Is there Information in the Volatility Skew?

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Abstract

Since the 1987 crash, option prices have exhibited a strong negative skew, implying higher implied volatility for out-of-the-money puts than at- and in-the-money puts. This has resulted in incorporating multiple jumps and stochastic volatility within the data generating process to improve the Black-Scholes model in an attempt to capture negative skewness and a highly leptokurtic distribution. The general conclusion is that there is a large jump premium in the short-term, which best explains the significant negative skew for short maturity options. Alternative explanations for the negative skew are related to market liquidity driven by demand shocks and supply shortages. Regardless of the explanation for the negative skew, we assess the information content in the shape of the skew to infer if the option market can accurately forecast stock market crashes and/or spikes upward. We demonstrate, using all options on the S&P 100 from 1996-2002, that the shape of the skew can reveal with significant probability when the market will "crash" or "spike". However, we find the magnitude of the spike prediction is not economically significant. Our findings are strongest for the short-term out-of-the money puts, consistent with the notion of investors' aversion to large negative movements. We also find that the power of the "crash/spike prediction" decreases with an increase in the time to option maturity.

I. Introduction

The information content contained in implied volatility has been extensively examined by exploring the relationship between at-the-money (ATM) implied volatility and future realized volatility. The findings by Christensen and Prabhala (1998), Jorion (1993), Doran (2005), and others suggest that implied volatility is the most efficient, but biased estimator of future realized volatility. This research can be extended in several directions. In particular, is there information content beyond the ATM options that can be used to reveal future market movements? Specifically in this paper, our hypotheses contend that there is predictive power between the shape of the volatility skew and future large market movements.

The foundation for this argument comes from multiple strands of the literature. Several authors have expanded the Black and Scholes (1973) model by adding stochastic volatility, jumps, and other innovations to correct many of the model's perceived pricing shortcomings. In particular, Bates (1991) examines the prices of options and the skewed pricing distributions that evolve when call and put options are compared across moneyness. By incorporating a jump-diffusion process, the risk-averse investor is more affected by the probability of a decline in asset prices than by the probability of an increase in prices. The asymmetric jump-diffusion process allows for volatility skewness that adjusts with changes in investors' perceptions of an asset's (or the market in general) future return. If option investors are well informed, as Manaster and Rendleman (1982) propose, then the information contained within the skew ex-ante, should reveal ex-post performance.

Bates (2000) broadens the scope of his earlier paper by studying option price skewness for out-of-the-money (OTM) puts for an extended time period and with a more intricate model. Bates reports that since the 1987 crash, implied volatility has permanently and dramatically changed, with very pronounced negative skewness in option prices. Bates finds that even after controlling for a jump in volatility, the stock market believed there was a very high probability of a large decline in asset prices in the

1988 to 1993 period. Consistent with earlier studies, the market continues to price information from implicit volatility into option prices. However, Bates' results still leave much unanswered concerning the shape of the skew, and the implication for market movements if the shape of the skew changes.

Pan (2002) addresses the option pricing skewness ("smirks") found by Bates (2000) and Bakshi, Cao, and Chen (1997). Pan claims that the driving force for "smirks" in pricing distributions is investors' fear of a negative price jump. As the market becomes more volatile, the price of volatility goes up, increasing the price-jump component of option pricing. In other words, as the market becomes more volatile, investors become more worried about a "market crash" and are willing to pay a higher premium to purchase the put option's "insurance" attribute. Pan's empirics support the claim that there is a jump-risk premium whose price is highly correlated with market volatility, and for a strong association between implied volatility and future negative market movements. Like other studies, Pan's leaves the subject of the shape of the skew and the role of differing maturity lengths largely unexplored.

Chen, Hong, and Stein (2001) attempt to forecast crashes in asset markets using trading volume, past returns, and price skewness. They employ the model presented in Hong and Stein (1999) to include asymmetric volatility seen in stocks that results in a negative skewness in stock returns. Chen et al present a model to forecast asset market crashes that employs parameters from an array of similar characteristics to those studied in the option/volatility literature. Additionally, model structures similar to theirs may accommodate option volatility "sneers" and "smirks".

