TERRORISM AND STOCK MARKET SENTIMENT☆

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This paper examines the effects of terrorism on stock market sentiment by focusing on the behavior of expected probability density functions of the FTSE 100 index around terrorist attacks. We find that terrorism has a strong adverse impact on stock market sentiment. In particular, terrorist attacks are found to cause a pronounced downward shift in the expected value of the FTSE 100 index and a significant increase in stock market uncertainty. Furthermore, our results show that the expected FTSE 100 probability densities became significantly more negatively skewed and fat-tailed in the immediate aftermath of terrorist acts.

JEL classification: G10; G13; G14

Keywords: terrorism, stock market sentiment, implied probability densities, options

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1. Introduction

Although terrorism has a long history in human societies, recent years have nonetheless witnessed exceptionally disastrous terrorist attacks against both civilian and military targets. Most infamously, on September 11, 2001 suicide terrorists crashed hijacked commercial airplanes into the World Trade Center twin towers and the Pentagon, killing altogether more than 3,000 people. Besides the indisputable direct effects in terms of loss of human life and destruction of property, these kinds of terrorist acts are likely to have wide-ranging indirect effects on social and economic conditions. Terrorist attacks against civilian population and business facilities may, for instance, have an adverse impact on consumer and investor confidence, and thereby also on economic outlook and financial markets (see e.g., Johnston and Nedelescu, 2006; Frey, Luechinger, and Stutzer, 2007).[1]

The indirect economic consequences of terrorism on global financial markets have received considerable attention in the academic literature over the past few years. Several studies have examined the effects of terrorism on stock markets. Chen and Siems (2004), Maillet and Michel (2005), Charles and Darné (2006), Johnston and Nedelescu (2006), and Nikkinen, Omran, Sahlström, and Äijö (2008) demonstrate that the major stock markets throughout the world were negatively affected by the September 11 terrorist attacks. Carter and Simkins (2004), Drakos (2004), and Ito and Lee (2005) assess the impact of the September 11 attacks on airline demand and stock returns, and report terrorism's drastic consequences on the airline industry. Using a sample of 639 attacks, Eldor and Melnick (2004) show that terrorism has a permanent effect on stock and foreign exchange markets in

[1] Abadie and Gardeazabal (2008), Blomberg, Hess, and Orphanides (2004), and Eckstein and Tsiddon (2004) show that terrorism may have a substantial effect on major macroeconomic variables.

Israel. Overall, their findings suggest that not even prolonged periods of terrorism seem to desensitize financial markets.

The impact of terrorism on financial market sentiment is examined in Burch, Emery, and Fuerst (2003) and Glaser and Weber (2005). Burch, Emery, and Fuerst (2003) find a significant increase in closed-end mutual fund discounts in the aftermath of the September 11 attacks, and thereby conclude that these attacks caused a negative shift in investor sentiment. Glaser and Weber (2005) use questionnaire data to analyze the expectations of individual investors before and after the September 11 attacks. Somewhat surprisingly, they find that the stock return forecasts of individual investors are higher and the differences of opinion lower after the terrorist attacks. Glaser and Weber (2005), however, also report a pronounced increase in investors' volatility expectations.

In this paper, we take an alternative approach to examine the effects of terrorism on stock market sentiment by utilizing probability densities implied by option prices. Option prices, as inherently forward-looking financial indicators, implicitly contain information about market participants' expectations regarding future asset price developments. In particular, since the price of an option depends on the probability of the underlying asset price exceeding the strike price of the option, a set of option prices with the same maturity but with different strike prices can be used to extract the entire probability density function of the underlying asset price at the maturity of the option (see e.g., Bliss and Panigirtzoglou, 2002; Sherrick, Irwin and Forster, 1996; Söderlind and Svensson, 1997). To assess the impact of terrorism on stock market sentiment, we use data on implied density functions of the FTSE 100 index around the September 11, 2001 attacks in New York and Washington, D.C., the March 11, 2004 attacks in Madrid, and the July 7, 2005 attacks in London. These three attacks are considered the most disastrous terrorist acts against civilian targets over recent years. By focusing on the behavior of implied probability density functions around three distinct terrorist attacks, this paper offers new insights into the effects of terrorism on financial markets.

