

Table VIII.
Error-correction model results for call options with dummy variables

	r_s	*t*-stat.		r_s	*t*-stat.		r_c	*t*-stat.		r_c	*t*-stat.
c	0.0000	−1.5727				c	0.0000**	−2.9823			
$\hat{e}_c(-1)$	0.0000	0.1037				$\hat{e}_c(-1)$	0.0001**	5.0524			
$r_c(-1)$	0.1018**	17.9309	$D_c r_c(-1)$	0.0176*	2.3403	$r_s(-1)$	0.4421**	46.3048	$D_c r_s(-1)$	0.0642**	5.2419
$r_c(-2)$	0.0731**	11.6201	$D_c r_c(-2)$	0.0234**	3.2288	$r_s(-2)$	0.3282**	32.4396	$D_c r_s(-2)$	0.0584**	4.7626
$r_c(-3)$	0.0562**	8.4488	$D_c r_c(-3)$	0.0176*	2.4556	$r_s(-3)$	0.2557**	24.6997	$D_c r_s(-3)$	0.0349**	2.8287
$r_c(-4)$	0.0397**	5.8427	$D_c r_c(-4)$	0.0219**	3.0443	$r_s(-4)$	0.2019**	19.1376	$D_c r_s(-4)$	0.0394**	3.1922
$r_c(-5)$	0.0322**	4.6801	$D_c r_c(-5)$	0.0052*	0.7155	$r_s(-5)$	0.1437**	13.5194	$D_c r_s(-5)$	0.0297*	2.3637
$r_c(-6)$	0.0324**	4.6741	$D_c r_c(-6)$	0.0166*	2.2733	$r_s(-6)$	0.1245**	11.6650	$D_c r_s(-6)$	0.0207	1.6388
$r_c(-7)$	0.0255**	3.6734	$D_c r_c(-7)$	0.0117	1.5951	–			–		
$r_c(-8)$	0.0226**	3.2525	$D_c r_c(-8)$	0.0013	0.1809	$r_s(-14)$	0.0359**	3.3668	$D_c r_s(-14)$	0.0133	0.9897
$r_c(-9)$	0.0178*	2.5545	$D_c r_c(-9)$	0.0050	0.6623	$r_s(-15)$	0.0360**	3.3747	$D_c r_s(-15)$	0.0097	0.7039
$r_c(-10)$	0.0118	1.6894	$D_c r_c(-10)$	0.0041	0.5408	$r_s(-16)$	0.0171	1.6098	$D_c r_s(-16)$	0.0077	0.5532
–		–	–			$r_s(-17)$	0.0159	1.5000	$D_c r_s(-17)$	0.0103	0.7332
$r_c(-20)$	0.0097*	1.4473	$D_c r_c(-20)$	−0.0077	−0.9199	–			–		
$r_c(-21)$	0.0089	1.3398	$D_c r_c(-21)$	0.0017	0.2017	$r_s(-21)$	0.0008	0.0798	$D_c r_s(-21)$	0.0277	1.9063
$r_c(-22)$	0.0047	0.7181	$D_c r_c(-22)$	−0.0007	−0.0878	$r_s(-22)$	0.0148	1.4526	$D_c r_s(-22)$	−0.0263	−1.7964
$r_c(-23)$	−0.0003	−0.0465	$D_c r_c(-23)$	0.0048	0.5707	$r_s(-23)$	0.0098	0.9868	$D_c r_s(-23)$	0.0197	1.3459
$r_c(-24)$	−0.0041	−0.7010	$D_c r_c(-24)$	−0.0183*	−2.1418	$r_s(-24)$	0.0184*	1.9643	$D_c r_s(-24)$	−0.0115	−0.7781
$r_c(-25)$	−0.0007*	−0.13 70	$D_c r_c(-25)$	−0.0068*	−0.8075	$r_s(-25)$	0.0022	0.2623	$D_c r_s(-25)$	0.0067	0.4318