Giot (2005) demonstrates a strong negative contemporaneous relation between VIX and the associated underlying asset indices.[1] For example, Giot finds that when the S&P 100 index experiences a 1% drop, the VIX implied volatility index rose 4.72%. The interpretation for this reaction is that periods of high implied volatility have concurrent periods of poor performance for the underlying stock index; the investors are suffering from a substantial "fear factor". The study also shows that short-term positive returns

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[1] The CBOE introduced the Volatility Index (VIX) in 1993 as weighted average of eight OEX puts and calls close to ATM options to represent the implied volatility of a hypothetical OEX ATM option that has 30 days to expiration. In 2003, the CBOE introduced a revised VIX that uses a broader range of strike prices that moderately deviate from ATM strikes.

will likely follow periods of high implied volatility as the market will "return to the mean". This important result is enhanced by the findings of Banerjee, Doran, and Peterson (2006) that imply a degree of forecasting power in implied volatility. In particular, implied volatility has short-term return forecasting power for the index when incorporating the mean-reversion and level of the VIX index. However, by only examining VIX, these authors ignore the information in the tails of the skew, and thus ignore the effect of the jump premium.

We do not try to rank the effectiveness of one option pricing model compared to another. Instead, our premise is that there is information in the skewness of the implied volatility curves that is not captured completely by any single model. Other researchers offer explanations that refute a negative jump aversion explanation for the negative skewness in option prices. Their results are consistent with the possibility that there is both a positive jump premium and a negative jump premium embedded in option prices. The factors that lead to this conclusion include the demand pressures of dealers versus end-users as shown by Garleanu, Pedersen, and Poteshman (2005), the costs of short-selling stocks found by Evans, Geczy, Musto, and Reed (2005), and limits to arbitrage discussed in Bollen and Whaley (2004). Unlike these works, we make no statement to why the skew arises, but we argue that there is information within the volatility curves and that this information provides some predictive power in short-term options.

We build upon prior findings by examining the predictive power of the entire volatility skew, and not just information contained in ATM options. Since implied volatility has been shown to predict future returns and realized volatility, and volatility skews contain information about high jump fears, we test whether large negative skews can predict future market crashes. Implied volatility from OEX S&P 100 index put and call options are used to predict significant price movements in the underlying S&P 100 Index. Options are sorted into maturity and moneyness baskets so that the information content between the different option categories can be examined.

We add to the literature by more comprehensively defining the direct predictive link between the option markets and the asset markets than is possible when using a VIX-type volatility measure. Theoretically, the differences in the implied volatility levels within "smiles" and "smirks" provided by option prices could be evidence of a rational market if the additional premiums embedded in the implied volatility are justified by a “market crash” risk premium.[2] If the market is paying an additional risk premium that does not seem to be justified by market crash fears, then the search must continue for other conclusive risk measures in order to justify the implied volatility “smiles” and “smirks” in a rational market. A more complete study of implied volatility across moneyness and maturities can provide more evidence about investors’ risk perceptions and trading activities.

Specifically, we explore the implied volatility of deep out–of-the-money (DOTM) puts and how it relates to the implied volatility of: (1) OTM puts, (2) ATM puts, and (3) in-the-money (ITM) puts. If investors fear a market crash in the relative near-term, anticipated stock volatility is likely to increase in the options market as opinions about market expectations deviate. For instance, some traders who are fearful of a sharp market decline can trade DOTM puts with investors who do not share their fears concerning the severity of the potential market drop. If these groups of traders who fear the chance of a market crash are better informed than other traders, then more information should surface in the implied volatility of DOTM and OTM put options when compared to other options. Similarly, if there is less fear, or greater optimism in the market, then information about an apparent spike upward should be apparent in the OTM call skew. This will occur only if there is both a positive and negative jump premium, which is in direct conflict with the one-sided jump premium specification typically used in fitting the implied distribution. Thus, in the spirit of Bates (1991, 2000), we study how the option pricing skewness changes across the moneyness, and if the jump premium related to crash insurance is justified.