A number of papers use option-implied risk-neutral density functions to examine the behavior of market expectations around specific economic events, such as macroeconomic news announcements and central bank actions (e.g., Vähämaa, Watzka, and Äijö, 2005; Morel and Teiletche, 2008), or financial crises (e.g., Söderlind, 2000; Haas, Mittnik, and Mizrach, 2006). Perhaps most relevant to our paper, Melick and Thomas (1997) show that implied density functions reflected a significant probability of major disturbances in the oil markets during the Persian Gulf crisis in 1990-91. In general, the previous studies demonstrate that option-implied density functions are useful for assessing changes in market sentiment. Hence, we consider implied probability densities to provide an expedient setting to examine the effects of terrorism on stock market sentiment.

2. Probability density functions implied by option prices

Let c_t denote the time t value of a call option written on an underlying asset S_t, with a single expiration date T, and a contractual terminal payoff function $\max[S_T - K, 0]$, where K is the strike price of the option. Given a risk-neutral probability density function of the underlying asset price at the maturity of the option, $f(S_T)$, the value of the call option at time t can be written as:

$$c_t = e^{-r(T-t)} \int_{-\infty}^{\infty} \max(S_T - K, 0) f(S_T) dS_T = e^{-r(T-t)} \int_{K}^{\infty} (S_T - K) f(S_T) dS_T \,. \qquad (1)$$

where *r* denotes the risk-free interest rate. Since the price of an option can be expressed as a function of the risk-neutral probability density of the underlying asset price at the maturity of the option, a set of observed option prices with the same maturity but with different strike prices implicitly contain information about market participants' expectations regarding the price distribution of the underlying asset price at the maturity of the option.

Several alternative techniques for extracting the expected probability density function from option prices have been proposed in the literature (for a review, see e.g. Jackwerth, 1999). These techniques may be broadly classified to parametric and nonparametric methods. In the parametric methods, a certain parametric form for the terminal underlying asset price distribution needs to be specified. Rather than specifying a particular parametric form for the terminal price distribution, the nonparametric methods initiated by Shimko (1993) utilize some flexible functions to fit the observed option prices as well as possible, and then apply the results derived by Breeden and Litzenberger (1978) to extract the implied probability density.

Campa, Chang, and Reider (1998), Bliss and Panigirtzoglou (2002), and Andersson and Lomakka (2005) provide comparisons of alternative techniques for estimating probability densities from option prices. Although Campa, Chang, and Reider (1998) show that different approaches lead to virtually similar implied distributions, the findings in Bliss and Panigirtzoglou (2002) and Andersson and Lomakka (2005) indicate that the nonparametric smoothing methods à la Shimko (1993) produce more accurate estimates of implied density functions.

In this paper, we estimate the implied probability densities with the nonparametric volatility-smoothing method proposed by Bliss and Panigirtzoglou (2002).[2] Besides being computationally efficient, this nonparametric method is also flexible in the sense that it allows for arbitrary asymmetries and multimodality in implied probability densities. The starting point in our estimation of implied densities is the Breeden-Litzenberger (1978) result, which demonstrates that the second partial derivative of Equation (2) with respect to the strike price of the option gives the discounted risk-neutral probability density function of the underlying asset price:

$$f(S_T) = e^{-r\tau} \frac{\partial^2 C(K,T,t)}{\partial K^2}. \tag{2}$$

Equation (2) is of limited use because only a discrete set of option prices can be observed in the market. Thus, in order to extract the implied probability density, the discrete option price observations must first be transformed into a continuous pricing function. For this purpose, the Black-Scholes (1973) model is applied to convert the observed option prices from the price/strike price space into the implied volatility/delta space.[3] Then, a cubic spline is fitted to the discrete implied volatilities as a function of option deltas by solving the following minimization problem:

$$\min_{\Theta} \sum_{i=1}^{N} \omega_i \left[IV_i - \hat{IV}_i\left(\Delta_i, \Theta\right) \right]^2 + \lambda \int_{-\infty}^{\infty} f''(\Delta,\Theta)^2 \, d\Delta \tag{3}$$

[2] Bliss and Paniqirtzoglou (2002) combine the approaches of Malz (1997) and Campa, Chang, and Reider (1998) by using cubic splines to fit implied volatilities as a function of option deltas.

