THE PERFORMANCE OF TRADERS' RULES IN OPTIONS MARKET

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This study focuses on the usefulness of the traders' rules to predict future implied volatilities for pricing and hedging KOSPI 200 index options. There are two versions of this approach. In the "relative smile" approach, the implied volatility skew is treated as a fixed function of moneyness. In the "absolute smile" approach, the implied volatility skew is treated as a fixed function of the strike price. It is found that the "absolute smile" approach shows better performance than Black, F. and Scholes, L. (1973) model and the stochastic volatility model for both pricing and hedging options. Consistent with Jackwerth, J. C. and Rubinstein, M. (2001) and Li, M. and Pearson, N. D. (2007), the traders' rules dominate mathematically more sophisticated model, that is, the stochastic volatility model. The traders' rules can be an alternative to the sophisticated and complicated models for pricing and hedging options. © 2009 Wiley Periodicals, Inc. Jrl Fut Mark 29:999–1020, 2009

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INTRODUCTION

Since Black and Scholes published their seminal article on option pricing in 1973, there have been various theoretical and empirical researches on option pricing. One important direction in which the Black and Scholes (1973) model can be modified is to generalize the geometric Brownian motion, which is used as a process for the dynamics of log stock prices. For example, Merton (1976) and Naik and Lee (1990) propose a jump-diffusion model. Hull and White (1987), Johnson and Shanno (1987), Scott (1987), Wiggins (1987), and Heston (1993) suggest a stochastic volatility model. Naik (1993) considers a regime-switching model. Duan (1995) and Heston and Nandi (2000) develop an option pricing framework based on the GARCH process. Madan, Carr, and Chang (1998) use a three-parameter stochastic process, termed the VG process, as an alternative model for capturing the dynamics of log stock prices.

However, in striking empirical findings, Jackwerth and Rubinstein (2001) and Li and Pearson (2007) examine the performance of a number of these mathematically sophisticated models and find that they predict option prices less well than a pair of ad hoc approaches sometimes used by option traders. Dumas, Fleming, and Whaley (1998) examine the predictive and hedging performance of the option valuation model considering the deterministic volatility function and find that it is no better than an ad hoc procedure that merely smoothes Black and Scholes (1973) implied volatilities across exercise prices and times to expiration. Ad hoc procedure can be an alternative to the complicated models for pricing options. On the other hand, Kirgiz (2001) and Kim and Kim (2004) show that ad hoc procedure does not show better performance than other sophisticated option pricing models. Why are reported results inconsistent?

There are two versions of the ad hoc approach. In the "relative smile" approach, the implied volatility skew is treated as a fixed function of moneyness, S/K and the implied volatility for a fixed strike K varies as the stock index S varies. This is also known as the "sticky volatility" method. In the "absolute smile" approach, the implied volatility is treated as a fixed function of the strike price K and the implied volatility for a fixed strike does not vary with S. This is also known as the "sticky delta" method. These models are so called the ad hoc Black–Scholes model (henceforth AHBS). Dumas et al. (1998), Jackwerth and Rubinstein (2001), and Li and Pearson (2007), who report the AHBS model outperforms other models, adopt the "absolute smile" approach. On the other hand, Kirgiz (2001) and Kim and Kim (2004), who report the AHBS model does not outperform other models, adopt the "relative smile" approach. That is, the type of the AHBS model seems to be important for pricing and hedging options.

In this study, we examine the empirical performance of the AHBS model for KOSPI 200 index options market. We compare the performance between the "relative smile" approach and the "absolute smile" approach for pricing and hedging KOSPI 200 index options. The AHBS model hypothesizes that the volatility is a linear function of the strike price (or moneyness) and the multiplication of that price.[1] The number of independent variables can be significant for the pricing and hedging performance. We examine the effect of overparameterization. We consider not only the traders' rules but also the stochastic volatility model. Bakshi, Cao, and Chen (1997, 2000) and Kim and Kim (2005) have conducted a comprehensive empirical study on the relative merits of competing option pricing models. They have found that taking stochastic volatility into account is of the first order in importance for improving upon the Black and Sholes model. If we can show that traders' rules outperform the stochastic volatility model, this would be a much stronger and more interesting conclusion to practitioners and researchers.

We fill a gap that has not been resolved in previous researches. This is the first study to examine the performance of the mixture between the type of the AHBS model and the number of independent variables. Second, Jackwerth and Rubinstein (2001) and Li and Pearson (2007) consider the backward- and forward-looking performance. They examine whether the various models, when fit to the prices of longer-term (shorter-term) options, accurately value shorter-term (longer-term) options. We consider the conventional comparison between various models following Bakshi et al. (1997, 2000). We examine one-day and one-week ahead pricing performance. Third, we examine the hedging performance. Jackwerth and Rubinstein (2001) and Li and Pearson (2007) only consider the pricing performance of the AHBS model. The hedging performance is an important element of performance measures for the option pricing model but has been passed over. Finally, we consider KOSPI 200 index options market marking the most active index options product internationally. If the AHBS model shows good performance in KOSPI 200 index options market, that model can be competitive for both advanced and emerging options market.

It is found that the "absolute smile" approach shows better performance than Black and Scholes (1973) model and the stochastic volatility model for both pricing and hedging options. Consistent with Jackwerth and Rubinstein (2001) and Li and Pearson (2007), the traders' rules dominate mathematically more sophisticated model, that is, the stochastic volatility model. The AHBS model can be an alternative to the sophisticated and complicated models for pricing and hedging options.

[1]The time-to-maturity and the multiplication of that can be an independent variable for the AHBS model. However, Dumas et al. (1998) show that the specification that includes a time parameter does worst of all, indicating that the time variable is an important cause of overfitting at the estimation stage. Hence, we do not consider the time variable as an independent variable.

The outline of this study is as follows. The AHBS models and the stochastic volatility model are reviewed in the section "Model." The data used for analysis are described in the section "Data." The section "Empirical Results" describes parameter estimates of each model and evaluates pricing and hedging performances of alternative models. The last section concludes our study by summarizing the results.

MODEL

Ad Hoc Black–Scholes Model

Despite its significant pricing and hedging biases, the Black and Scholes (1973) model (henceforth the BS model) continues to be widely used by market practitioners. However, when practitioners apply the BS model, they commonly allow the volatility parameter to vary across strike prices and maturities of options, to fit the volatility to the observed smile pattern. As Dumas et al. (1998) show, this procedure can circumvent some of the biases associated with the BS model's constant volatility assumption.

We have to construct the AHBS model in which each option has its own implied volatility depending on a strike price and the time-to-maturity. Specifically, the spot volatility of the asset that enters the BS model is a function of the strike price and the time-to-maturity or a combination of both. However, we only consider the function of the strike price because the liquidity of the KOPSI 200 index options market is concentrated in the nearest expiration contract. Dumas et al. (1998) show that the specification that includes a time parameter does worst of all, indicating that the time variable is an important cause of overfitting problem at the estimation stage.

