Pricing FTSE 100 Index Options under Stochastic Volatility

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The autoregressive conditional heteroscedasticity/generalized autoregressive conditional heteroscedasticity (ARCH/GARCH) literature and studies of implied volatility clearly show that volatility changes over time. This article investigates the improvement in the pricing of Financial Times-Stock Exchange (FTSE) 100 index options when stochastic volatility is taken into account. The major tool for this analysis is Heston's (1993) stochastic volatility option pricing formula, which allows for systematic volatility risk and arbitrary correlation between underlying returns and volatility. The results reveal significant evidence of stochastic volatility implicit in option prices, suggesting that this phenomenon is essential to improving the performance of the Black–Scholes model (Black & Scholes, 1973) for FTSE 100 index options. © 2001 John Wiley & Sons, Inc. Jrl Fut Mark 21:197–211, 2001

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INTRODUCTION

Numerous empirical studies have found that the Black–Scholes (BS) model (Black & Scholes, 1973) results in systematic biases across moneyness and maturity (e.g., Gemmill, 1996; Rubinstein, 1985). The BS pricing biases usually produce an implied volatility smirk for equity options, indicating that the underlying distribution implicit in option prices is skewed and fat-tailed. Studies of time-series returns also find evidence of substantial skewness and leptokurtosis in underlying returns (e.g., Kon, 1984; Taylor, 1986). These moment properties of the underlying distribution imply that the assumption of geometric Brownian motion with constant volatility is invalid. One possible explanation is that the volatility of the underlying asset returns is not constant over time and instead follows a separate stochastic process.

Option pricing models incorporating stochastic volatility (SV) have been studied extensively in the literature. Examples of early studies are Hull and White (1987), Scott (1987), Wiggins (1987), Bailey and Stulz (1989), Chesney and Scott (1989), and Melino and Turnbull (1990, 1991). These studies are subject to a number of general weaknesses. First, most of the models do not admit analytical solutions and are computationally demanding. Second and more important, the models are developed under very restrictive assumptions such as zero correlation between asset returns and volatility shocks and a zero-risk premium for SV.

Stein and Stein (1991) developed an option pricing model where volatility follows an arithmetic Ornstein–Uhlenbeck process and provided a closed-form formula for European options that involves a single numerical integration. However, the model was also developed under the unrealistic assumption that asset return and volatility shocks are not correlated. Heston's (1993) model relaxes the zero-correlation restriction and specifies a mean-reverting square-root process for volatility. Heston's model is an appealing choice for modeling option pricing under SV because it allows for systematic volatility risk and arbitrary correlation between volatility and underlying returns.

Recent research has examined the empirical application of models based on Heston's closed-form option pricing solution. On currencies, Bates (1996) estimated the parameters of a diffusion–jump model with SV for deutsche mark options. Bates found that an SV model explains implicit excess kurtosis only by assigning implausible values to SV parameters. Guo (1998) used Heston's model to examine volatility risk premiums implicit in currency option prices and showed that the compensation for volatility risk is a significant factor in currency market risk premiums. On stock index options, Bates (2000) examined post-1987 data for Standard & Poor's (S&P) 500 futures options. He found that an SV model captures the strong negative skewness implicit in S&P 500 futures options through a negative correlation between index and volatility shocks and an implausibly high volatility of volatility. Bakshi, Cao, and Chen (1997) evaluated the performance of alternative models for the S&P 500 index option contract. Although their results were consistent with those of Bates (2000), they showed that SV provides a first-order improvement over the BS model. Nandi (1998) documented the importance of allowing for correlation between S&P 500 index returns and volatility in an SV option pricing model. He found that allowing for nonzero correlation provides a significant improvement in the mispricing of out-of-the-money (OTM) options and overall pricing performance.

This study considered the improvement over the BS model from allowing for SV in pricing FTSE 100 index options. Although there are several studies that have examined the performance of Heston's model on S&P 500 index options, no study has investigated its performance in other major index options markets, and this study fills this void. The risk-neutral parameters of Heston's (1993) mean-reverting square-root SV model were estimated with European-style FTSE 100 index option prices over the period 1994 to 1996. It is shown that these implied parameters can be used to perform out-of-sample pricing, allowing a comparison of the SV and BS models, which explains empirically the impact of SV on option pricing for index options. The results show that Heston's SV model significantly outperforms the BS model in terms of both in-sample and out-of-sample pricing fits.