[3] The delta is the first partial derivative of the option pricing function with respect to the value of the underlying asset.

where $f(\Delta,\Theta)$ is the cubic spline function, Θ denotes the parameter matrix of the cubic spline, IV_i and $\hat{IV}_i(\Delta_i,\Theta)$ are the actual and the spline fitted implied volatility observations, respectively, Δ_i is the option delta corresponding to implied volatility observation i, ω_i is the weighting parameter for observation i, and λ is the smoothing parameter.

The fitted cubic smoothing spline provides a continuous function of implied volatilities in terms of option deltas. By again utilizing the Black-Scholes model, the continuous implied volatility function is next converted from the implied volatility/delta space into the option price/strike price space to obtain a continuous pricing function. Then finally, the Breeden-Litzenberger result given by Equation (3) can be applied to calculate the implied probability density function of the underlying asset.

To mitigate the day-to-day variation in the estimated implied densities due to time-to-maturity effects of option prices, we construct a time-series of implied density functions with a constant maturity of three months. The constant maturity densities are obtained by using a cubic spline to interpolate between implied volatilities of options with different maturities, but with the same delta. By repeating this interpolation for different values of delta, we obtain a hypothetical implied volatility/delta space with three months to maturity for each trading day in the data set. This set of hypothetical implied volatilities against deltas is then used to estimate the constant maturity implied densities. The changes in these constant maturity implied probability densities over time may be considered to reflect changes in market sentiment.

3. Data

The implied probability density functions used in the analysis are extracted from the daily settlement prices of the FTSE 100 index options traded on the NYSE Liffe. The FTSE

100 index is a capitalization-weighted index consisting of the 100 largest companies traded on the London Stock Exchange. Both European and American options on the FTSE 100 index are traded on the NYSE Liffe. In this paper, we use the European-style options to estimate implied probability density functions of the FTSE 100 index. The sample period used in our analysis extends from January 4, 2000 through December 30, 2005, for a total of 1535 trading days. We focus on three specific large-scale terrorist acts during the sample period: the September 11, 2001 attacks in New York and Washington, D.C., the March 11, 2004 attacks in Madrid, and the July 7, 2005 attacks in London.

The market for the European-style FTSE 100 index options is the most active equity options market in the United Kingdom. Because a wide range of strike prices is continuously available for trading, these options are ideal for extracting implied distributions. Moreover, the high liquidity of the FTSE 100 index options ensures that the observed option prices reasonably accurately reflect the information set available to the market participants.

To reduce noise in the estimation of implied densities, we impose three filtering constraints to the option data. First, options with less than five trading days to maturity are eliminated in order to avoid expiration-related unusual fluctuations in option prices. Second, only at-the-money (ATM) and out-of-the-money (OTM) options are used in the empirical analysis. In-the-money (ITM) options are discarded because they are less liquid than OTM and ATM options, and because by using both out-of-the-money call and put options it can be ensured that the complete strike price spectrum is efficiently utilized in the estimation of implied density functions. Finally, we require that the option prices are convex and monotonic functions of the corresponding strike prices, and thereby satisfy the basic theoretical option price conditions.

4. Terrorism and stock market sentiment

Table 1 presents descriptive statistics for the moments of implied probability density functions of the FTSE 100 index. Panel A reports the statistics for the levels of implied moments, while Panel B provides the corresponding descriptives for the day-to-day changes in implied moments. The reported changes for the mean expectation, volatility, and kurtosis are logarithmic first differences, while the figures for skewness estimates are first differences. As can be noted from Panel A, in terms of the levels of implied moments, the implied probability densities on the days of the three terrorist attacks seem not remotely exceptional. In fact, the implied moments on the attack days are quite far from the minimum and maximum moment estimates.

(insert Table 1 about here)

Panel B of Table 1 shows that the estimated implied densities are, on average, unchanged on a daily basis. A simple *t*-test suggests that none of the reported mean changes is statistically significant. Turning the focus onto the effects of the terrorist attacks, the expected value of the FTSE 100 index falls considerably on all three attack days. The decline on September 11, 2001 is the largest daily change in the expected value of the index during our six year sample period. The three terrorist attacks also are associated with soaring implied volatility. The increase in implied volatility on September 11, 2001 is the maximum daily change in implied volatility during the sample period.