A refined predictive link would prove useful for practitioners as well. Many option users fall under the category of hedgers and speculators. Hedgers are more likely to use options (especially DOTM and OTM put options) to act as insurance against a substantial market devaluation. If there is a relation between implied volatility for options with varying degrees of moneyness and movement of the underlying asset prices, the association may inform hedgers of optimal hedging times to protect their assets. If

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[2] An alternative explanation for high implied volatilities may be a result of the imperfect substitutability across moneyness.

volatility skew shifts can accurately identify periods exposed to a higher "market crash" probability, then the additional "crash premium" may well be worth the expense to protect assets with a put option. Of course, if increased implied volatility cannot be linked to higher "market crash" probabilities, then the extra "crash premium" may be an inefficient use of funds and simply a function of market liquidity.

The remainder of the paper is formatted as follows. Section II outlines the empirical data and methodology, including the model for estimating the predictive power of the implied volatility measures. Section III reports the results derived from the model. Section IV summaries the key results of the paper and suggests some possible research extensions.

II. Methodology and Data

A. Methodology

In order to identify the information content available within implied volatilities, put and call options are sorted across moneyness and maturity. By sorting the options into various bins, the shape of the cross-sections can be captured to highlight the differences between smiles, smirks, and sneer patterns. For example, a volatility smirk is captured if 5% OTM puts have a higher implied volatility than put options ATM, and the ATM put options have an implied volatility higher than the 5% ITM put options. As Bates (2000) points out, it is necessary to distinguish between calls and puts, as higher crash concerns will result in higher implied volatility for OTM puts than the corresponding ITM calls.

We calculate implied volatilities via the Black-Scholes model. Actual market-traded prices for the associated call and put options are inputted into the Black-Scholes model, yielding implied volatility values for European-style options. The implied volatility values are then adjusted for the early exercise feature using the methodology in Barone-Adesi and Whaley (1987). The S&P 100 index (the underlying asset) pays dividends, but the dividend payouts are small in magnitude and not clustered through time, avoiding any dividend-induced valuation jumps.[3] It is critical that we use the American adjusted Black-Scholes implied volatility, since the model's misspecification does not account for stochastic volatility and jumps. As a result, the implied volatility of the options should contain information about jumps and/or stochastic volatility premiums. We will address potential measurement errors in implied volatility shortly.

In order to capture the shape of the skew, three variables are created. The first variable, $\Delta\sigma^{P}_{do,o}$ ($\Delta\sigma^{C}_{o,do}$), quantifies the difference in implied volatility levels between a DOTM put (OTM call) option and the related OTM put (DOTM call) option. The second variable, $\Delta\sigma^{P}_{do,a}$ ($\Delta\sigma^{C}_{a,do}$), quantifies the difference in implied volatility levels between a DOTM put (ATM call) option and the related ATM put (DOTM call) option. The third variable, $\Delta\sigma^{P}_{do,i}$ ($\Delta\sigma^{C}_{i,do}$), quantifies the difference in implied volatility levels between a DOTM put (ITM call) option and the related ITM put (DOTM call) option.

We define moneyness as $K/S(t)e^{rT}$, where K is the strike price, $S(t)$ is price of the index at time t, r is the risk-free rate and T is the time to maturity of the option. The moneyness categories are similar to those given in Bakshi and Kapadia (2003). DOTM put options are assigned to a moneyness interval of .875 to .925. OTM puts and ITM call options are assigned to a bin interval of .925 to .975. ATM options include the interval from .975 to 1.025. OTM calls and ITM puts have an interval of 1.025 to 1.075. And DOTM calls are assigned to the 1.075 to 1.125 bin.[4]

As shown by Hentschel (2003), inverting individual OTM and ITM options can result in incorrect inferences on the implied volatility if the option price is measured with error. By examining multiple implied volatilities over each category, individual option measurement errors can be greatly mitigated. As such, the average implied volatility within the categories will allow comparison between sections of the ITM side of the implied volatility curve and the related sections of the OTM side to capture the skewness. The strike prices of all traded options are measured against the last reported trade of the underlying asset.

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[3] See Christensen and Prabhala (1998).

[4] For example, the .875 to .925 moneyness interval includes options with strike prices that are approximately between 12.5% and 7.5% below the current level of the forward price of the index.