DATA AND RESEARCH METHODOLOGY

Data

This study was based on European-style FTSE 100 index (FTSE 100) options over the period December 22, 1993 to December 18, 1996. Price data on FTSE 100 options and contemporaneous index levels came from the transaction records provided by the London International Financial Futures Exchange (LIFFE). Intradaily data were used to avoid imperfect synchronization of closing prices with the underlying index price. Midpoints of bid and ask quotes were used. The analysis used the last quote for a particular option in terms of exercise price, maturity, and type between 12:00 and 16:10[1] every Wednesday in the sample period. In com-

[1]Trading in LIFFE begins at 8:35 and ends at 16:10.

parison with Bakshi et al.'s (1997) study of SPX contracts extracted from tick data quoted between 15:00 and 15:30, the wider data window for obtaining FTSE 100 option prices reflects the lower liquidity in the FTSE 100 option market. London Euro-currency rates, collected from Datastream, for pounds sterling with maturity closest to an option's maturity were used as risk-free interest rates. Because FTSE 100 contracts are European-style, index levels were adjusted for dividends by the subtraction of the present value of future cash dividend payments before each option's expiration date. This study also did some additional data screening. The trading volume for FTSE 100 options is substantially less than for S&P 100 index option (OEX) or SPX contracts in the United States. Therefore, to enhance the integrity of the study, less heavily traded options were eliminated here. On the basis of an analysis of patterns of trading volumes on FTSE 100 options, the option contracts retained were the two nearest in-the-money (ITM) and the eight nearest OTM call options and the two nearest ITM and the ten nearest OTM put options. This represents a compromise between increasing the number of observations available for estimating option model parameters and avoiding highly illiquid option contracts that could add noise or bias to the estimation process. All data had to satisfy certain no-arbitrage relationships, including lower and upper bounds and bearish, bullish, and butterfly spread boundaries.[2] Option data with bid–ask spreads larger than 36 pence and with maturities less than 6 days were also eliminated from the sample. Only a small fraction of the data was excluded: 8.15% for maturities less than 6 days, bid–ask spreads larger than 36 pence, and violations of upper and lower boundaries, 0.08% and 0.01% for bullish–bearish spread and butterfly spread arbitrages, respectively. A total of 8,764 records of simultaneous index and option prices were used for the estimation of the parameters of the BS and SV models over the sample period, consisting of 157 Wednesdays. Of these, 3,981 were calls and 4,783 were puts. Table I presents characteristics of the data sample across maturity and moneyness, where moneyness is defined as $(S_t - D_t)e^{r(T-t)}/X$ and D_t is the present value of all cash dividends paid over the life of the option. Average option quotes ranged from 6.22 pence for deep OTM short-term calls to 211.50 pence for ITM long-term puts. Bid–ask spreads ranged from 3.57 pence for short-term deep OTM puts to 22.04 pence for long-term near-the-money puts.[3]

[2]Because of the option contracts included, put–call violations were not examined.

[3]Bid–ask spreads for FTSE 100 options are substantially larger than for SPX options, reflecting the relative illiquidity of the FTSE 100 options market. This further justifies the screening out of less heavily traded options and the use of midpoints of bid and ask quotes.