Table 1, Panel B also shows that the changes in skewness coefficients of implied density functions are negative on the days of the terrorist attacks. This increasing negative skewness indicates that market participants quickly imposed higher probabilities of further sharp downward movements in the FTSE 100 index after the attacks. Finally, implied probability densities become more fat-tailed in the aftermath of the terrorist acts, thereby suggesting that terrorism causes market participants to revise their expectations about the likelihood of future extreme movements in the FTSE 100 index. Overall, the statistics in Panel B indicate that terrorism has a strong adverse effect on stock market sentiment.

(insert Table 2 about here)

Table 2 reports the percentile ranks of the changes in the moments of implied densities on the days of the terrorist attacks among the day-to-day changes during the complete sample period. The percentile ranks show that the terrorist attacks are associated with truly exceptional movements in the moments of implied FTSE 100 density functions. As already seen in Table 1, the largest daily changes during our 1535-day sample period in the expected value of the FTSE 100 index and also in implied volatility occurred on September 11, 2001. The decline in skewness and the increase in kurtosis on September 11 are among the bottom two and the top three percent of the day-to-day movements, respectively. The percentile ranks demonstrate consistent drastic movements in implied moments of FTSE 100 distributions also on March 11, 2004 and July 7, 2005. The changes in the expected value of the index and in implied skewness are among the very bottom observations, while the changes in implied volatility and implied kurtosis are in the top percentiles. The percentile ranks in Table 2 indicate that stock market uncertainty, in particular, is substantially affected by terrorist attacks, as the largest, the second largest, and the fifth largest daily increases in implied volatility took place on September 11, 2001, July 7, 2005, and March 11, 2004, respectively.

Table 2 also reports the number of days before a given implied moment reverted back to the level on the day before the terrorist acts. In general, the data suggest that terrorist attacks may have a prolonged, albeit transitory impact on stock market sentiment. After the September 11 and the March 11 attacks, the expected value of the FTSE 100 index rebound in about one month (19 and 27 trading days, respectively). The July 7 attack in London, however, has only a very short-term effect on mean expectations. Market participants' volatility expectations remain at the higher levels for several weeks in the aftermath of the New York-Washington and Madrid attacks, and never return to pre-attack levels after the London attack. Further, Table 2 shows that after the September 11 and the March 11 attacks, the recovery of the higher-order moments of implied densities takes four to six months. In contrast, implied skewness and kurtosis rebound in just two days after the July 7 attack. Nevertheless, our findings generally indicate that the adverse effects terrorist attacks on implied moments are largely transitory, and thereby suggest that stock market sentiment is relatively resilient to terrorism in the long run. This conclusion is supported by the existing literature. Chen and Siems (2004), Johnston and Nedelescu (2006), and Nikkinen, Omran, Sahlström, Äijö (2008) report that financial markets recover quickly after the September 11 attacks, while Fernandez (2006), using wavelet-based variance analysis, shows that the September 11 attacks do not cause permanent shifts in stock market volatility.

To assess the effects and significance of terrorist attacks on stock market sentiment, we regress the daily changes in the moments of implied FTSE 100 probability density functions on a set of dummy variables that identify the days of the terrorist attacks and the two days following each attack:

$$\Delta\mu_{i,t} = \alpha + \beta_1 D_{ATTACK} + \beta_2 D_{ATTACK+1} + \beta_3 D_{ATTACK+2} + \varepsilon_t \quad (4)$$

where $\mu_{i,t}$ denotes the logarithm of the *i*th moment (except for skewness) of implied probability density at time *t*, D_{ATTACK} is a dummy variable that equals one on September 11, 2001, March 11, 2004, and July 7, 2005, $D_{ATTACK+1}$ and $D_{ATTACK+2}$ are corresponding dummy variables identifying the two days following each terrorist attack, and Δ is the first difference operator. Engle's LM test indicates significant conditional heteroskedasticity in the residuals of the regression specifications, which we attack with a GARCH(1,1) error structure. Model diagnostics suggest that this specification is adequate.