We attempt to identify investors' option-market behavior associated with near-term market declines and increases. As such, it is important to control for macroeconomic changes that affect implied volatilities. There is a well-established link between the term structure of interest rates and future economic activity within the United States and other countries.[5] Of special interest to our study is the timing link between an inverted (or inverting) yield curve and subsequent economic downturns, notably recessionary periods in the economy. To control for the economic changes, a term structure of interest rates variable is included (TS). By constructing the time varying difference between the 10-year Treasury Bond and the 1-year Treasury Note, the information content associated with macroeconomic issues can be controlled.

As noted by Pan (2002) and others, the general level of risk in the options market increases as volatility levels rise. Thus, a measure of overall option market volatility is an important control. Since ATM options typically have the smallest pricing bias, ATM put (call) implied volatility is chosen as the control variable, designated by σ_a^P (σ_a^C).[6]

We are particularly interested in the overall sense of movement in the OTM side of the volatility curve. As such, several factors that could mitigate or enhance skew changes must be controlled for to help reveal the actual information innovations that are manifested within implied volatility curve changes. George and Longstaff (1993), and others, link cross-sectional differences in bid-ask spreads in the S&P 100 index option market to trading activity. Consequently, average percentage bid-ask spreads for OTM puts (calls) are included as controls, denoted as BA_o^P (BA_o^C). With higher uncertainty in the market, investors should expect wider bid-ask spreads, consistent with the conclusions in Bollen and Whaley (2004), which may have additional or independent predicative power beyond the volatility skew.

Recognizing the likely participation of both hedgers and speculators within the options market, and to address illiquidity issues for OTM put and call options, two controls are developed. We construct an open interest control variable, OI_o^P (OI_o^C), to

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[5] Chan, Karceski, and Lakonishok (1998) provide evidence that the interest rate term premium performs well as a macroeconomic factor in capturing return co-movements.

[6] Hentschel (2003) discusses the potential measurement error in inverting option prices using Black-Scholes with small pricing errors. He documents that the pricing errors are significant for OTM and ITM options. ATM implied volatility has, by comparison, fewer problems when inverting prices.

help capture the effects of hedgers entering and exiting the market, since new OTM put (OTM call) positions should be opened when more hedgers believe there is an increase in the likelihood of a market crash (increase). An OTM put (call) volume control variable, V_o^P (V_o^C), is introduced to capture the effects of changing speculator positions driven by the expectation of price movements, but not necessarily a crash (spike). Also, with this series of volume-related variables, we hope to negate any measurement error that a few trades in thinly traded options might introduce into the results.[7]

To understand the additional information held within implied volatilities, it is key to evaluate the role of options' maturity structures. It is reasonable to believe that "market timing" is a difficult task even when an option trader believes he has superior information. It is also well documented that jump-concerns are more prevalent for short maturities, highlighted by muted long-term skews. To address these concerns and to better understand the maturity structure of options, three different days-to-maturity intervals are evaluated: 10 days to 30 days, 31 days to 60 days, and 61 days to 90 days. Options with maturities less than 10 days are eliminated from the sample to avoid excessive measurement error that is often embedded within short-maturity options.[8] An impending market crash or spike upward should materialize itself in greater magnitude within the 10 to 30 day interval, with diminishing impact in 31 to 60 days and 61 to 90 days-to-maturity intervals.

To mitigate potential measurement error, all options assigned to a specific maturity bin (e.g. 10-30 days) are grouped together. Each grouping of options is then evaluated together, so the results are an average for a particular group. For example, an option with 15 days to maturity is grouped in the 10-30 days bin. All options contained within the 10-30 days bin are always the near-term month expiration option. Options within the 31-60 days are the 2nd near-term month expiration, and so on. Consequently, all options grouped in the same maturity bin expire on the same day and the evaluations do not suffer from multiple confounding expiration dates.

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[7] See Jorion (1995) and Hentschel (2003).

[8] See Harvey and Whaley (1992).

B. Model

If investors have increased aversion to negative market movements, the information will manifest itself within the volatility skew. To assess this it is necessary to define what a market crash is. We define large market movements as a given percentage change in the index over a given day. These threshold values, v, are set at 3% and 4%, which corresponds to the top 1% and 0.5% of all daily returns over the period respectively. Lower values could have been selected, but these daily movements are considered economically meaningful. Negative jumps (circles) and positive jumps (squares) are highlighted in Figures 1, 2 and 3. As the figures show, jumps can be clustered together, and tend to occur during periods of high volatility. Figure 1 includes the VIX index, demonstrating the relationship between periods of high volatility, and large daily movements. Figures 2 and 3 highlight certain sub-periods where there were multiple large daily jumps. In particular, notice that jumps can be clustered together, and a negative jump can be subsequently followed by a positive jump. Consequently, it is important not only to examine a jump as a stand-alone event, but also whether a jump leads or follows another jump, and whether that jump is positive or negative.