TABLE I

Sample Characteristics of European-Style FTSE 100 Index Options

		Days to Expiration					
		Calls			Puts		
Moneyness		*<60*	*60–180*	*>180*	*<60*	*60–180*	*>180*
<0.94	Option price	6.22	17.63	62.34	N/A	N/A	N/A
	Bid–ask spread	3.88	7.72	19.87	N/A	N/A	N/A
	Observations	184	448	387	N/A	N/A	N/A
0.94–0.97	Option price	12.45	40.99	104.18	124.50	162.33	211.50
	Bid–ask spread	3.98	9.78	21.58	5.67	12.67	21.00
	Observations	383	319	237	9	6	1
0.97–1.00	Option price	32.80	76.57	146.80	81.65	124.16	189.32
	Bid–ask spread	4.82	9.96	21.44	5.39	10.21	22.04
	Observations	511	302	230	427	284	214
1.00–1.03	Option price	84.05	126.28	197.56	35.46	80.03	144.12
	Bid–ask spread	5.32	10.12	21.51	4.98	10.08	20.96
	Observations	431	284	214	479	293	227
1.03–1.06	Option price	120.13	156.83	210.50	16.95	48.09	109.09
	Bid–ask spread	5.74	9.25	20.25	4.15	9.64	20.80
	Observations	23	20	8	408	279	207
>1.06	Option price	N/A	N/A	N/A	7.14	20.37	58.95
	Bid–ask spread	N/A	N/A	N/A	3.57	7.67	18.03
	Observations	N/A	N/A	N/A	531	772	646

Note: This study includes 8 OTM and 2 ITM calls and 10 OTM and 2 ITM puts. Defining $F = (S_t - D_t)e^{r(T-t)}$, these are given as:

Calls: $-400 \leq F - X \leq 100$, 8 OTM + 2 ITM calls

Puts: $-100 \leq F - X \leq 500$, 2 ITM + 10 OTM puts

The option price was calculated as the midpoint of bid and ask quotes. Moneyness was defined as $(S_t - D_t)e^{r(T-t)}/X$.

Heston's SV Option Pricing Model

Heston (1993) provided a closed-form solution for pricing a European-style option when volatility follows a mean-reverting square-root process. The actual diffusion processes for the index and its volatility are specified as

$$
\begin{aligned}
dS_t &= \mu S dt + \sqrt{v_t}\, S dW_{S,t} \\
dv_t &= k(\theta - v_t)dt + \sigma_v \sqrt{v_t}\, dW_{v,t}
\end{aligned}
\tag{1}
$$

where $dW_{S,t}$ and $dW_{v,t}$ have an arbitrary correlation ρ, v_t is the instantaneous variance, k is the speed of adjustment to the long-run mean θ, and σ_v is the variation coefficient of variance.

The square-root process for volatility offers a distinct advantage: The model can easily incorporate a risk premium for volatility. When volatility follows a square-root process, the volatility risk premium can be modeled as proportional to the variance (Bates, 1996; Cox, Ingersoll, & Ross, 1985). Therefore, the risk-neutral volatility process is given by

$$\begin{aligned} dv_t &= k(\theta - v_t)dt - \varphi v_t dt + \sigma_v \sqrt{v_t}\, dW^*_{v,t} \\ &= k^*(\theta^* - v_t)dt + \sigma_v \sqrt{v_t}\, dW^*_{v,t} \end{aligned} \quad (2)$$

where φ is the market price of volatility and $k^* = k + \phi$ and $\theta = k\theta/(k + \varphi)$ are the risk-neutral mean-reverting adjustment speed and long-term mean of the volatility process, respectively. Hence, the price of volatility risk explains the difference in the drift term between the actual and risk-neutral volatility processes. Note that the parameters v, σ_v, and ρ, implicit in the risk-neutral process, are the same as those governing the actual process. Given these dynamics, Heston (1993) derived a closed-form option pricing formula for a European call:

$$c = SP_1 - Xe^{-r\tau} P_2 \quad (3)$$

where the risk-neutral probabilities, P_1, and P_2, are recovered numerically from the inversion of the respective characteristic functions. For further details, refer to Heston (1993).

Estimation Procedure

For the SV model, the instantaneous variance, v_t, and the vector of structural parameters, $\Phi = \{k^*, \theta^*, \sigma_v, \rho\}$ are backed out by the minimization of the sum of the squared pricing errors between option model and market prices. Following the standard approach in the literature, the minimization is given by

$$\min_{v_t, \Phi} \sum_{t=1}^{T} \sum_{n=1}^{N_t} [C_n - C^*_n(v_t, \Phi)]^2 \quad (4)$$

where T is the number of trading days in the estimation sample, N_t is the number of options on day t, and C_n and C^*_n are the observed and SV model option prices, respectively.