(insert Table 3 about here)

Table 3 presents the results. The coefficient estimates for the attack day dummies are statistically highly significant, and the signs of these estimates confirm that terrorist attacks have an adverse effect on stock market sentiment. The results show that attacks cause a downward shift in the expected value of the FTSE 100 index and a significant increase in the dispersion expectations. Also, on the days of the attacks, implied FTSE 100 probability distributions appear to become more negatively skewed and fat-tailed. However, on the first day after, implied probability densities tend to revert towards the pre-attack shapes. The estimated coefficients for the day-after dummy variables are significant at the 1 % level. Finally, the regression results indicate further deterioration of stock market sentiment on the second day after the attacks, as the implied density functions again become significantly more negatively skewed and leptokurtic.

To ascertain the robustness of the above findings, we re-estimate Equation (4) using data on the VIX and VSTOXX indices that represent the implied volatilities of the S&P 500 and the DJ Euro STOXX 50 stock indices. In general, these estimations (not tabulated) provide further evidence to suggest that stock market uncertainty is significantly affected by the terrorist attacks. The estimated coefficients for the attack day dummy variables are positive and statistically highly significant. Consistent with Table 3, the coefficient estimate for the day-after dummy is negative and statistically significant for the VSTOXX index, while the estimates also suggest that uncertainty in the U.S. stock markets increases significantly on the second trading day after the attacks. Overall, the additional estimations indicate that our empirical findings may also apply to other stock markets.

(insert Figure 1 about here)

To further illustrate the impact of terrorism on stock market sentiment, Figure 1 plots the developments in the higher-order moments of implied FTSE 100 probability distributions over a four month period around the September 11 attacks. The dashed lines in each figure present the average levels of the implied moment during the two months preceding and the two months following the attacks. As can be seen from Figure 1a, the impact of the September 11 attacks on market uncertainty is manifested as a distinct spike in implied volatility. The figure also indicates that the average level of implied volatility was considerably higher in the aftermath of the attacks than during the two preceding months. Correspondingly, Figure 1b shows that the implied FTSE 100 distribution became significantly more negatively skewed in the immediate aftermath of the terrorist acts. Finally, Figure 1c demonstrates that implied kurtosis increased substantially on September 11, 2001, and the average level of implied kurtosis rose drastically during the weeks following the attacks.

Overall, our empirical findings provide further evidence about the impact of terrorism on stock markets. The results suggest that terrorist attacks cause investors to significantly revise their expectations regarding future profits or risk premiums. Nevertheless, consistent with previous studies (see e.g., Chen and Siems, 2004; Fernandez, 2006; Johnston and Nedelescu, 2006), we find that financial markets are relatively resilient to terrorism in the longer run, as the adverse effects of terrorist attacks on stock market sentiment appear largely transitory.

6. Conclusions

This paper examines the effects of terrorism on stock market sentiment by focusing on the behavior of expected probability density functions of the FTSE 100 index around recent terrorist attacks. In particular, we use option prices to extract a time-series of expected probability densities of the FTSE 100 index, and analyze the movements in these densities around the September 11, 2001 attacks in New York and Washington, D.C., the March 11, 2004 attacks in Madrid, and the July 7, 2005 attacks in London.

The results show that terrorism has a strong adverse effect on stock market sentiment. All three attacks are associated with drastic short-term movements in the implied FTSE 100 probability densities. We find that the attacks cause a pronounced downward shift in the expected value of the FTSE 100 index and a significant increase in the dispersion expectations. Stock market uncertainty, in particular, is found to be substantially affected by the terrorist attacks, as the largest, the second largest, and the fifth largest daily increases in implied volatility during our 1535-day sample period take place on September 11, 2001, July 7, 2005, and March 11, 2004, respectively. Further, our results demonstrate that implied probability density functions became more negatively skewed on the days of the terrorist attacks. This finding suggests that terrorism causes market participants to quickly impose higher probabilities for further sharp downward movements in the FTSE 100 index. Finally, we find that market expectations about the likelihood of future extreme movements in the FTSE 100 index, as measured by implied kurtosis, are revised upwards in the immediate aftermath of the terrorist attacks.