A probit model is employed to capture the information content in the volatility skew to determine the association between the severity of the skew and the probability of a market crash or spike upward. The probit model is used to analyze the event that the S&P 100 index experiences a return, R_t, in excess of the absolute value of v from day t, the current day, to $t+\tau$, the expiration of the option, j. If a jump occurs at any time from day t to $t+\tau$, all option days, D, up to the day the jump occurred receive a value of one. Correspondingly, that is why there are 105 option day observations in the model when the market fell 4%.[9] If no jump occurs any time within the options maturity, all option days receive a value of zero.

The actual day the jump occurs is not important to the option holder. All that is important is that a jump occurs within the maturity of the option. Concurrently, it should not be expected that the jump could be perfectly forecasted, only that there is a general fear that the market is going to experience a decline at some point. Since OEX options

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[9] Over the estimation window, the market fell 4% seven times.

have American style execution, the option holder does not need to wait for maturity, and can sell or exercise the option right after the jump occurs. This reasoning leads to the implementation of two additional controls in the model. If there is a corresponding jump in the opposite direction that exceeds the jump definition, *v*, anytime prior to the day of the measured jump, *t*, the measured jump receives a value of zero. This is done to control for potential market microstructure effects such as profit taking and/or short-selling constraints, which could bias the results. Furthermore, the five business days after a measured jump are eliminated for similar reasoning.

The following model tests for the relationship using put contracts:

$$\begin{aligned}\text{Prob}(\text{D}_{\text{j,t->t+}\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^P_{SKEW,t} + \beta_2 \sigma^P_{a.t} + \beta_3 BA^P_{o.t} \\ + \beta_4 V^P_{o.t} + \beta_5 OI^P_{o.t} + \beta_6 TS_t) + e_t \qquad (1)\end{aligned}$$

where

$\text{Prob}(\text{D}_{\text{j,t}\rightarrow\text{t+}\tau} = 1)$	is the probability of jump occurring within the option window,
Φ	is the standard cumulative normal probability distribution,
$\Delta\sigma^P_{SKEW,t}$	is the difference in the implied volatility at time *t* of either: • $\Delta\sigma^P_{do,o}$ DOTM and OTM options • $\Delta\sigma^P_{do,a}$ DOTM and ATM options • $\Delta\sigma^P_{do,i}$ DOTM and ITM options
$\sigma^P_{a,t}$	is the average implied volatility of ATM options at time *t*,
$BA^P_{o,t}$	is the average percentage bid-ask spread of OTM puts at time *t*,
$V^P_{o,t}$	is the average volume of OTM puts at time *t* expressed in 100,000s,
$OI^P_{o,t}$	is the average open interest of OTM puts at time *t* expressed in 100,000s, and
TS_t	is the difference between the 10-year U.S. Treasury Bond rate and the 1-year U.S. Treasury Note rate at time *t*, and
α, β	are coefficients to be estimated.

The call model is similar, but $\Delta\sigma^P_{SKEW,t}$ becomes $\Delta\sigma^C_{SKEW,t}$, where the three categories become $\Delta\sigma^C_{o,do}$, $\Delta\sigma^C_{a,do}$, and $\Delta\sigma^C_{i,do}$ representing the difference in implied volatility between OTM and DOTM calls, ATM and DOTM calls, and ITM and DOTM calls, respectively. Also the BA, V, and OI variables are redefined to apply to OTM calls. Thus the call model is:

$$\text{Prob}(\text{D}_{\text{j,t->t+}\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^{C}_{SKEW,t} + \beta_2 \sigma^{C}_{a.t} + \beta_3 BA^{C}_{o.t} + \beta_4 V^{C}_{o.t} + \beta_5 OI^{C}_{o.t} + \beta_6 TS_t) + e_t \tag{2}$$

The appropriate model is initially applied to call and put options in the 10-30 day maturity bin. In subsequent tests, the model will then be used to evaluate longer maturities.