As mentioned before, there are two versions of this approach. In the "relative smile" approach, the implied volatility skew is treated as a fixed function of moneyness, S/K and the implied volatility for a fixed strike K varies as the stock index S varies. In the "absolute smile" approach, the implied volatility skew is treated as a fixed function of the strike price K and the implied volatility for a fixed strike does not vary with S. Specifically, we adopt the following four specifications for the BS implied volatilities:

$$\mathrm{AHBS_{R2}}: \sigma_i = \beta_1 + \beta_2 \cdot (S/K_i) \tag{1}$$

$$\mathrm{AHBS_{R3}}: \sigma_i = \beta_1 + \beta_2 \cdot (S/K_i) + \beta_3 (S/K_i)^2 \tag{2}$$

$$\mathrm{AHBS_{A2}}: \sigma_i = \beta_1 + \beta_2 \cdot K_i \tag{3}$$

$$\mathrm{AHBS_{A3}}: \sigma_i = \beta_1 + \beta_2 \cdot K_i + \beta_3 \cdot K_i^2 \tag{4}$$

where σ_i is the implied volatility for an ith option of strike K_i and spot price S.

First and second models are the "relative smile" approach using the moneyness as the independent variables. Third and fourth models are the "absolute smile" approach using the strike price as the independent variables. $AHBS_{R2}$ is the ad hoc Black–Scholes model that considers the intercept and the moneyness as the independent variable. $AHBS_{R3}$ is the ad hoc Black–Scholes model that considers the intercept, the moneyness, and the square of the moneyness as the independent variable. $AHBS_{A2}$ is the ad hoc Black–Scholes model that considers the intercept and the strike price as the independent variable. $AHBS_{A3}$ is the ad hoc Black–Scholes model that considers the intercept, the strike price, and the square of the strike price as the independent variable. Although we could consider more variables like third or fourth power of the moneyness or strike price, we found that the models considering third or fourth power do not show better performance than others. Hence, we do not display the results of the AHBS models with higher degrees.

For the implementation, we follow a four-step procedure. First, we abstract the BS implied volatility from each option. Second, we set up the implied volatilities as the dependent variable and the moneyness or the strike price as the independent variables. And we estimate the β_i ($i = 1, 2, 3$) by ordinary least squares. Third, using estimated parameters from the second step, we plug each option's moneyness or the strike price into the equation, and obtain the model-implied volatility for each option. Finally, we use volatility estimates computed in the third step to price options with the following BS formula:

$$C(t, T; K) = S(t)N(d_1) - Ke^{-r(T-t)}N(d_2) \tag{5}$$

$$P(t, T; K) = Ke^{-r(T-t)}N(-d_2) - S(t)N(-d_1) \tag{6}$$

$$d_1 = \frac{\ln[S(t)/K] + (r + \sigma^2/2)(T - t)}{\sigma\sqrt{T - t}}, \; d_2 = d_1 - \sigma\sqrt{T - t} \tag{7}$$

where $N(\cdot)$ is the cumulative standard normal density. The AHBS model, although theoretically inconsistent, can be a more challenging benchmark than the simple BS model for any competing option valuation model.

Stochastic Volatility Model

We consider the continuous-time stochastic volatility model (henceforth SV) of Heston (1993), which models the square of the volatility process with mean-reverting dynamics, allowing for changes in the underlying asset price to be contemporaneously correlated with changes in the volatility process. We choose this model among other continuous-time stochastic models because of the allowance of the correlation between asset returns and volatility, and it yields the closed-form solution. The actual diffusion processes for the underlying asset and its volatility are specified as

$$dS = \mu S dt + \sqrt{v_t} S dW_s \tag{8}$$

$$dv_t = \kappa(\theta - v_t)dt + \sigma_v \sqrt{v_t} dW_v \tag{9}$$

where dW_S and dW_v have an arbitrary correlation ρ, v_t is the instantaneous variance. κ is the speed of adjustment to the long-run mean θ, and σ is the variation coefficient of variance.

Given the dynamics in (8) and (9), Heston (1993) shows that the closed-form pricing model of a European call option with τ periods to maturity is given by

$$C = SP_1 - Ke^{-r\tau}P_2 \tag{10}$$

$$P_j = \frac{1}{2} + \frac{1}{\pi}\int_0^{\infty} \mathrm{Re}\left[\frac{e^{-i\phi \ln[K]} f_j(x, v_t, \tau; \phi)}{i\phi}\right] d\phi \quad (j = 1, 2) \tag{11}$$

where Re[·] denotes the real part of complex variables, i is the imaginary number, $\sqrt{-1}$, $f_j(x, v_t, \tau; \phi) = \exp[C(\tau; \phi) + D(\tau; \phi)v_t + i\phi x]$, and $C(\tau; \phi)$ and $D(\tau; \phi)$ are functions of θ, κ, ρ, σ, and v_t.

In applying option pricing models, one always encounters the difficulty that spot volatilities and structural parameters are unobservable. As estimated in the standard practice, we estimate the parameters of each model every sample day. As closed-form solutions are available for an option price, a natural candidate for the estimation of parameters in the pricing and hedging formula is a nonlinear least squares procedure, involving a minimization of the sum of squared errors between the model and the market prices. Estimating parameters from the asset returns can be an alternative method, but historical data reflect only what happened in the past. Furthermore, the procedure using historical data is not capable of identifying risk premiums, which must be estimated from the options data conditional on the estimates of other parameters. The important advantage of using option prices to estimate parameters is to allow one to use the forward-looking information contained in the option prices.

Let $O_i^*(t, \tau; K)$ denote the model price of the option i on day t and $O_i(t, \tau; K)$ denote the market price of option i on day t. To estimate parameters for each model, we minimize the sum of squared errors between the model and the market prices:

$$\min_{\phi_t} \sum_{i=1}^{N} [O_i^*(t, \tau; K) - O_i(t, \tau; K)]^2 \; (t = 1, \ldots, T) \tag{12}$$

TABLE I
The World's Top 10 Derivative Contracts

Rank	*Contract*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
1	KOSPI 200 Options, Korea Exchange	823	1,890	2,838	2,522	2,535	2,414	2,642
2	Eurodollar Futures, CME	184	202	209	298	410	502	621
3	E-mini S&P500 Futures, CME	39	116	161	167	207	258	415
4	10y T-Note Futures, CME	58	96	147	196	215	256	349
5	Euro-Bund Futures, Eurex	178	191	244	240	299	320	338
6	DJ Euro Stoxx 50 Futures, Eurex	38	86	116	122	140	214	327
7	Eurodollar Options on Futures, CME	88	106	101	131	188	269	313
8	DJ Euro Stoxx 50 Options, Eurex	19	40	62	71	91	150	251
9	1d Inter-Bank Deposit Futures, BM&F	46	49	58	100	121	161	221
10	3m Euribor Futures, Liffe	91	106	138	158	167	202	221

Note. This table shows the ten most active derivative contracts, measured in millions of contracts from the year 2001 to the year 2007. The rank is determined based on the trading volume of the year 2007.

Source. Futures Industry Association (http://www.futuresindustry.org).

where N denotes the number of options on day t, and T denotes the number of days in the sample.

DATA

On July 7, 1997, the Korean exchange for options introduced the KOSPI 200 index options. The KOSPI 200 options market has become one of the fastest growing markets in the world, despite its short history. Table I shows the trading volume in millions of contracts for the top 10 derivative products in the world between 2001 and 2007. As seen in the Table I, KOSPI 200 options stand out markedly from the other top 10 derivatives markets. The KOSPI 200 index option product strongly held its number-one position throughout the seven-year period.[2]

Three consecutive near-term delivery months and one additional month from the quarterly cycle (March, June, September, and December) make up four contract months. The expiration day is the second Thursday of each contract month. Each options contract month has at least five strike prices. The number of strike prices may, however, increase according to the price movement. Trading in the KOSPI 200 index options is fully automated. The exercise style of the KOSPI 200 options is European and thus contracts can be exercised only on the expiration dates. Hence, our test results are not affected by the complication that arises due to the early exercise feature of American options. Moreover it is important to note that liquidity is concentrated in the nearest expiration contract.