Notes: * and ** are statistically significant at 5% and 1% levels; the error-correction model results between real index price and implied index price from call options using the Black and Scholes (1973) model with dummy variables which is determined according to the type of news; the error-correction model with dummy variables is as follows:

$$r_{s,t} = \alpha_1 + \alpha_s \hat{e}_{c,t-1} + \sum_{k=1}^{n} \alpha_{11}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{12}(k) r_{c,t-k} + \sum_{k=1}^{n} \alpha_{13}(k) r_{c,t-k} \cdot D_c + \varepsilon_{s,t};$$

$$r_{c,t} = \alpha_2 + \alpha_c \hat{e}_{c,t-1} + \sum_{k=1}^{n} \alpha_{21}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{22}(k) r_{c,t-k} + \sum_{k=1}^{n} \alpha_{23}(k) r_{s,t-k} \cdot D_c + \varepsilon_{c,t};$$

$$P_{c,t} - \hat{\beta}_0 - \hat{\beta}_1 P_{s,t} = \hat{e}_{c,t};$$

r_s and r_c are log returns of stock price and implied index price, respectively; D_c is set to 1 for Quintile 1, consisting of the top 20 percent returns

	r_s	t-stat.		r_s	t-stat.		r_p	t-stat.		r_p	t-stat.
c	0.0000	1.7334				c	0.0000	1.0771			
$\hat{e}_p(-1)$	0.0000	−1.1640				$\hat{e}_p(-1)$	0.0002**	11.0833			
$r_p(-1)$	0.0302**	9.4722	$D_p r_p(-1)$	0.0363**	7.0415	$r_s(-1)$	0.5722**	47.8964	$D_p r_s(-1)$	0.1059**	5.8464
$r_p(-2)$	0.0259**	7.2324	$D_p r_p(-2)$	0.0257**	4.8568	$r_s(-2)$	0.4779**	38.6747	$D_p r_s(-2)$	0.0757**	4.1723
$r_p(-3)$	0.0202**	5.2779	$D_p r_p(-3)$	0.0140**	2.6409	$r_s(-3)$	0.4116**	32.5193	$D_p r_s(-3)$	0.0310	1.7102
$r_p(-4)$	0.0096**	2.4032	$D_p r_p(-4)$	0.0206**	3.8739	…	…	…	$D_p r_s(-4)$	0.0445*	2.4451
$r_p(-5)$	0.0029	0.7177	$D_p r_p(-5)$	0.0184**	3.4339	$r_s(-14)$	0.0829**	6.5065	$D_p r_s(-5)$	0.0552**	3.0296
$r_p(-6)$	0.0067	1.6084	$D_p r_p(-6)$	0.0068	1.2605	$r_s(-15)$	0.0708**	5.5763	$D_p r_s(-6)$	−0.0004	−0.0203
$r_p(-7)$	0.0019	0.4667	…	…	…	$r_s(-16)$	0.0605**	4.7748	$D_p r_s(-7)$	0.0722*	3.8409
…	…	…	$D_p r_p(-17)$	−0.0064	−1.0777	$r_s(-17)$	0.0584**	4.6498	…	…	…
$r_p(-18)$	−0.0057	−1.3871	$D_p r_p(-18)$	0.0086	1.4772	$r_s(-18)$	0.0428**	3.4068	$D_p r_s(-18)$	0.0552*	2.6197
$r_p(-19)$	−0.0100*	−2.4487	$D_p r_p(-19)$	0.0069	1.1895	$r_s(-19)$	0.0351**	2.7988	$D_p r_s(-19)$	0.0172	0.8226
$r_p(-20)$	−0.0105**	−2.6067	$D_p r_p(-20)$	0.0112	1.9351	$r_s(-20)$	0.0364**	2.9198	$D_p r_s(-20)$	0.0174	0.8323
$r_p(-21)$	−0.0059	−1.4757	$D_p r_p(-21)$	0.0123*	2.1273	$r_s(-21)$	0.0418**	3.3877	$D_p r_s(-21)$	0.0092	0.4344
$r_p(-22)$	−0.0057	−1.4585	$D_p r_p(-22)$	0.0029	0.5022	$r_s(-22)$	0.0350**	2.8891	$D_p r_s(-22)$	−0.0152	−0.7142
$r_p(-23)$	−0.0060	−1.6045	$D_p r_p(-23)$	0.0088	1.5249	$r_s(-23)$	0.0117	0.9874	$D_p r_s(-23)$	0.0341	1.6022
$r_p(-24)$	−0.0041	−1.1950	$D_p r_p(-24)$	0.0031	0.5567	$r_s(-24)$	0.0124	1.0955	$D_p r_s(-24)$	−0.0255	−1.2061
$r_p(-25)$	−0.0057*	−1.9827	$D_p r_p(-25)$	0.0000	−0.0047	$r_s(-25)$	0.0199*	1.8848	$D_p r_s(-25)$	−0.0056*	−0.2637