C. Ex-ante Expectations

There are four scenarios that are explicitly examined: market crashes and upward spikes using put and call contracts. We first examine the case of significant market declines. If there is information contained within the volatility skew, and investors have aversion to market crashes, our expectation for equation (1) is that $\beta_1>0$ for all definitions of the skew variable cases using put contracts. The positive β_1 coefficients are reflective of an increase in the implied volatility skewness on the OTM side of the put curve when a jump occurs. For market crashes, the DOTM and OTM puts will become more valuable, so their implied volatilities will likely increase compared to ATM and ITM put implied volatilities whose owners have little reason to trade. This implies that a positive coefficient β_1 is associated with an increase in the probability of a market decline. In addition, since volatility and the occurrence of jumps are related, we also expect that $\beta_2>0$.

For the call contracts using the model in equation (2), there are two probable scenarios. If investors have greater aversion to crashes than upward spikes, consistent with the concept of a negative jump premium as proposed in Pan (2002) and Bates (2000), β_1 may be of either sign but will be statistically insignificant.[10] However, if the market reacts to demand pressures of dealers and end-users[11] by changing the implied

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[10] It is possible that here is both a negative jump premium for the probability of a market crash and a positive jump premium for the probability of a market spike that results in a net negative premium; however, the models in Pan (2002) and Bates (2000) depict an single affine-Gaussian jump premium. As such, β_1 should be statistically indistinguishable from zero for the call option model.

[11] See Garleanu, Pedersen, and Poteshman (2005).

volatilities of the call options, we expect β_1 to be negative and statistically significant.[12] Consistent with the belief that information is embedded in the implied volatility curves for both put and call options, we expect β_1 to be negative and statistically significant. Additionally, as in the case for the put contracts, we expect $\beta_2>0$.

This leads to our first two formal hypotheses:

Hypothesis 1a: In periods of high volatility, when the market experiences a significant market decline, the put volatility skew in prior days will be more negatively skewed than on low volatility days and when no market crashes occur.

Hypothesis 2a: In periods of high volatility, when the market experiences a significant market decline, the call volatility skew in prior days may be more negatively skewed than on low volatility days and when no market crashes occur.

To test for symmetry in option markets, we explore the case of positive jumps. For put contracts, our expectation is that $\beta_1<0$. The rational is that positive jumps traders would be willing to sell puts for lower implied volatility if there is an expected market increase. However, it is plausible that β_1 may be insignificant if the market shows less aversion to upward spikes, with traders less likely to adjust the put volatility skew in response. The coefficient for $\sigma^P_{a,t}$, β_2, is expected to be positive, consistent with higher volatility conditions regardless of the direction of the jump.

Our expectation for the call options in the advent of a market upward spike is for $\beta_1>0$. If the market expects a large positive movement, then DOTM calls should be expensive relative to ITM calls compared to non-jump periods. The arguments raised earlier against a positive jump premium still stand; however, we expect the information innovation related to a near-term market spike to materialize in the put implied volatility curve. As with the other conditions of significant market movements, we expect $\beta_2>0$.

This leads to our second set of hypotheses:

Hypothesis 1b: In periods of high volatility, when the market experiences a significant market increase, the put volatility skew in prior days may be more positively skewed than on low volatility days and when no market spikes occur.

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[12] A negative coefficient for $\Delta\sigma^C_{o,do}$ is equivalent to a positive coefficient for $\Delta\sigma^C_{do,o}$. For the call implied volatility curve, our measure for DOTM to OTM value is calculated as OTM-DOTM. For the put curve, we use DOTM-OTM.

Hypothesis 2b: In periods of high volatility, when the market experiences a significant market increase, the call volatility skew in prior days will be more positively skewed than on low volatility days and when no market spikes occur.

Finally, since jump premiums are strongest in shorter maturity options, in part due the short-run inability to recover from an exposure to a significant market movement in either direction, our expectation is that longer-term volatility skews will have less information about future market crashes and spikes upward than shorter-term volatility skews. This is consistent with the empirical observation of muted longer-term skews in equity options. This leads to our third hypothesis:

Hypothesis 3: For both puts and calls, as the maturity of the option increases, longer-term volatility skews have little predictive power in forecasting future crashes/spikes due to longer time to recovery.