[2]Average daily trading volume in 2007 is 11,015, 636.

We use out-of-the-money options for calls and puts. First of all, because there is only a very thin trading volume for the in-the-money (henceforth ITM) option, the reliability of price information is not entirely satisfactory. Therefore, we use price data regarding both put and call options that are near-the-money and out-of-the-money (henceforth OTM). Second, if both call and put option prices are used, ITM calls and OTM puts that are equivalent according to the put–call parity are used to estimate the parameters. Third, as Huang and Wu (2004) mention, "the Black–Scholes model has been known to systematically misprice equity index options, especially those that are out-of-the-money (OTM)." We recognize the need for alternative option pricing model to mitigate this effect.

The sample period extends from January 4, 2000, through June 30, 2007. The minute-by-minute transaction prices for the KOSPI 200 options are obtained from the Korea Exchange. The three-month CD rates are used as risk-free interest rates.[3] The following rules are applied to filter data needed for the empirical test. For each day in our sample, only the last reported transaction price prior to 2:50 P.M.[4] of each option contract is employed in the empirical test. As options with less than seven days to expiration may induce biases due to low prices and bid–ask spreads, they are excluded from the sample. Because the liquidity of KOSPI 200 option contracts is concentrated in the nearest expiration contract, we only consider options with the nearest maturity. To mitigate the impact of price discreteness on option valuation, prices lower than 0.02 are not included. Prices not satisfying the arbitrage restriction are excluded.

We divide the option data into several categories according to the moneyness, S/K. Table II describes certain sample properties of the KOSPI 200 option prices used in the study. Summary statistics are reported for the option price and the total number of observations, according to each moneyness-option type category. Note that there are 12,708 call- and 14,866 put-option observations, with deep OTM[5] options, respectively, taking up 52% for call and 63% for put. Table III presents the "volatility smiles" effects for 15 consecutive subperiods. We employ six fixed intervals for the degree of moneyness, and compute the mean over alternative subperiods of the implied volatility. It is interesting to note that the Korean options market seems to be "sneer" independent of the subperiods employed in the estimation. As the S/K increases, the implied volatilities decrease to near-the-money but after that increase to

[3]Korea does not have a liquid Treasury bill market, so the three-month CD rates are used in spite of the mismatch of maturity of options and interest rates.
[4]In the Korean stock market, there are simultaneous bids and offers from 2:50 P.M.
[5]For call option, deep OTM options are options in $S/K<0.94$. For put option, deep OTM options are options in $S/K > 1.06$.

TABLE II
KOSPI 200 Options Data

Moneyness	*Price*	*Number*
Call options		
$S/K < 0.94$	0.3810	6,550
$0.94 < S/K < 0.96$	1.0185	2,741
$0.96 < S/K < 1.00$	2.4048	3,417
Total	1.0626	12,708
Put options		
$1.00 < S/K < 1.03$	2.4862	3,147
$1.03 < S/K < 1.06$	1.2551	2,332
$S/K > 1.06$	0.3358	9,387
Total	0.9352	14,866

Note. This table reports average option price and the number of options for each moneyness and type (call or put) category. The sample period is from January 4, 2000, to June 30, 2007. Daily information from the last transaction prices (prior to 2:50 P.M.) of each option contract is used to obtain the summary statistics. Moneyness of an option is defined as S/K where S denotes the spot price and K denotes the strike price.

TABLE III
Implied Volatility

	$S/K < 0.94$	$0.94 < S/K < 0.96$	$0.96 < S/K < 1.00$	$1.00 < S/K < 1.03$	$1.03 < S/K < 1.06$	$S/K > 1.06$
2000-01-06	0.4263	0.4072	0.4077	0.4261	0.4199	0.4660
2000-07-12	0.5291	0.4799	0.4869	0.5186	0.5169	0.5214
2001-01-06	0.3830	0.3771	0.3726	0.3900	0.3856	0.4051
2001-07-12	0.3540	0.3185	0.3137	0.3702	0.3576	0.4383
2002-01-06	0.3889	0.3705	0.3680	0.3745	0.3753	0.4239
2002-07-12	0.3685	0.3471	0.3437	0.3910	0.3872	0.4150
2003-01-06	0.3307	0.3086	0.3123	0.3415	0.3532	0.3840
2003-07-12	0.2358	0.2265	0.2309	0.2560	0.2634	0.3157
2004-01-06	0.2656	0.2306	0.2431	0.2699	0.2728	0.3051
2004-07-12	0.2252	0.2154	0.2192	0.2827	0.2887	0.3191
2005-01-06	0.1798	0.1640	0.1665	0.1914	0.2028	0.2475
2005-07-12	0.1991	0.1814	0.1864	0.2295	0.2354	0.2747
2006-01-06	0.2060	0.1903	0.1991	0.2325	0.2433	0.2765
2006-07-12	0.1921	0.1629	0.1745	0.1931	0.2086	0.2467
2007-01-06	0.1689	0.1569	0.1683	0.1996	0.2149	0.2867

Note. This table reports the implied volatilities calculated by inverting the Black–Scholes model separately for each moneyness category. The implied volatilities of individual options are then averaged within each moneyness category and across the days in the sample. Moneyness is defined as S/K where S denotes the spot price and K denotes the strike price. 2000-01-06 is the period from January, 2000, to June, 2000.

out-of-the-money put options. The implied volatility of deep out-of-the-money puts is larger than that of deep out-of-the-money calls. That is, a volatility smile is skewed toward one side. The skewed volatility smile is sometimes called a "volatility smirk" because it looks more like a sardonic smirk than a sincere