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Figure 1. **Implied FTSE 100 densities around September 11, 2001**

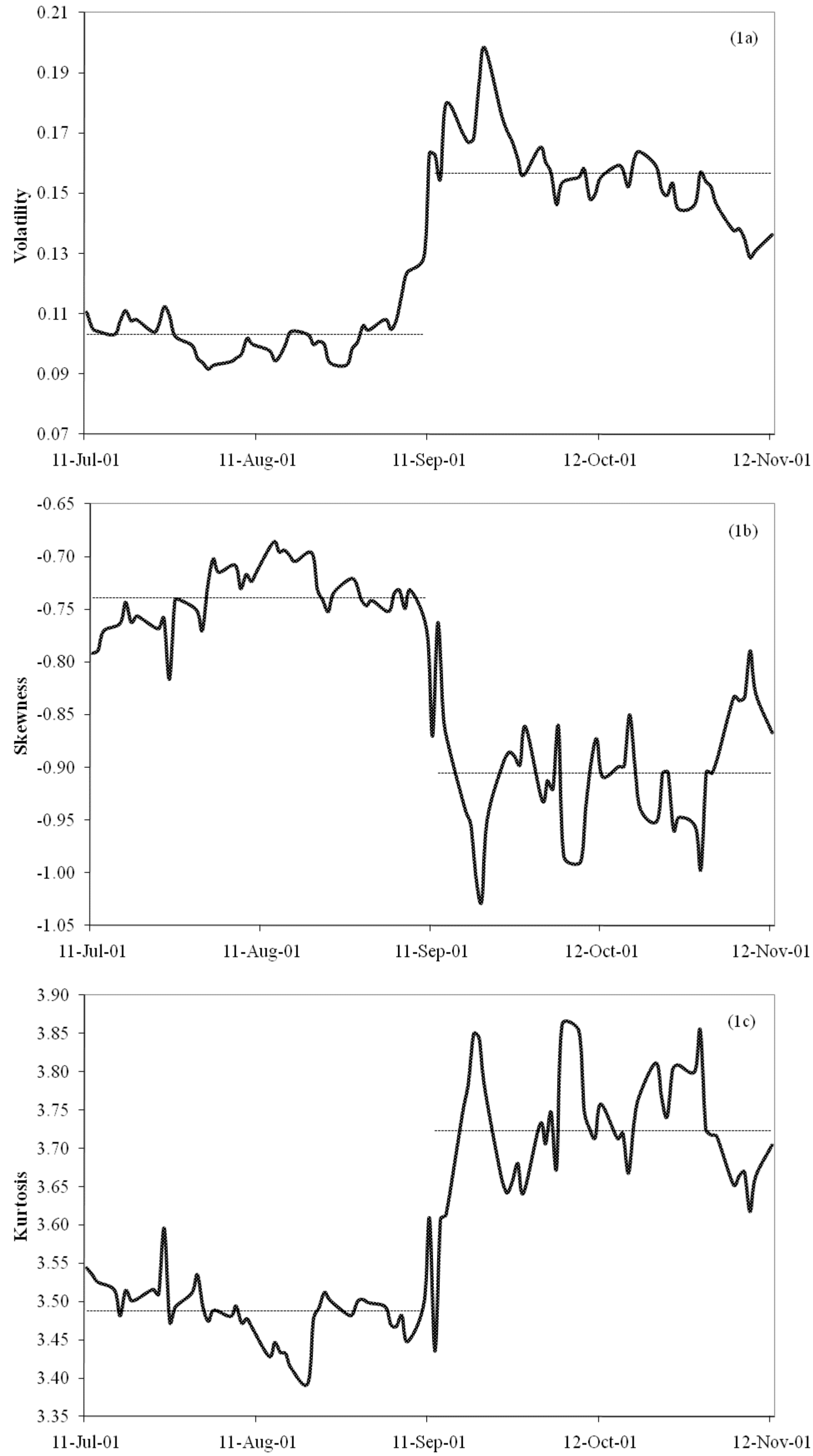

Table 1
Descriptive statistics for implied FTSE 100 densities

The table reports statistics for the moments of option-implied FTSE 100 probability densities from January 4, 2000 through December 30, 2005, for a total of 1535 trading days.