The model was estimated separately each month. Because Wednesday option data were used and v_t is an instantaneous variance, values of v_t were estimated for each Wednesday of the month, but Φ was assumed to be constant over a month. The assumption that the structural parameters Φ were constant over a month is justified by an appeal to parameter

TABLE II

Summary Statistics of Implied Volatilities and Structural Parameters of the BS and SV Models

Parameters	MSE_{BS}	MSE_{SV}	Vol_{BS}	Vol_{SV}	k^*	θ^*	$\sqrt{\theta^*}$	σ_v	ρ
Sample size	36	36	157	157	36	36	36	36	36
M	55.15	16.61	0.1481	0.1379	4.36	0.0290	0.1696	0.400	−0.535
Mdn	49.99	13.25	0.1435	0.1283	3.63	0.0280	0.1673	0.337	−0.540
Maximum	115.48	60.94	0.1877	0.2074	13.46	0.0449	0.2119	0.799	−0.098
Minimum	20.88	5.24	0.1065	0.0837	1.09	0.0212	.1456	0.099	−1.000
SE	23.21	10.14	0.0187	0.0349	2.83	0.0052	0.0146	0.187	0.223
Q1	39.38	10.18	0.1338	0.1080	2.69	0.0256	0.1601	0.258	−0.616
Q2	49.99	13.25	0.1435	0.1283	3.63	0.0280	0.1673	0.337	−0.540
Q3	63.97	19.94	0.1663	0.1674	5.61	0.0313	0.1770	0.535	−0.361
Skewness	1.06	2.51	0.1856	0.4466	1.41	1.5812	1.2904	0.430	−0.391
Excess kurtosis	0.70	9.58	−1.0616	−1.0710	2.22	3.2321	2.2950	−0.856	0.143

stability. Thus, for the SV model, the estimation design gave values of Φ that varied monthly and different values for v_t each Wednesday.

For the BS model, the implied volatility was estimated for each Wednesday of the sample period with the minimization criterion:

$$\min_{\sigma} \sum_{n=1}^{N_t} [C_n - C_n^*(\sigma)]^2 \tag{5}$$

where N_t is the number of options and C_n and C_n^* are the observed and BS model option prices, respectively.

RISK-NEUTRAL PARAMETER ESTIMATES AND IN-SAMPLE PRICING FIT

Summary statistics for volatilities from the BS model and for instantaneous volatility and risk-neutral parameter estimates from the SV model implicit in option prices along with in-sample mean squared errors are shown in Table II. The in-sample mean standard error was considerably and consistently smaller under the SV model (Mdn = 13.24) than under the BS model (Mdn = 49.99).

The risk-neutral mean-reverting volatility process is controlled by three parameters: the long-term mean, $\sqrt{\theta^*}$, to which volatility reverts, the speed of reversion, k^*, and the variation coefficient, σ_v. On the basis of median values of $\{k^*, \sqrt{\theta^*}, \sigma_v\} = \{3.63, 0.1673, 0.337\}$, volatility took

48 trading days to revert halfway toward a long-term mean of 16.73%.[4] The median speed of reversion value of 3.63 for FTSE 100 options over the period 1993 to 1996 is higher than the values of 1.49 and 1.15 found by Bates (2000) for S&P 500 futures options for the period 1988 to 1993 and Bakshi et al. (1997) for S&P 500 index options over the period 1988 to 1991. However, it is close to the value of 3.29 found by Nandi (1998) for S&P 500 index options over the period 1991 to 1992. The median long-term mean volatility of 16.73% compares with values of 25.91% in Bates and 18.65% in Bakshi et al.

The variation coefficient, σ_v, determines how fat-tailed the distribution is and thereby the relative values of deep OTM options versus near-the-money options. The median value of 0.337 found in this study compares with values of 0.742 in Bates (2000), 0.39 in Bakshi et al. (1997), and 0.26 in Nandi (1998).