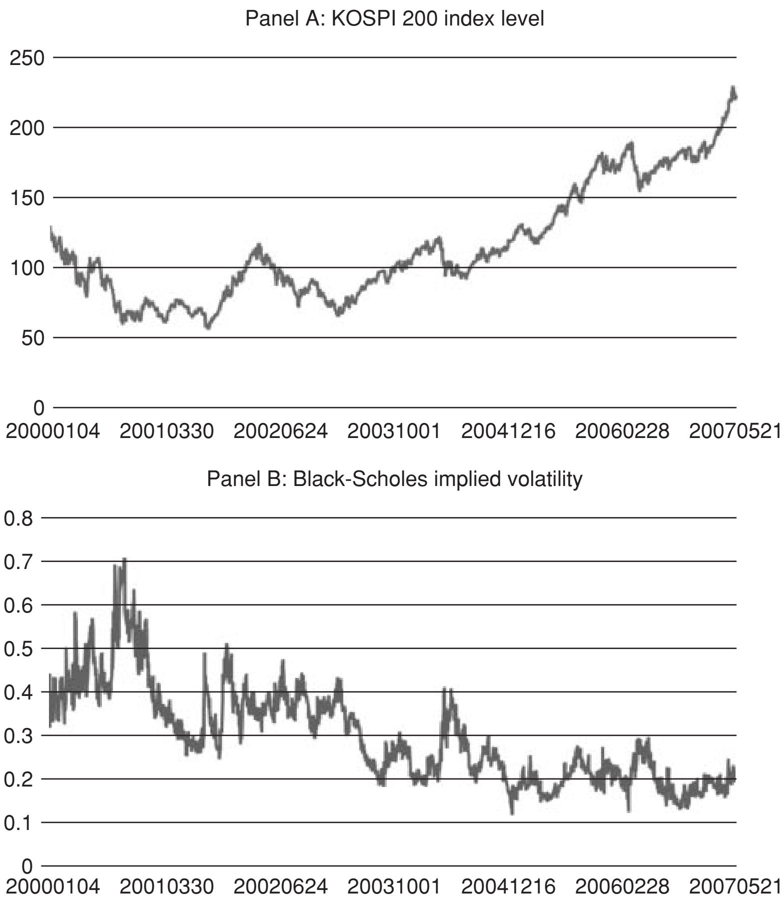

FIGURE 1
KOSPI 200 index level and Black–Sholes implied volatility. This figure shows KOSPI 200 index level and the level of Black–Scholes implied volatility during the sample period of our study, January 4, 2000, through June 30, 2007. The Black–Scholes implied volatilities are daily implied volatilities of the at-the-money straddle with 30 days to maturity. Panel A. KOSPI 200 index level. Panel B. Black–Scholes implied volatility.

smile. In the equity options market, the volatility smirk is often negatively skewed where lower strike prices for out-of-the money puts have higher implied volatilities and, thus, higher valuations.[6] Figure 1 shows KOSPI 200 index level and the level of Black–Scholes implied volatility during the sample period of our study, January 4, 2000, through June 30, 2007. The Black–Scholes implied volatilities are daily implied volatilities of the at-the-money straddle with 30 days to maturity.[7] As the KOSPI 200 index level trends up, the level of implied volatility trends down. This is consistent with Rubinstein (1994),

[6]See Rubinstein(1994) and Bakshi et al. (1997).
[7]The interpolation of the volatility of the nearest contract whose maturity is less than 30 days and the volatility of the second nearest contract whose maturity is more than 30 days are applied.

Derman (1999), Bakshi, Kapadia, and Madan (2001), and Dennis and Mayhew (2002). As the smile evidence is indicative of negatively skewed implicit return distribution with excess kurtosis, a better model must be based on a distributional assumption that allows for negative skewness and excess kurtosis.

Li and Pearson (2004) documented that there is the stable skew pattern in the implied volatilities of S&P 500 index options as follows.

$$\Delta\sigma\sqrt{\tau} = \alpha d\,\sigma_F\sqrt{\tau} + \beta d^2\sigma_F\sqrt{\tau} + \gamma d\sigma_F^2\tau \tag{13}$$

where $d = \ln(F/K)/\sigma_F(\tau)\sqrt{\tau}$, F is the forward price of the index, and $\sigma_F(\tau)$ is the at-the-money-forward volatility of an option with time-to-expiration τ.[8] Li and Pearson (2004) show that this regression model explains 95.50% of the variation in $\Delta\sigma$ for S&P 500 index options. We examine whether KOSPI 200 index options also have the stable skew pattern documented by Li and Pearson (2004). Table IV reports the estimates and R^2 values of the regression model for the subperiods. Over the entire sample period, the model results in parameter estimates $\alpha = 0.0733$, $\beta = 0.0237$, and $\gamma = -0.2326$, and explains 67.68% of the variations in $\Delta\sigma$. For the entire period, the R^2 value of our study is smaller than that of Li and Pearson (2004). That is, the price deviations of KOSPI 200 index options from the BS model do not follow the simple pattern derived by Li and Pearson (2004). However, for the subperiods, the R^2 values of the regression model increase as time goes by. In the period from January 2000, to June 2000, the R^2 value is 32.18% but the value grows to 93.69% in the period from January 2007, to June 2007. As the KOSPI 200 index options market mature, the market seems to behave like S&P 500 index options market.

EMPIRICAL RESULTS

In this section, we compare empirical performances of each model with respect to in-sample pricing, out-of-sample pricing, and hedging performance. The analysis is based on two measures: mean absolute percentage errors (henceforth MAPE), and mean squared errors (henceforth MSE) as follows:

$$\text{MAPE} = \frac{1}{T}\sum_{t=1}^{T}\frac{1}{N}\sum_{i=1}^{N}\left|\frac{O_i(t,\tau;K) - O_i^*(t,\tau;K)}{O_i(t,\tau;K)}\right| \tag{14}$$

$$\text{MAPE} = \frac{1}{T}\sum_{t=1}^{T}\frac{1}{N}\sum_{i=1}^{N}[O_i(t,\tau;K) - O_i^*(t,\tau;K)]^2 \tag{15}$$

where $O_i^*(t,\tau;K)$ denote the model price of the option i on day t and $O_i(t,\tau;K)$ denote the market price of option i on day. N denotes the number of options on

[8]The at-the-money-forward volatility is interpolated from the implied volatilities of the straddles with strike prices closest to the forward price.

TABLE IV
Implied Volatility Pattern

	α	β	γ	R^2
2000-01-06	−0.0392	0.0244	0.6961	0.3218
2000-07-12	−0.0232	0.0275	0.5185	0.4236
2001-01-06	−0.0103	0.0215	0.1318	0.4903
2001-07-12	−0.0147	0.0313	0.5345	0.6415
2002-01-06	0.0039	0.0329	0.0377	0.8435
2002-07-12	0.0106	0.0194	0.2558	0.6251
2003-01-06	0.0429	0.0176	0.1346	0.7222
2003-07-12	0.0571	0.0245	0.0372	0.8387
2004-01-06	0.0046	0.0197	1.0585	0.7978
2004-07-12	0.0785	0.0112	0.6179	0.7608
2005-01-06	0.0626	0.0239	0.3852	0.8995
2005-07-12	0.1069	0.0108	−0.0182	0.7813
2006-01-06	0.0562	0.0140	0.8825	0.8467
2006-07-12	0.0968	0.0174	0.0266	0.8383
2007-01-06	0.1223	0.0191	−0.4374	0.9369
Total	0.0733	0.0237	−0.2326	0.6769

Note. This table reports the estimates and R^2 values of the following regression derived by Li and Pearson (2004).

$$\Delta\sigma\sqrt{\tau} = \alpha d\sigma_F\sqrt{\tau} + \beta d^2\sigma_F\sqrt{\tau} + \gamma d\sigma_F^2\tau$$

where $d = \ln(F/K)/\sigma_F(\tau)\sqrt{\tau}$ and $\sigma_F(\tau)$ is the at-the-money-forward volatility of an option with time to expiration τ. 2000-01-06 is the period from January, 2000, to June, 2000.

day t, and T denotes the number of days in the sample. MAPE measures the magnitude of pricing errors, whereas MSE measures the volatility of errors.