Notes: * and ** are statistically significant at 5% and 1% levels; the error-correction model results between real index price and implied index price from put options using the Black and Scholes (1973) model with dummy variables which is determined according to the type of news; the error-correction model with dummy variables is as follows:

$$r_{s,t} = \alpha_1 + \alpha_s \hat{e}_{p,t-1} + \sum_{k=1}^{n} \alpha_{11}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{12}(k) r_{p,t-k} + \sum_{k=1}^{n} \alpha_{13}(k) r_{p,t-k} \cdot_p + \varepsilon_{s,t};$$

$$r_{p,t} = \alpha_2 + \alpha_p \hat{e}_{p,t-1} + \sum_{k=1}^{n} \alpha_{21}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{22}(k) r_{p,t-k} + \sum_{k=1}^{n} \alpha_{23}(k) r_{s,t-k} \cdot D_p + \varepsilon_{p,t};$$

$$P_{p,t} - \hat{\beta}_0 - \hat{\beta}_1 P_{s,t} = \hat{e}_{p,t};$$

r_s and r_p are log returns of stock price and implied index price, respectively. D_p is set to 1 for Quintile 5, consisting of the bottom 20 percent returns

Table IX.
Error-correction model results for put options with dummy variables

put options have a stronger price discovery role in a good (bad) news market than in normal times.

On the other hand, as Tables X and XI show, the lead times of OTM call and put options are 45 and 25 minutes, respectively, and the dummy variables are significant to 30 and 15 minutes, respectively. Thus, OTM options also have a stronger price discovery role in a good (bad) news market than in normal times. However, the lead effect of OTM options on the stock index is weaker than that of all options, and this is similar to the previous results.

On the other hand, the lead times of the stock index to the options are 75 and 110 minutes, respectively, and the dummy variables are significant to 25 and 25 minutes, for the calls and puts, respectively. The sum of estimates of the index-lead and dummy variables is larger than the previous estimates of the index-lead variables, as Table III shows. As a result, in a volatile market, the mutual relationship of the options market and the stock index market becomes greater, and the observation that the real index leads the implied index estimated from options market is not changed.

5. Conclusion

We studied the price discovery role of KOSPI 200 stock index options. We conducted various analyses on the assumption that options have different information according to moneyness, and followed a specific option pricing model, the BS model. First, to eliminate the possibility of errors associated with choosing a specific option pricing model, we employed the stochastic volatility option pricing model of Heston (1993) and other research, to confirm its usefulness, and to compare the results with the BS model. Second, we examined whether the OTM options purchased by individual investors, who account for over 50 percent of the trading volume of the options market and generally have a speculative purpose, have a stronger price discovery role than options with other moneyness. Finally, we tested whether options have a stronger price discovery role in bullish and bearish markets than in normal markets.