The consistently negative estimates of ρ indicate that implied volatility and index returns are negatively correlated. This means the implied distribution perceived by option traders is negatively skewed. The value of ρ reached -1 in 3 months: July 1994, October 1994, and January 1995. An explanation for these extreme values is that a relatively continuous bear market in the FTSE 100 index over the first half of 1994[5] caused investors to perceive the underlying distribution as being heavily left skewed.[6] The SV model captures this effect by attaching an extreme value to ρ.[7] The median value of ρ of -0.54 compares with more extreme values of -0.57 in Bates (2000), -0.64 in Bakshi et al. (1997), and -0.79 in Nandi (1998).

Detailed results, not tabulated, give the t values for the parameter estimates of the volatility process. For the instantaneous volatility, v_t, these are significant in all but two cases. For the parameters $\{k^*, \theta^*, \sigma_v, \rho\}$, the median t values are $\{3.70, 23.48, 5.18, -7.80\}$, and the proportion that are significantly different from zero are {69%, 89%, 92%, 81%}.[8]

Following Bates (1996), this study also derived maximum likelihood estimates of the actual parameters, k and θ, of the mean-reverting process from the time series of implied instantaneous volatilities. Comparing the estimated values of k and θ with those of k^* and θ^* gave an estimate of

[4]The half-life of volatility shocks for the square-root process was calculated as $\ln(2)/k^* \times 253$ trading days.

[5]The FTSE 100 index fell by 18.3% from a half-year high of 3520.3 on February 2, 1994 to a half-year low of 2876.6 on June 24, 1994.

[6]This explanation is supported by the fact that virtually no ITM calls and no OTM puts were traded in these months.

[7]Jump fears, which might explain this effect, were not modeled in this study.

[8]For ρ, the proportion relates to the 33 cases falling inside the $\rho = -1$ boundary.

the volatility risk premium. These results indicate a substantial negative premium for volatility risk, consistent with the negative correlation between volatility and market returns.[9]

Implied Volatility Graphs

Implied volatility smile graphs show the cross-sectional pricing ability of an option pricing model. A nonflat implied volatility curve across moneyness is an indication of model misspecification. The information on implied volatility taken from an option is directly related to option traders' expectations of the underlying volatility over the remaining life of the option. In other words, implied volatilities over substantially different horizons indicate different market perceptions of the underlying volatility. Thus, alternative volatility smiles should be compared for given trading dates and a fixed horizon. As an illustration for this study, BS implied volatility curves and SV (average) implied volatility[10] curves were backed out from FTSE 100 options trading on February 22, 1995 with 23, 86, and 296 days to expiration.[11] The results are shown in Figure 1. Given estimated structural parameters,[12] the SV implied volatilities display a flatter curve across moneyness than those of the BS model, indicating a superior pricing fit for FTSE 100 options. However, the shapes of SV implied instantaneous volatilities across moneyness still exhibit a slight smirk pattern, especially for short-term OTM puts.

Autocorrelation Structure of SV Implied Instantaneous Variances

Figure 2 shows the autocorrelation structure of (weekly) SV implied instantaneous variances. The SV implied instantaneous variances exhibit positive autocorrelation, indicating a tendency to mean-revert. The first-order autocorrelation coefficient is 0.9376. Such a mean-reverting process for variances implies an autoregressive process for implied variances in discrete time, for example, a GARCH process. The autocorrelation in

[9]Detailed results are available on request from the authors.

[10]The BS implied volatility and the SV instantaneous volatility were calculated for each option price. In backing out the SV instantaneous volatility, we used the estimated values of the structural parameters, $\{k^*, \sqrt{\theta^*}, \sigma_v, \rho\}$, for the corresponding months. The SV (average) implied volatility was the square root of the average implied variance over the life of the options contract. For the square-root volatility process, the average implied variance was given by $\omega v_t + (1 - \omega)\theta^*$, where $\omega = e^{k^*\tau} - 1/k^*\tau e^{k^*\tau}$ and τ is the time to maturity.

[11]An investigation of alternative maturities and trading dates showed that these dates and maturities were representative.

[12]The relevant estimates of $\{k^*, \sqrt{\theta^*}, \sigma_v, \rho\}$ were $\{2.0394, 0.1678, 0.1590, -0.7150\}$.