In-Sample Pricing Performance

Table V reports the mean and the standard error of the parameter estimates for each model. R^2 values for each model are reported. For the AHBS-type models, each parameter is estimated by the ordinary least squares every day. For the BS and SV models, each parameter is estimated by minimizing the sum of squared errors between model and market option prices every day. First, the estimates of each model's parameters have excessive standard errors of daily parameters. However, such estimation will be valuable for the following reasons. The estimated parameters can be generated by indicating market sentiment on a daily basis and the estimated parameters may suggest the future specification of more complicated dynamic models. Because this ad hoc Black– Scholes method is based on not theoretical backgrounds but the traders' rule, it is not a fatal problem. Second, as expected, the models that have three independent variables show higher R^2 values than the models that have two independent variables. Hence, it is necessary to check overfitting problem by examining the out-of-sample

TABLE V
Parameters

	β_0	β_1	β_2	R^2	
Panel A: AHBS-type models					
$AHBS_{R2}$	0.0188(0.0077)	0.2995(0.0061)		0.6438(0.2995)	
$AHBS_{R3}$	1.4484(0.0455)	−2.5273(0.0900)	1.3888(0.0444)	0.8286(0.1952)	
$AHBS_{A2}$	0.6318(0.0056)	−0.0028(0.0001)		0.6095(0.2970)	
$AHBS_{A3}$	2.3854(0.0472)	−0.0384(0.0009)	0.0002(0.0000)	0.8280(0.1969)	
Panel B: other models					
	σ				
BS	0.2952(0.0026)				
	κ	θ	σ_v	ρ	ν_t
SV	1.5260(0.2479)	0.3001(0.0889)	1.0821(0.1466)	−0.3042(0.0307)	0.1395(0.0117)

Note. The table reports the mean and the standard error of the parameter estimates for each model. The mean and the standard deviation of R^2s for each model are reported. For the AHBS-type models, each parameter is estimated by the ordinary least squares every day. $AHBS_{R2}$ is the ad hoc Black–Scholes model that considers the intercept and the moneyness as the independent variable. $AHBS_{R3}$ is the ad hoc Black–Scholes model that considers the intercept, the moneyness, and the square of the moneyness as the independent variable. $AHBS_{A2}$ is the ad hoc Black–Scholes model that considers the intercept and the strike price as the independent variable. $AHBS_{A3}$ is the ad hoc Black–Scholes model that considers the intercept, the strike price, and the square of the strike price as the independent variable. BS is the Black–Scholes (1973) option pricing model. SV is Heston's (1993) option pricing model considering the continuous-time stochastic volatility. For the BS and SV models, each parameter is estimated by minimizing the sum of squared errors between model and market option prices every day.

pricing performance. Third, the implied correlation of the SV model has negative values. The negative estimate indicates that the implied volatility and the index returns are negatively correlated and the implied distribution perceived by option traders is negatively skewed. This is consistent with the volatility sneer pattern in Table III.

We evaluate the in-sample pricing performance of each model by comparing market prices with model's prices computed by using the parameter estimates from the current day. Table VI reports in-sample valuation errors for the alternative models computed over the whole sample of options. The $AHBS_{A3}$ model shows the best performance for MAPE and the $AHBS_{R3}$ model does for MSE. This is a rather obvious result when the use of larger number of parameters in the $AHBS_{A3}$ and $AHBS_{R3}$ model is considered. Although the SV model has five parameters, the SV model does not show better performance than the $AHBS_{A3}$ and the $AHBS_{R3}$ model with three parameters. The in-sample pricing performance is not simply contingent on the number of free parameters. Lastly, all models show moneyness-based valuation errors. The models exhibit the worst fit for the out-of-the-money options. The fit, as measured by MAPE, steadily improves as we move from out-of-the-money to near-the-money

TABLE VI
In-Sample Pricing Errors

Moneyness	*BS*	*SV*	$AHBS_{R2}$	$AHBS_{R3}$	$AHBS_{A2}$	$AHBS_{A3}$
MAPE						
$S/K < 0.94$	0.4644	0.1003	0.2271	0.1262	0.2432	0.1075
$0.94 < S/K < 0.96$	0.3479	0.0676	0.1709	0.1181	0.1847	0.1086
$0.96 < S/K < 1.00$	0.1214	0.0842	0.1131	0.0923	0.1218	0.0899
$1.00 < S/K < 1.03$	0.0936	0.1102	0.0819	0.0689	0.0842	0.0710
$1.03 < S/K < 1.06$	0.2283	0.0984	0.1117	0.0615	0.1219	0.0615
$S/K > 1.06$	0.6063	0.1185	0.1713	0.0827	0.2027	0.0932
Total	0.3964	0.1022	0.1620	0.0944	0.1802	0.0925
MSE						
$S/K < 0.94$	0.0176	0.0052	0.0063	0.0025	0.0073	0.0025
$0.94 < S/K < 0.96$	0.0753	0.0135	0.0318	0.0185	0.0345	0.0184
$0.96 < S/K < 1.00$	0.1077	0.0705	0.1012	0.0819	0.1120	0.0842
$1.00 < S/K < 1.03$	0.1252	0.1826	0.0992	0.0910	0.1000	0.0966
$1.03 < S/K < 1.06$	0.0912	0.0469	0.0286	0.0176	0.0289	0.0178
$S/K > 1.06$	0.0281	0.0070	0.0040	0.0022	0.0049	0.0020
Total	0.0566	0.0385	0.0323	0.0252	0.0346	0.0261

Note. This table reports in-sample pricing errors for the KOSPI 200 option with respect to moneyness. S/K is defined as moneyness where S denotes the asset price and K denotes the strike price. Each model is estimated every day during the sample period and in-sample pricing errors are computed using estimated parameters from the current day. MAPE denotes mean absolute percentage errors and MSE denotes mean squared errors. BS is the Black–Scholes (1973) option pricing model. SV is Heston's (1993) option pricing model considering the continuous-time stochastic volatility. $AHBS_{R2}$ is the ad hoc Black–Scholes model that considers the intercept and the moneyness as the independent variable. $AHBS_{R3}$ is the ad hoc Black–Scholes model that considers the intercept, the moneyness, and the square of the moneyness as the independent variable. $AHBS_{A2}$ is the ad hoc Black–Scholes model that considers the intercept and the strike price as the independent variable. $AHBS_{A3}$ is the ad hoc Black–Scholes model that considers the intercept, the strike price, and the square of the strike price as the independent variable.

options. Overall, all AHBS-type models show better performance than the BS model. The traders' rule can explain the current market price in the options market although it is not rooted in rigorous theory.

Out-of-Sample Pricing Performance

In-sample pricing performance can be biased due to the potential problem of overfitting to the data. A good in-sample fit might be a consequence of having an increasingly larger number of parameters. To lower the impact of this connection to inferences, we turn to examining the model's out-of-sample cross-sectional pricing performance. In the out-of-sample pricing, the presence of more parameters may actually cause overfitting and have the model penalized if the extra parameters do not improve its structural fitting. This analysis also has the purpose of assessing the stability of each model's parameter over time. To control the parameters' stability over alternative time periods, we analyze out-of-sample valuation errors for the following day (week). We use the current day's estimated structural parameters to price options for the following day (week).