We showed that the stock index leads the implied index estimated from both the BS and Heston (1993) models. As a result, irrespective of the option pricing model used, a lead effect of the stock index market to the options market was observed. The evidence examined here calls into question previous work in this area. The general consensus in the literature is that the options market leads the stock index market. This is supported by the trading cost hypothesis suggested by Fleming *et al.* (1996), which argued that the derivative markets give investors much lower trading costs than stock index markets. In addition, the lead-lag relationships between the markets are in accordance with the leverage effect hypothesis, which argues that derivatives markets should lead the stock index markets. Our results, which used more refined data and a more general methodology, indicate that the consensus on the Korean financial markets may be wrong.

Second, OTM options, which individual investors prefer, do not improve the lead effect of the options market. This result shows that individual investors in Korean financial markets are not informed traders. Most trading volume involves individual investors in the KOSPI stock index options market, but they do not strengthen the lead effect.

Finally, in a stock index market with marked increases or decreases, the interrelationship between the two markets is strengthened. However, the lead effect of the stock index market on the options market remains unchanged. This result is consistent with the general viewpoint that options are an instrument for volatility trading.

Table X. Error-correction model results for OTM call options with dummy variables

	r_s	t-stat.		r_s	t-stat		r_c	t-stat		r_c	t-stat
c	0.0000	−1.3073				c	−0.0001**	−4.6199			
$\hat{e}_c$ (−1)	0.0000	0.1930				$\hat{e}_c$ (−1)	0.0002**	9.8116			
r_c (−1)	0.0374**	12.3488	D_c (−1)	0.0092*	1.9538	r_s (−1)	0.4564**	36.3261	$r_c r_s$ (−1)	0.1471**	7.7995
r_c (−2)	0.0234**	6.8375	D_c (−2)	0.0231**	4.7998	r_s (−2)	0.3919**	31.1158	$r_c r_s$ (−2)	0.0827**	4.3450
r_c (−3)	0.0180**	4.9653	D_c (−3)	0.0193*	3.9729	r_s (−3)	0.3351**	26.4186	$r_c r_s$ (−3)	0.0183	0.9552
r_c (−4)	0.0178**	4.7730	D_c (−4)	0.0129**	2.6142	r_s (−4)	0.2664**	20.9471	$r_c r_s$ (−4)	0.0800**	4.1416
r_c (−5)	0.0140**	3.7022	D_c (−5)	0.0169*	3.3972	r_s (−5)	0.2009**	15.7172	$r_c r_s$ (−5)	0.0689**	3.5506
r_c (−6)	0.0131**	3.4486	D_c (−6)	0.0175*	3.4877	...	...	...	$r_c r_s$ (−6)	0.0023	0.1179
r_c (−7)	0.0112**	2.9223	D_c (−7)	0.0164	3.2081	r_s (−15)	0.0629**	5.0467	$r_c r_s$ (−7)	0.0456*	2.2950
r_c (−8)	0.0115**	3.0029	D_c (−8)	0.0055	1.0705	r_s (−16)	0.0254*	2.0486	$r_c r_s$ (−8)	0.0248	1.2436
r_c (−9)	0.0102**	2.6535	D_c (−9)	0.0109	2.1198	r_s (−17)	0.0259*	2.0951	$r_c r_s$ (−9)	0.0251	1.2570
r_c (−10)	0.0075**	1.9569	D_c (−10)	0.0087	1.6823	r_s (−18)	0.0456**	3.7093	$r_c r_s$ (−10)	0.0100	0.4854
...	...	...	...	...	...	r_s (−19)	0.0184	1.5035	...	...	...
r_c (−20)	0.0015*	0.4095	D_c (−20)	0.0041	0.7535	r_s (−20)	0.0297*	2.4489	$r_c r_s$ (−20)	−0.0137	−0.5990
r_c (−21)	0.0016	0.4357	D_c (−21)	0.0018	0.3184	r_s (−21	0.0220	1.8310	$r_c r_s$ (−21)	0.0318	1.3704
r_c (−22)	0.0013	0.3751	D_c (−22)	0.0013	0.2247	r_s (−22	0.0203	1.7096	$r_c r_s$ (−22)	−0.0056	−0.2370
r_c (−23)	−0.0004	−0.1258	D_c (−23)	0.0026	0.4687	r_s (−23)	0.0214	1.8412	$r_c r_s$ (−23)	0.0184	0.7714
r_c (−24)	−0.0042	−1.3464	D_c (−24)	−0.0024*	−0.4409	r_s (−24)	0.0098*	0.8690	$r_c r_s$ (−24)	−0.0081	−0.3382
r_c (−25)	0.0002*	0.0634	D_c (−25)	−0.0043*	−0.8787	r_s (−25)	0.0090	0.8391	$r_c r_s$ (−25)	−0.0319	−1.3366