It is not clear how the coefficients for the percentage bid-ask spread control variable (β_3) will react to market crash conditions. Increasing risk associated with increased volatility and decreasing spreads associated with increasing volume are likely to have mitigating effects upon each other. As such, it is not clear ex-ante the directional signs for coefficients for the percentage bid-ask spread control variables, or if OTM put and call options will have the same sign. The same uncertainty exists for market spikes; therefore, there are no definitive ex-ante expected directional signs for the coefficients during market positive jumps.

Ex-ante, the coefficient for the put open interest expected sign is $\beta_5>0$ for market crashes. For call options, the sign should be reversed. For market spikes upward we expect $\beta_5<0$ for the put contracts, while the coefficients for call options should be positive. This expectation is consistent with increased trading of put (call) options when option traders believe there is an increased probability of a market crash (spike). Hedgers are likely to seek an increase in their put positions when they believe the probability of a market crash increases. A caveat is necessary for our expectations. If there is asymmetric information in the market and the better-informed traders are options traders, it is possible that it might be hard to find an offsetting buyer for new open put positions. This could lead to little change in the open interest variable, or an impact linked to the restriction of the supply for OTM put contracts. The reverse could exist for the call option open interest when there is a market increase.

The volume control variable is adopted to capture the effects of illiquidity in the market. Volume will also likely capture the effects of increased speculator activity in the marketplace. As such, we expect the coefficient β_5 to be positive during all times of large market movements, consistent with an increased dispersion of market expectations.

For the term structure of interest rates control variable, the expectation is that the coefficient $\beta_6<0$ if a crash is likely to occur. As noted previously, there is a negative relation between narrowing or inverting term structures of interest rates and general economic activity. Therefore, ex-ante, a negative coefficient for the term structure of interest rates is likely to be associated with increases in the probability of a market crash for call and puts. By contrast, for market spikes upward, the coefficient should have a positive sign.

D. Data

Several sources are utilized to acquire the data. Daily S&P 100 index option prices are secured via Goldman-Sachs. The data set covers the period January 1996 through December 2002. The data includes option trades covering a variety of strike prices, providing a rich range of moneyness coverage. Options with prices below $0.25 are removed from the sample. Option maturities range from 1 to 360 days, resulting in more than 300,000 total observations over the sample period.

Daily best closing bid and ask prices are reported; so, all option prices in the sample are set to be the mid-point of the two reported observations. Daily best closing bid and ask prices for OTM puts (calls) are scaled by the mid-point price to create the bid-ask control variable. Any option that has a zero bid price is removed from the sample. Daily open interest and volume for each option traded are collected, so the open interest and volume control variables are constructed by aggregating both varaibles for all options within the OTM moneyness classification (e.g. open interest of OTM puts).

The daily settlement value of the S&P 100 index is collected from the CBOE and is adjusted for dividends. Values for the 10-year U.S. Treasury Bond and the 1-year U.S. Treasury Note are assembled from data supplied by the Federal Reserve.

III. Results

A. Descriptive statistics and preliminary findings

For the sample period covering January 1996 through December 2002, there are 1760 option trading days reported. Within the sample period, there are 26 trading days where the S&P 100 index experienced at least a –3% daily valuation decline, seven days with at least a –4% daily valuation decline, 31 days with a daily market gain of 3% or more, and five days with a positive daily jump of 4% or greater.

Descriptive statistics for the entire sample are presented in Table 1. Moneyness based maturity bins ranging from DDOTM (deep-deep-out-of-the-money) to DDITM (deep-deep-in-of-the-money) are presented with the representative mean implied volatility, standard deviation of the implied volatility, number of observations, percentage bid-ask spread, volume, and option interest. While not all of the moneyness bins are used in estimation due to small number of observations or low liquidity, all are shown to present an idea of the shape of the skew at each category. As is evident in Panel A, pronounced implied volatility curve skewness exists for both puts and calls for the 10-30 day maturity bin. The skewness is much less pronounced for longer maturities, with a 3% drop in OTM puts for the 31-60 day and 61-90 day bins. This appears consistent with hypothesis 3 and the loss of forecasting ability in longer maturity volatility skews.