Tables VII and VIII, respectively, report one-day and one-week ahead out-of-sample valuation errors for alternative models computed over the whole sample of options. For one-day ahead out-of-sample pricing, the $AHBS_{A2}$ model generally shows the best performance, closely followed by the $AHBS_{R2}$ model. The $AHBS_{A2}$ model also exhibits better fit for the one-week ahead out-of-sample pricing. For the in-sample pricing performance, $AHBS_{A3}$ and $AHBS_{R3}$ that have more parameters than other models show better performance. However, for the out-of-sample pricing performance, the simpler $AHBS_{A2}$ model is the best. That is, the presence of more parameters actually cause overfitting. Consistent with Jackwerth and Rubinstein (2001) and Li and Pearson (2007), the traders' rules dominate mathematically more sophisticated model, the SV model, although the SV model is not far behind. With respect to moneyness-based errors, similar to the case of in-sample pricing, MAPE steadily decreases as we

TABLE VII

One-Day Ahead Out-of-Sample Pricing Errors

Moneyness	*BS*	*SV*	*$AHBS_{R2}$*	*$AHBS_{R3}$*	*$AHBS_{A2}$*	*$AHBS_{A3}$*
MAPE						
$S/K < 0.94$	0.5349	0.3225	0.3398	0.3420	0.3462	0.4181
$0.94 < S/K < 0.96$	0.3846	0.1818	0.2278	0.1930	0.2295	0.2111
$0.96 < S/K < 1.00$	0.1410	0.1114	0.1341	0.1159	0.1362	0.1189
$1.00 < S/K < 1.03$	0.1133	0.1071	0.1064	0.0979	0.1014	0.1017
$1.03 < S/K < 1.06$	0.2353	0.1466	0.1606	0.1300	0.1547	0.1365
$S/K > 1.06$	0.6035	0.4245	0.3498	1.1608	0.3373	0.6618
Total	0.4210	0.2776	0.2648	0.5320	0.2614	0.3835
MSE						
$S/K < 0.94$	0.0335	0.0387	0.0236	0.0282	0.0254	0.0388
$0.94 < S/K < 0.96$	0.1077	0.0840	0.0637	0.0533	0.0651	0.0577
$0.96 < S/K < 1.00$	0.1530	0.1815	0.1443	0.1231	0.1495	0.1288
$1.00 < S/K < 1.03$	0.1859	0.2170	0.1569	0.1554	0.1460	0.1537
$1.03 < S/K < 1.06$	0.1181	0.1047	0.0705	0.0571	0.0675	0.0538
$S/K > 1.06$	0.0337	0.0420	0.0313	0.2049	0.0290	0.0590
Total	0.0803	0.0879	0.0643	0.1195	0.0632	0.0731

Note. This table reports one-day ahead out-of-sample pricing errors for the KOSPI 200 option with respect to moneyness. S/K is defined as moneyness where S denotes the asset price and K denotes the strike price. Each model is estimated every day during the sample period and one-day ahead out-of-sample pricing errors are computed using estimated parameters from the previous trading day. MAPE denotes mean absolute percentage errors and MSE denotes mean squared errors. BS is the Black–Scholes (1973) option pricing model. SV is Heston's (1993) option pricing model considering the continuous-time stochastic volatility. $AHBS_{R2}$ is the ad hoc Black–Scholes model that considers the intercept and the moneyness as the independent variable. $AHBS_{R3}$ is the ad hoc Black–Scholes model that considers the intercept, the moneyness, and the square of the moneyness as the independent variable. $AHBS_{A2}$ is the ad hoc Black–Scholes model that considers the intercept and the strike price as the independent variable. $AHBS_{A3}$ is the ad hoc Black–Scholes model that considers the intercept, the strike price, and the square of the strike price as the independent variable.

TABLE VIII
One-Week Ahead Out-of-Sample Pricing Errors

Moneyness	*BS*	*SV*	*AHBS*$_{R2}$	*AHBS*$_{R3}$	*AHBS*$_{A2}$	*AHBS*$_{A3}$
MAPE						
$S/K < 0.94$	0.6667	0.5625	0.5129	0.6649	0.5129	0.8321
$0.94 < S/K < 0.96$	0.4751	0.3414	0.3286	0.3045	0.3049	0.3105
$0.96 < S/K < 1.00$	0.1828	0.1890	0.1762	0.1623	0.1667	0.1550
$1.00 < S/K < 1.03$	0.1455	0.1751	0.1411	0.1380	0.1301	0.1305
$1.03 < S/K < 1.06$	0.2595	0.2746	0.2217	0.2071	0.2042	0.1938
$S/K > 1.06$	0.6046	0.6819	0.7030	2.0014	0.5879	1.1779
Total	0.4726	0.4664	0.4505	0.9228	0.4051	0.6800
MSE						
$S/K < 0.94$	0.0574	0.1164	0.0536	0.0635	0.0558	0.0961
$0.94 < S/K < 0.96$	0.1676	0.2519	0.1225	0.1082	0.1178	0.1244
$0.96 < S/K < 1.00$	0.2490	0.4165	0.2397	0.2159	0.2276	0.2077
$1.00 < S/K < 1.03$	0.2797	0.4939	0.2450	0.2557	0.2248	0.2269
$1.03 < S/K < 1.06$	0.1729	0.2885	0.1339	0.1208	0.1222	0.1018
$S/K > 1.06$	0.0457	0.0987	0.0604	0.1835	0.0570	0.0907
Total	0.1232	0.2187	0.1145	0.1545	0.1086	0.1263

Note. This table reports one-week ahead out-of-sample pricing errors for the KOSPI 200 option with respect to moneyness. S/K is defined as moneyness where S denotes the asset price and K denotes the strike price. Each model is estimated every day during the sample period and one-week ahead out-of-sample pricing errors are computed using estimated parameters from one week ago. MAPE denotes mean absolute percentage errors and MSE denotes mean squared errors. BS is the Black–Scholes (1973) option pricing model. SV is Heston's (1993) option pricing model considering the continuous-time stochastic volatility. $AHBS_{R2}$ is the ad hoc Black–Scholes model that considers the intercept and the moneyness as the independent variable. $AHBS_{R3}$ is the ad hoc Black–Scholes model that considers the intercept, the moneyness, and the square of the moneyness as the independent variable. $AHBS_{A2}$ is the ad hoc Black–Scholes model that considers the intercept and the strike price as the independent variable. $AHBS_{A3}$ is the ad hoc Black–Scholes model that considers the intercept, the strike price, and the square of the strike price as the independent variable.

move from deep out-of-the-money to near-the-money options for all models. Generally, the $AHBS_{A2}$ model outperforms all the other models.

Second, pricing errors increase from in-sample to out-of-sample pricing. The average of MAPE of all the models is 0.1713 for the in-sample pricing, and grows to 0.3567 for one-day ahead out-of-sample pricing. One-week ahead out-of-sample pricing errors grow to 0.5662 almost three times as much as in-sample pricing errors. The relative margin of performance is significantly changed when compared to that of the in-sample pricing case. The difference of the BS and the best model ($AHBS_{A2}$ or $AHBS_{A3}$) becomes smaller in the out-of-sample pricing. The ratio of the BS model to the $AHBS_{A3}$ model for MAPE is 4.2854 for in-sample pricing errors. The ratio of the BS model to the $AHBS_{A2}$ model decreases to 1.6105 and to 1.1666 for one-day ahead and one-week ahead out-of-sample errors, respectively. As the term of the out-of-sample pricing gets longer, the difference between the BS model and the best model, the $AHBS_{A2}$ model, becomes smaller. The pricing performance of the $AHBS_{A3}$ model that is the best model for in-sample pricing is not maintained as the term of out-of-sample pricing gets longer, implying that the presence of more parameters actually cause overfitting.