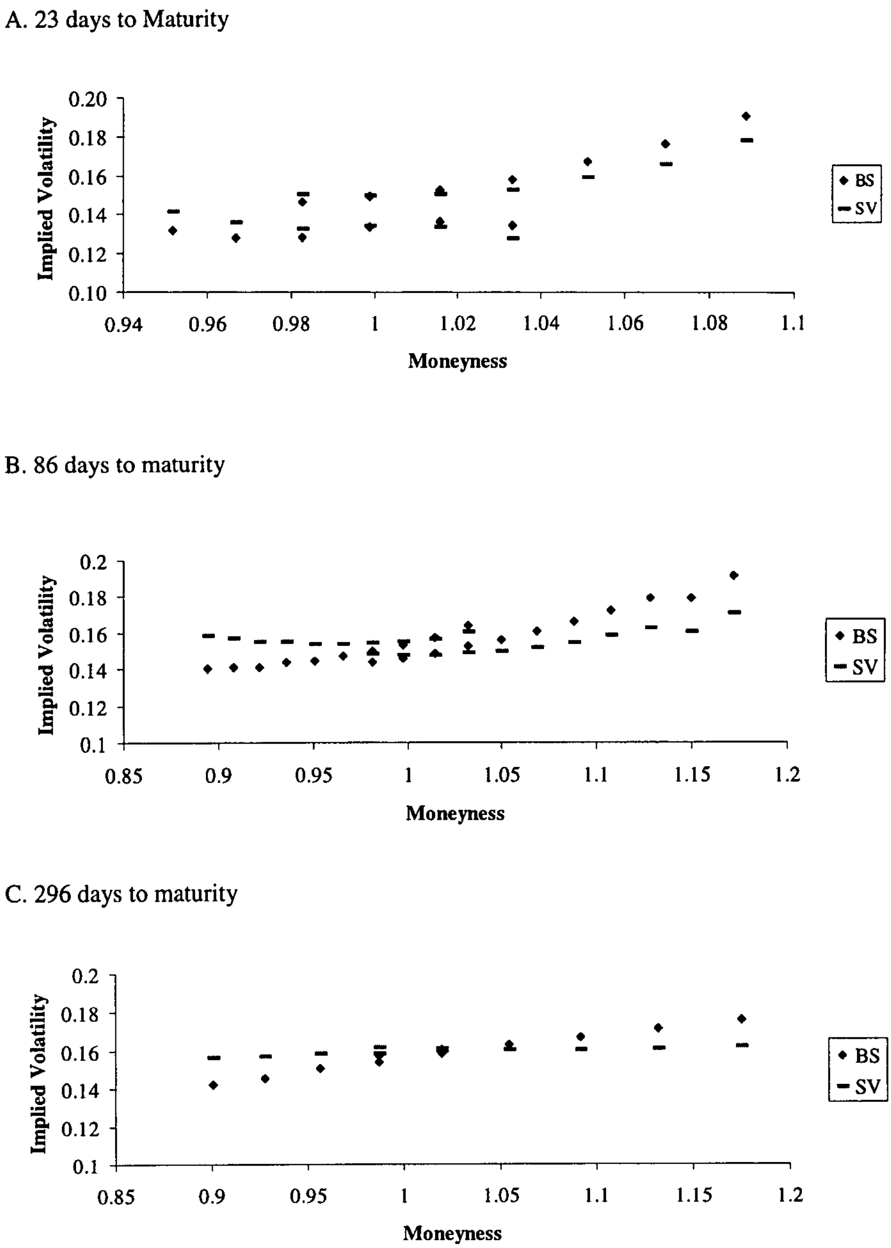

FIGURE 1
Implied volatility curves of the BS and SV models for FTSE 100 index options on February 22, 1995.