Notes: * and ** are statistically significant at 5% and 1% levels; the error-correction model results between real index price and implied index price from the OTM call options using the Black and Scholes (1973) model with dummy variables which is determined according to the type of news; the error-correction model with dummy variables is as follows:

$$r_{s,t} = \alpha_1 + \alpha_s \hat{e}_{c,t-1} + \alpha_d D_c + \sum_{k=1}^{n} \alpha_{11}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{12}(k) r_{c,t-k} + \sum_{k=1}^{n} \alpha_{13}(k) r_{c,t-k} \cdot D_c + \varepsilon_{s,t};$$

$$r_{c,t} = \alpha_2 + \alpha_c \hat{e}_{c,t-1} + \alpha_d D_c + \sum_{k=1}^{n} \alpha_{21}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{22}(k) r_{c,t-k} + \sum_{k=1}^{n} \alpha_{23}(k) r_{s,t-k} \cdot D_c + \varepsilon_{c,t};$$

$$P_{c,t} - \hat{\beta}_0 - \hat{\beta}_1 P_{s,t} = \hat{e}_{c,t};$$

r_s and r_c are log returns of stock price and implied index price, respectively. D_c is set to one for Quintile 1, consisting of the top 20 percent returns

Table XI.
Error-correction model results for OTM put options with dummy variables

	r_s	t-stat.		r_s	t-stat.		r_p	t-stat.		r_p	t-stat.
c	0.0000	1.2152				c	0.0001	1.7387			
$\hat{e}_p(-1)$	0.0000	−0.4605				$\hat{e}_p(-1)$	0.0002**	8.4091			
$r_p(-1)$	0.0139**	7.8300	$D_pr_p(-1)$	0.0223**	6.9721	$r_s(-1)$	0.5768**	27.7418	$D_pr_s(-1)$	0.1859**	5.4124
$r_p(-2)$	0.0127**	6.0888	$D_pr_p(-2)$	0.0155**	4.3372	$r_s(-2)$	0.4899**	23.3437	$D_pr_s(-2)$	0.1375**	3.9818
$r_p(-3)$	0.0107**	4.7518	$D_pr_p(-3)$	0.0100**	2.7191	$r_s(-3)$	0.3905**	18.5690	$D_pr_s(-3)$	0.0850*	2.4401
$r_p(-4)$	0.0090**	3.8382	$D_pr_p(-4)$	0.0065	1.7522	...	...	...	$D_pr_s(-4)$	0.0444	1.2699
$r_p(-5)$	0.0049*	2.0573	$D_pr_p(-5)$	0.0057	1.5288	$r_s(-13)$	0.0726**	3.5925	$D_pr_s(-5)$	0.0164	0.4660
$r_p(-6)$	0.0046	1.9074	$D_pr_p(-6)$	0.0035	0.9356	$r_s(-14)$	0.0765**	3.7972	...	...	...
$r_p(-7)$	0.0019	0.7966	$D_pr_p(-7)$	0.0052	1.3702	$r_s(-15)$	0.0783**	3.9009	$D_pr_s(-15)$	−0.0649	−1.6362
...	...	...	...	...	...	$r_s(-16)$	0.0346	1.7280	$D_pr_s(-16)$	0.0362	0.9090
$r_p(-20)$	−0.0059*	−2.5033	$D_pr_p(-20)$	0.0026	0.6408	$r_s(-17)$	0.0385	1.9268	$D_pr_s(-17)$	0.0733	1.8155
$r_p(-21)$	−0.0024	−1.0388	$D_pr_p(-21)$	0.0027	0.6603	$r_s(-18)$	0.0646*	3.2246	$D_pr_s(-18)$	0.0025	0.0633
$r_p(-22)$	−0.0032	−1.4192	$D_pr_p(-22)$	0.0052	1.3015	$r_s(-19)$	0.0363	1.8096	$D_pr_s(-19)$	−0.0156	−0.3949
$r_p(-23)$	−0.0060**	−2.7434	$D_pr_p(-23)$	0.0075	1.9021	$r_s(-20)$	0.0384	1.9154	$D_pr_s(-20)$	−0.0648	−1.6563
$r_p(-24)$	−0.0031	−1.5240	$D_pr_p(-24)$	−0.0027	−0.7124	$r_s(-21)$	0.0301	1.5059	$D_pr_s(-21)$	0.1170**	2.9755
$r_p(-25)$	−0.0034*	−2.0072	$D_pr_p(-25)$	0.0021	0.6345	$r_s(-22)$	0.0513*	2.5806	$D_pr_s(-22)$	0.0480	1.2190