Finally, we consider the relative effect of the absolute and relative smile models. The $AHBS_{A2}$ model reduces MAPE of the BS model by 0.1596 and 0.0675 for one-day and one-week ahead pricing errors, respectively. The $AHBS_{R2}$ model reduces MAPE of the BS model by 0.1562 and 0.0221 for one-day and one-week ahead pricing errors, respectively. In other words, the effects of the reduction in pricing errors for the $AHBS_{A2}$ model are much better compared with those for the $AHBS_{R2}$ model. This result is consistent with that of Jackwerth and Rubinstein (2001) and Li and Pearson (2007) who report that the "absolute smile" model beats the "relative smile" model in predicting prices. The result can be explained by the fact that the absolute smile model implicitly adjusts for the negative correlation between the index level movement and the level of implied volatilities. Because the absolute model treats the skew as a fixed function of the strike instead of the moneyness S/K, it makes out a smaller implied volatility than the relative smile model when there is an increase in the stock price.

Hedging Performance

Hedging performance is important to gauge the forecasting power of the volatility of underlying assets. We examine hedges in which only a single instrument (i.e., the underlying asset) can be employed. In practice, option traders usually focus on the risk due to the underlying asset price volatility alone, and carry out a delta-neutral hedge, employing only the underlying asset as the hedging instrument.

We implement hedging with the following method. Consider hedging a short position in an option, $O(t, \tau; K)$ with τ periods to maturity and strike price of K. Let $\Delta_S(t)$ be the number of shares of the underlying asset to be purchased, and $\Delta_0(=O(t, \tau; K) - \Delta_s(t)S_t)$ be the residual cash positions. We consider the delta hedging strategy of $\Delta_S = \partial O(t, \tau; K)/\partial S_t$ and $\Delta_0(t)$.

To examine the hedging performance, we use the following steps. First, on day t, we short an option, and construct a hedging portfolio by buying $\Delta_S(t)$ shares of the underlying asset,[9] and investing $\Delta_0(t)$ in a risk-free bond. To compute $\Delta_S(t)$, we use estimated parameters from the previous trading day and the current day's asset price. For the SV model, we use estimated instantaneous volatility from the previous day. For the AHBS model, the volatility parameter necessary to compute the delta position is obtained by plugging the option-specific strike price into the regression equation along with the previous day's

[9]The delta, for a put option, is negative, which means that a short position in put options should be hedged with a short position in the underlying stock.

parameter estimates. Second, we liquidate the position after the next trading day or the next week. Then we compute the hedging error as the difference between the value of the replicating portfolio and the option price at the time of liquidation:

$$\varepsilon_t = \Delta_S \cdot S_{t+\Delta t} + \Delta_0 e^{r\Delta t} - O(t + \Delta t, \tau - \Delta t; K). \qquad (16)$$

Tables IX and X present one day and one week hedging errors over alternative moneyness categories, respectively. The AHBS_{A2} model and the AHBS_{R2} model have the best hedging performance for one day and one week, respectively. For the hedging performance, the AHBS-type models show better performance than the BS model. However, the difference among models is not so large. The ratios of the BS model to the AHBS_{A2} model and the AHBS_{R2}, which are the best performers, are 1.0570 and 1.0298 for one-day ahead and one-week ahead hedging errors, respectively. The SV model is the worst performer. In each moneyness category, the hedging errors are highest for ATM options

TABLE IX

One-Day Ahead Hedging Errors

Moneyness	*BS*	*SV*	*AHBS$_{R2}$*	*AHBS$_{R3}$*	*AHBS$_{A2}$*	*AHBS$_{A3}$*
MAE						
$S/K < 0.94$	0.0925	0.0830	0.0830	0.0850	0.0835	0.0858
$0.94 < S/K < 0.96$	0.1303	0.1365	0.1222	0.1215	0.1224	0.1223
$0.96 < S/K < 1.00$	0.1585	0.1721	0.1581	0.1580	0.1582	0.1583
$1.00 < S/K < 1.03$	0.2003	0.2279	0.1956	0.1970	0.1951	0.1966
$1.03 < S/K < 1.06$	0.1446	0.1622	0.1360	0.1356	0.1352	0.1349
$S/K > 1.06$	0.0579	0.0571	0.0547	0.0560	0.0540	0.0549
Total	0.1075	0.1115	0.1019	0.1029	0.1017	0.1027
MSE						
$S/K < 0.94$	0.0362	0.0376	0.0339	0.0337	0.0342	0.0342
$0.94 < S/K < 0.96$	0.0403	0.0519	0.0382	0.0376	0.0385	0.0381
$0.96 < S/K < 1.00$	0.0511	0.0609	0.0514	0.0512	0.0517	0.0515
$1.00 < S/K < 1.03$	0.1035	0.1272	0.0996	0.1005	0.0991	0.1001
$1.03 < S/K < 1.06$	0.0510	0.0622	0.0462	0.0455	0.0459	0.0453
$S/K > 1.06$	0.0128	0.0136	0.0116	0.0118	0.0116	0.0114
Total	0.0383	0.0447	0.0364	0.0363	0.0364	0.0363

Note. This table reports one-day ahead hedging errors for the KOSPI 200 option with respect to moneyness. Only the underlying asset is used as the hedging instrument. Parameters and spot volatility implied by all options of the previous day are used to establish the current day's hedge portfolio, which is then liquidated the following day. For each option, its hedging error is the difference between the replicating portfolio value and its market price. MAE denotes mean absolute errors and MSE denotes mean squared errors. BS is the Black–Scholes (1973) option pricing model. SV is Heston's (1993) option pricing model considering the continuous-time stochastic volatility. AHBS_{R2} is the ad hoc Black–Scholes model that considers the intercept and the moneyness as the independent variable. AHBS_{R3} is the ad hoc Black–Scholes model that considers the intercept, the moneyness, and the square of the moneyness as the independent variable. AHBS_{A2} is the ad hoc Black–Scholes model that considers the intercept and the strike price as the independent variable. AHBS_{A3} is the ad hoc Black–Scholes model that considers the intercept, the strike price, and the square of the strike price as the independent variable.

TABLE X

One Week-Ahead Hedging Errors

Moneyness	*BS*	*SV*	$AHBS_{R2}$	$AHBS_{R3}$	$AHBS_{A2}$	$AHBS_{A3}$
MAE						
$S/K < 0.94$	0.3178	0.3051	0.2985	0.3044	0.2994	0.3058
$0.94 < S/K < 0.96$	0.3202	0.3223	0.2959	0.2965	0.2965	0.2970
$0.96 < S/K < 1.00$	0.4085	0.4317	0.4051	0.4013	0.4074	0.4023
$1.00 < S/K < 1.03$	0.5219	0.5502	0.5076	0.5079	0.5073	0.5074
$1.03 < S/K < 1.06$	0.3576	0.3936	0.3487	0.3485	0.3479	0.3483
$S/K > 1.06$	0.1615	0.1608	0.1646	0.1674	0.1642	0.1654
Total	0.2937	0.2990	0.2852	0.2873	0.2855	0.2870
MSE						
$S/K < 0.94$	0.3218	0.3487	0.3058	0.3057	0.3065	0.3073
$0.94 < S/K < 0.96$	0.1737	0.2089	0.1615	0.1601	0.1621	0.1606
$0.96 < S/K < 1.00$	0.2529	0.2853	0.2560	0.2512	0.2597	0.2538
$1.00 < S/K < 1.03$	0.4675	0.5212	0.4324	0.4312	0.4329	0.4303
$1.03 < S/K < 1.06$	0.2125	0.2567	0.2005	0.1996	0.2001	0.1988
$S/K > 1.06$	0.0657	0.0661	0.0689	0.0701	0.0693	0.0686
Total	0.2099	0.2327	0.2020	0.2016	0.2028	0.2016