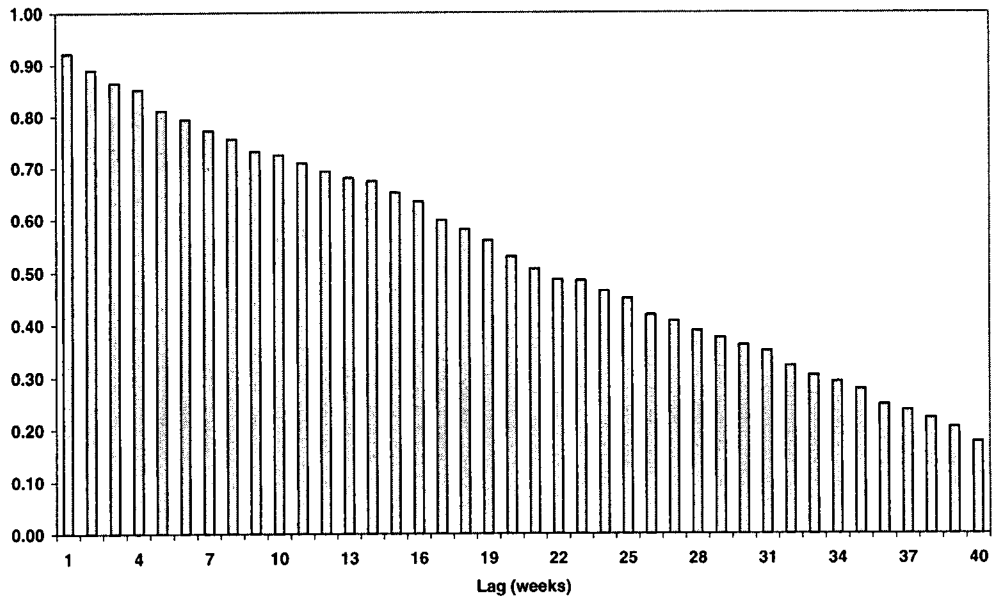

FIGURE 2
Autocorrelation function for SV implied instantaneous variances.

BS implied volatilities was studied by Poterba and Summers (1986) and Merville and Pieptea (1989), whereas Day and Lewis (1997) studied the autocorrelation in SV implied instantaneous volatilities.

OUT-OF-SAMPLE PRICING

Earlier results on implied parameter estimates and instantaneous volatilities of the SV model indicate the importance of allowing for SV when one models FTSE 100 option prices. However, improved in-sample pricing fits may result from more parameters being estimated in the SV model. A more complicated model will generally lead to a better in-sample fit, but it will not necessarily perform better in out-of-sample pricing because any overfitting will be penalized. To test whether the additional parameters of the SV model are economically informative for option pricing, this section provides a comparison of out-of-sample pricing.

Out-of-sample pricing was carried out with the previous day's (Tuesday's) option prices and the previous month's structural parameters $\{k^*, \theta^*, \sigma_v, \rho\}$ to back out Tuesday's instantaneous volatility; Wednesday data plus Tuesday's instantaneous volatility were then used to calculate

Wednesday's option model price.[13] Following Dumas, Fleming, and Whaley (1998), we defined the pricing error outside the bid–ask spread as

$$\text{Pricing Error} = \begin{cases} \text{Model Price} - \text{Bid Price, if Model Price} < \text{Bid price} \\ \text{Model Price} - \text{Ask Price, if Model Price} > \text{Ask Price} \\ 0\text{, otherwise} \end{cases}$$

Three measures of goodness of fit were then employed to assess the out-of-sample pricing performance of the BS and SV option pricing models. These were the root mean squared pricing error (RMSE), the mean percentage pricing error (PE), and the mean absolute pricing error (MAE).

Table III reports RMSE, PE, and MAE values for several categories according to moneyness and time to expiration. Out of 30 moneyness–maturity combinations reported in Table III, RMSE was lower for the SV model in 28 cases. The improvement was generally greater for short-term OTM options and long-term options. Results not separately tabulated show that the SV model reduced the BS model RMSE across the whole sample by 46%. From the panel of PE values, the BS model substantially overpriced the short-term and medium-term OTM call options and underpriced the short-term and medium-term OTM put options. With three exceptions, the PE values showed that the SV pricing errors were substantially smaller (closer to zero) than the BS pricing errors. For short-term OTM options, the SV errors were an order of magnitude smaller. Pricing errors for both the BS and SV models declined substantially as time to maturity increased. The MAE values confirmed the RMSE results.