Notes: * and ** are statistically significant at 5% and 1% levels; the error-correction model results between real index price and implied index price from the OTM put options using the Black and Scholes (1973) model with dummy variables which is determined according to the type of news; the error-correction model with dummy variables is as follows:

$$r_{s,t} = \alpha_1 + \alpha_s \hat{e}_{p,t-1} + \alpha_d D_p + \sum_{k=1}^{n} \alpha_{11}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{12}(k) r_{p,t-k} + \sum_{k=1}^{n} \alpha_{13}(k) r_{p,t-k} \cdot D_p + \varepsilon_{s,t};$$

$$r_{p,t} = \alpha_2 + \alpha_p \hat{e}_{p,t-1} + \alpha_d D_p + \sum_{k=1}^{n} \alpha_{21}(k) r_{s,t-k} + \sum_{k=1}^{n} \alpha_{22}(k) r_{p,t-k} + \sum_{k=1}^{n} \alpha_{23}(k) r_{s,t-k} \cdot D_p + \varepsilon_{p,t};$$

$$P_{p,t} - \hat{\beta}_0 - \hat{\beta}_1 P_{s,t} = \hat{e}_{p,t};$$

r_s and r_p are log returns of stock price and implied index price, respectively. D_p is set to 1 for Quintile 5, consisting of the bottom 20 percent returns

In addition, this result seems to be brought about not by informed trading according to foresight but by speculative trading by individual investors.

Notes

1. See Stoll and Whaley (1990), Chan (1992), Pizzi *et al.* (1998), and Kim and Kim (2000).
2. The proportions of individual investors in the KOSPI 200 index options market were 62.2, 52.6, and 48.2 percent in 2002, 2003, and 2004, respectively. For details, see the price and data section of the options market on the Korea Exchange website (http://fm.krx.co.kr:8888/english/).
3. If both call and put option prices are used, ITM calls and OTM puts, which are equivalent according to the put-call parity, are used to estimate the parameters.
4. Conventionally, the objective function is used to minimize the sum of squared errors. However, we adopted the above function as the conventional method, and this gives more weight to relatively expensive ITM options, and a worse fit for OTM options.
5. The price of an asset can reflect information within five minutes because the trading volume of the KOSPI 200 index options market is the largest in the world. Therefore, it is possible to examine the price discovery role over a shorter time interval. Using one-minute interval data, the result that the stock index market leads the options market remains unchanged. For better exposition, we show only the results using five-minutes interval data.
6. For better exposition, we display only the estimates of variables related to the lead-lag relationship between the real index and implied index prices.
7. In Section 4.5 however, we use the BS model. As six variables are used to estimate Heston's (1993) model, it is difficult to estimate the variables separately after clarification of options with regard to moneyness.

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Corresponding author

Seung Oh Nam can be contacted at: sonam@sch.ac.kr