Note. This table reports one-week ahead hedging errors for the KOSPI 200 option with respect to moneyness. Only the underlying asset is used as the hedging instrument. Parameters and spot volatility implied by all options of the previous day are used to establish the current day's hedge portfolio, which is then liquidated the next week. For each option, its hedging error is the difference between the replicating portfolio value and its market price. MAE denotes mean absolute errors and MSE denotes mean squared errors. BS is the Black–Scholes (1973) option pricing model. SV is Heston's (1993) option pricing model considering the continuous-time stochastic volatility. $AHBS_{R2}$ is the ad hoc Black–Scholes model that considers the intercept and the moneyness as the independent variable. $AHBS_{R3}$ is the ad hoc Black–Scholes model that considers the intercept, the moneyness, and the square of the moneyness as the independent variable. $AHBS_{A2}$ is the ad hoc Black–Scholes model that considers the intercept and the strike price as the independent variable. $AHBS_{A3}$ is the ad hoc Black–Scholes model that considers the intercept, the strike price, and the square of the

and get smaller as we move to OTM options. This pattern is true for every model and for each rebalancing frequency.

Statistical Validation

Different from what is done when using two measures (MAPE and MSE), we compare the models by using the statistical test to make the concrete results. Table XI summarizes the pair-wise comparison results among the models by providing the *t*-statistics of the probability that the errors of one model are larger than those of the other. Regarding the one-day ahead and one-week ahead out-of-sample pricing performance, the *t*-statistics of the difference between each model's absolute pricing errors are shown in panels A and B, respectively. In regard to the one-day ahead and one-week ahead hedging performance, the *t*-statistics of the difference between each model's absolute hedging errors are shown in panels C and D, respectively.

TABLE XI
Differences Between the Errors of Each Model

	BS	*SV*	*AHBS$_{R2}$*	*AHBS$_{R3}$*	*AHBS$_{A2}$*
Panel A. One-day ahead out-of-sample pricing errors					
SV	34.0451**				
AHBS$_{R2}$	37.8324**	2.8781**			
AHBS$_{R3}$	−2.6795**	−6.1351**	−6.4461**		
AHBS$_{A2}$	43.1646**	3.9919**	0.8511	6.5342**	
AHBS$_{A3}$	2.4221*	−6.7912**	−7.6257**	3.3711**	−7.8986**
Panel B. One-week ahead out-of-sample pricing errors					
SV	1.0427				
AHBS$_{R2}$	3.5223**	2.2004*			
AHBS$_{R3}$	−14.6001**	−14.7086**	−15.1938**		
AHBS$_{A2}$	12.4524**	9.4813**	6.7844**	16.7422**	
AHBS$_{A3}$	−13.0386**	−13.1173**	−14.0065**	7.0691**	−17.1000**
Panel C. One-day ahead hedging errors					
SV	−2.5965**				
AHBS$_{R2}$	3.8306**	6.2603**			
AHBS$_{R3}$	3.1763**	5.6419**	−0.6673		
AHBS$_{A2}$	3.9681**	6.3896**	0.1419	0.8089	
AHBS$_{A3}$	3.2876**	5.7471**	−0.5539	0.1134	−0.6956
Panel D. One-week ahead hedging errors					
SV	−1.3760				
AHBS$_{R2}$	2.3197*	3.6155**			
AHBS$_{R3}$	1.7476	3.0690**	−0.5837		
AHBS$_{A2}$	2.2274*	3.5254**	−0.0900	0.4927	
AHBS$_{A3}$	1.8268	3.1448**	−0.5030	0.0807	−0.4122

Note. This table reports the *t*-statistics of the difference between each model's absolute percentage (absolute) errors for pricing (hedging) are shown. Panel A reports *t*-statistics between one-day ahead out-of-sample pricing errors of each model. Panel B reports *t*-statistics between one-week ahead out-of-sample pricing errors of each model. Panel C reports *t*-statistics between one-day ahead hedging errors of each model. Panel D reports *t*-statistics between one-week ahead hedging errors of each model. BS is the Black–Scholes (1973) option pricing model. SV is Heston's (1993) option pricing model considering the continuous-time stochastic volatility. AHBS$_{R2}$ is the ad hoc Black–Scholes model that considers the intercept and the moneyness as the independent variable. AHBS$_{R3}$ is the ad hoc Black–Scholes model that considers the intercept, the moneyness, and the square of the moneyness as the independent variable. AHBS$_{A2}$ is the ad hoc Black–Scholes model that considers the intercept and the strike price as the independent variable. AHBS$_{A3}$ is the ad hoc Black–Scholes model that considers the intercept, the strike price, and the square of the strike price as the independent variable. "**" And "*" indicate the test statistic value that is significantly different from 1 and 5%, respectively.

The comparison results are very clear and similar with those using MAPE. For one-day ahead out-of-sample pricing performance, the AHBS$_{A2}$ model and the AHBS$_{R2}$ model are exceedingly superior to the BS model and the SV model. And the difference between the AHBS$_{A2}$ model and the AHBS$_{R2}$ model is not significant. The AHBS$_{A2}$ model shows better performance than the AHBS$_{A3}$ model and the AHBS$_{R3}$ model, which have three parameters. For one-week ahead out-of-sample pricing performance, the AHBS$_{A2}$ model outperforms other models significantly. As the term of the out-of-sample pricing gets longer, the superiority of the AHBS$_{A2}$ model becomes relatively strong.

For hedging performance, the AHBS-type models show better performance than the BS model and the SV model. However, as the term of the hedging gets longer, the superiority of the AHBS-type models becomes weak. The t-values of the one-day ahead hedging case are larger than those of the one-week ahead hedging case. The difference among the AHBS-type models is not significant. That is, for the hedging performance, the type of the AHBS is not significant.

CONCLUSION

For the KOSPI 200 Index options, we examine the traders' rules to predict future implied volatilities by applying simple ad hoc rules to the observed current implied volatility function for pricing and hedging options. There are two versions of this approach. In the "relative smile" approach, the implied volatility skew is treated as a fixed function of moneyness, S/K. In the "absolute smile" approach, the implied volatility is treated as a fixed function of the strike price K. It is found that the traders' rules show better performance than the BS model and the SV model for both pricing and hedging options. The "absolute smile" approach shows better performance than the "relative smile" approach. For the out-of-sample pricing performance, simpler model shows better performance than other models. That is, the presence of more parameters actually cause overfitting. For the hedging performance, the AHBS-type models show better performance than the BS model, but the differences among the mixtures of the type of the AHBS model and the number of independent variables are not significant. Consistent with Jackwerth and Rubinstein (2001) and Li and Pearson (2007), the traders' rules dominate mathematically more sophisticated model, the SV model, although the SV model is not far behind. As a result, the AHBS model has the advantage of simplicity and can be competitive model for pricing and hedging KOSPI 200 index options.

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