CONCLUSION

This study examined the effect of modeling SV in the FTSE 100 option market. The risk-neutral parameters of Heston's model were estimated with European-style FTSE 100 options over the period 1994 to 1996. The results show that incorporating SV gives a substantial improvement in the within-sample mean squared pricing error over the BS model. Estimates of the correlation coefficient between asset returns and volatility shocks in Heston's model were consistently negative. Out-of-sample pricing confirms the superiority of the SV model. Results in this study, however, show that significant mispricing remains for short-term options. Fu-

[13]We are grateful to the referee for pointing out that this approach does not constitute true out-of-sample valuation, as Wednesday's v_t is assumed to be unchanged from Tuesday's. However, it is consistent with previous approaches in the literature (e.g., Bakshi et al., 1997, p. 2026).

TABLE III

Out-of-Sample Root Mean Squared Pricing Errors (RMSE), Percentage Pricing Errors (PE), and Mean Absolute Pricing Errors (MAE)

	Days to Expiration					
	Call			*Put*		
Moneyness	*<60*	*60–180*	*>180*	*<60*	*60–180*	*>180*
$RMSE_{BS}$						
<0.94	1.66	2.87	2.28	N/A	N/A	N/A
0.94–0.97	4.28	4.20	1.87	8.77	1.90	1.05
0.97–1.00	5.28	3.90	2.75	7.31	5.35	3.15
1.00–1.03	4.97	4.30	5.24	4.59	3.51	3.64
1.03–1.06	3.20	3.44	1.64	3.29	2.86	5.09
>1.06	N/A	N/A	N/A	2.50	3.59	4.56
$RMSE_{SV}$						
<0.94	0.68	0.82	0.80	N/A	N/A	N/A
0.94–0.97	1.21	1.01	0.90	7.88	2.00	0.00
0.97–1.00	2.26	1.79	1.59	4.84	2.83	2.90
1.00–1.03	3.84	3.65	2.33	2.96	2.18	1.26
1.03–1.06	4.56	2.74	0.67	1.76	1.63	1.41
>1.06	N/A	N/A	N/A	0.95	1.36	1.66
PE_{BS}						
<0.94	16.81	13.55	1.54	N/A	N/A	N/A
0.94–0.97	38.53	8.91	0.11	−1.34	0.45	0.47
0.97–1.00	17.72	2.97	−0.25	4.94	2.43	0.47
1.00–1.03	1.68	0.62	−0.99	3.65	1.23	−0.49
1.03–1.06	0.47	−1.32	−0.19	−10.15	−1.92	−1.47
>1.06	N/A	N/A	N/A	−32.28	−14.09	−4.41
PE_{SV}						
<0.94	3.83	0.36	0.08	N/A	N/A	N/A
0.94–0.97	4.86	0.32	−0.07	−3.03	−0.70	0.00
0.97–1.00	1.52	0.20	−0.10	1.17	0.25	0.35
1.00–1.03	0.23	0.19	−0.35	−0.29	−0.05	0.08
1.03–1.06	2.24	−0.10	0.09	−3.78	0.17	−0.08
>1.06	N/A	N/A	N/A	−8.70	0.20	0.18
MAE_{BS}						
<0.94	0.94	1.71	0.85	N/A	N/A	N/A
0.94–0.97	3.03	2.43	0.46	7.80	0.89	1.05
0.97–1.00	3.77	2.00	0.82	5.35	3.57	0.97
1.00–1.03	3.28	1.82	2.18	2.92	2.05	1.12
1.03–1.06	2.06	2.27	0.94	1.77	1.37	1.59
>1.06	N/A	N/A	N/A	1.55	2.15	2.12
MAE_{SV}						
<0.94	0.25	0.26	0.13	N/A	N/A	N/A
0.94–0.97	0.53	0.32	0.17	6.10	1.14	0.00
0.97–1.00	1.17	0.70	0.39	2.85	1.30	0.79
1.00–1.03	2.38	1.39	0.82	1.48	0.82	0.34
1.03–1.06	3.27	1.63	0.28	0.79	0.60	0.30
>1.06	N/A	N/A	N/A	0.43	0.42	0.33

Note: Moneyness is defined as $(S_t - D_t)\, e^{r(T-t)}/X$.

ture research could usefully examine the incremental pricing improvement of incorporating jumps into the FTSE 100 index price process.

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