Panel A: Levels

	FTSE 100	Volatility	Skewness	Kurtosis
Mean	5057.46	9.901	-0.929	3.853
Median	5000.83	9.275	-0.916	3.812
Standard Deviation	850.49	3.818	0.142	0.258
Min	3262.95	4.329	-1.405	3.369
Max	6888.57	23.169	-0.456	4.769
September 11, 2001	4770.41	16.344	-0.881	3.621
March 11, 2004	4447.15	8.510	-1.038	4.095
July 7, 2005	5163.43	5.772	-1.034	4.172

Panel B: Differences

	FTSE 100	Volatility	Skewness	Kurtosis
Mean	0.000	-0.001	0.000	0.000
Median	0.000	-0.004	0.002	-0.001
Standard Deviation	0.012	0.041	0.042	0.017
Min	-0.061	-0.159	-0.240	-0.067
Max	0.059	0.237	0.236	0.099
September 11, 2001	-0.061	0.237	-0.105	0.033
March 11, 2004	-0.022	0.173	-0.057	0.011
July 7, 2005	-0.014	0.208	-0.134	0.046

Table 2

Terrorist attacks and implied FTSE 100 densities

The table reports the changes in the moments of option-implied FTSE 100 probability densities on the days of the terrorist attacks and the percentile ranks of these changes among the day-to-day changes during the sample period from January 4, 2000 through December 30, 2005. The table also reports the number of days before a given implied moment reverted back to the level that prevailed on the day before the terrorist acts.

	FTSE 100	Volatility	Skewness	Kurtosis
September 11, 2001:				
Change	-0.061	0.237	-0.105	0.033
Change percentile	0.000	1.000	0.020	0.969
No. of days to rebound	19	42	81	118
March 11, 2004:				
Change	-0.022	0.173	-0.057	0.011
Change percentile	0.036	0.997	0.073	0.810
No. of days to rebound	27	17	130	127
July 7, 2005:				
Change	-0.014	0.208	-0.134	0.046
Change percentile	0.092	0.999	0.008	0.983
No. of days to rebound	1	?	2	2

Table 3
Dummy regressions

The table reports estimates of the following regression:

$$\Delta\mu_{i,t} = \alpha + \beta_1 D_{ATTACK} + \beta_2 D_{ATTACK+1} + \beta_3 D_{ATTACK+2} + \varepsilon_t$$

where $\mu_{i,t}$ denotes the *i*th moment of option-implied FTSE 100 probability density at time *t*, D_{ATTACK} is a dummy variable that equals one on September 11, 2001, March 11, 2004, and July 7, 2005, $D_{ATTACK+1}$ and $D_{ATTACK+2}$ are corresponding dummy variables that identify the days after the terrorist attacks, and Δ is the first difference operator. The sample period extends from January 5, 2000 to December 30, 2005, for a total of 1534 observations. *t*-statistics are in parentheses.

	FTSE 100	Volatility	Skewness	Kurtosis
Constant	0.000 *	-0.001	0.000	0.000
	(1.67)	(-1.10)	(-0.11)	(0.19)
Attack day	-0.020 ***	0.205 ***	-0.108 ***	0.035 ***
	(-5.94)	(8.01)	(-2.87)	(2.82)
One day after	0.012 ***	-0.068 ***	0.109 ***	-0.043 ***
	(3.87)	(-8.37)	(4.98)	(-6.33)
Two days after	-0.001	0.001	-0.057 ***	0.026 ***
	(-0.35)	(0.03)	(-4.92)	(5.98)
ARCH(0)	0.000 **	0.000 ***	0.000 ***	0.000 ***
	(2.35)	(4.46)	(6.63)	(7.30)
ARCH(1)	0.098 ***	0.087 ***	0.123 ***	0.169 ***
	(7.56)	(7.47)	(9.60)	(7.99)
GARCH(1)	0.897 ***	0.860 ***	0.846 ***	0.751 ***
	(71.36)	(43.70)	(58.00)	(28.06)
Adjusted R^2	0.011	0.048	0.018	0.016
F-stat.	3.75 ***	14.01 ***	5.81 ***	5.128 ***

*** Indicates statistical significance at the 0.01 level.
** Indicates statistical significance at the 0.05 level.
* Indicates statistical significance at the 0.10 level.