For Panel B, it is important to note the relative lack of volume and open interest for ITM options compared to OTM options. For example, the 10-30 day maturity ITM put options have an average volume of 175 (in 100,000s) compared to the OTM put volume of 1611. Since options on the ITM side of the volatility curves are traded less frequently than the OTM side, we use the OTM moneyness bins to construct the control variables employed in equations (1) and (2). This choice of control variables will give a more representative depiction of the changes in the shape of the OTM side of the put and call implied volatility curves, capturing information innovations during periods of market crashes and upward spikes.

Table 2 reports the means, standard deviations, and number of observations for the differences in implied volatility between DOTM and OTM, DOTM and ATM, and DOTM and ITM put and call options between 10-30 days to maturity. The options are segmented by periods when a jump occurs, D=1, and when no jumps occur, D=0. For puts, the mean value of $\Delta\sigma^{P}_{do,o}$ is significantly higher, at the 1% level, when the market experiences a 3% or 4% crash, than when it does not. For $\Delta\sigma^{P}_{do,a}$, the same result holds with significance at the 1% level for 3% and 4% crashes. These results affirm the accentuation of the skew pattern for the OTM side of the volatility curve for puts in crash periods, as compared to a more muted effect when there is no jump. The ITM side of the put volatility curve does not react as strongly to crashes, with differences in means for $\Delta\sigma^{P}_{do,i}$ significant at the 5% level for 4% crashes but insignificant for 3% crashes. For positive jumps, the pattern of the volatility skew for the put curve as measured by the skewness variables is not statistically different for crash and non-crash periods.

For the call option volatility curve, the results during market crashes are mixed. While the OTM side of the curve shows some statistically significant evidence of changes during 3% crashes, the results weaken for 4% crashes. This inconsistency casts a doubt on any measurable predictability by the implied volatility of the call curve during times of market drops. However, the results for market revaluations by the OTM side of the call volatility curve provide strong preliminary evidence of forecast ability. The difference in means for $\Delta\sigma^{C}_{o,do}$ and $\Delta\sigma^{C}_{a,do}$ are significant at the 1% level for both 3% and 4% spikes upward. Additionally, during market spikes the ITM side of the call curve does not have statistically significant movement as measured by a change in the mean.

These results for the calls mirror the outcome of the put volatility curve, with the OTM side reflecting movement in the event of a crash for puts and movement in the event of an upward spike for calls. It should be reemphasized that the differences in means tests are rudimentary at best and do not necessarily cement the presence of forecast ability in implied volatilities. As such, this further motivates the use of the probit model described earlier to more completely examine the effects of changes in volatility curves while controlling for other important varying market conditions.

B. Short-term maturities

The probit model specified in equation (1) is applied to the put option data and the model specified in equation (2) is applied to the call option data. Both estimations employ the 10-30 days option maturities. The results are portrayed in Table 3 for both negative (market crashes) and positive (market gains) jumps of 3% and 4%.[13] Newey and West (1987) standard errors are used to correct the overlapping problem associated from inferring the implied volatility from the same option.

For put options, an increase in the difference between the implied volatility levels of DOTM put options and the related OTM put options ($\Delta\sigma^{P}_{do,o}$) is associated with a significant increase, at the 1% level, in the likelihood for both a 3% and 4% market crash. An increase in the difference between the implied volatility levels of DOTM put options and the related ATM put options ($\Delta\sigma^{P}_{do,a}$) is also associated with a significant increase, at the 1% level, in the likelihood of negative 3% and 4% market jumps.

An increase in the difference between the implied volatility levels of DOTM put options and the related ITM put options ($\Delta\sigma^{P}_{do,i}$) is associated with a significant increase, at the 1% level, in the likelihood of a negative market jump of 3% or 4%. Since the level of volatility is also significant, at the 1% level, the results here support hypothesis 1a. This suggests that prior to a large negative daily movement of at least 3%, the volatility skew is more negative.

In the case of upward market swings for put options, there is a change in the OTM side of the volatility curve, but in general it is not statistically significant. An increase in the difference between the implied volatility levels of DOTM put options and the related ATM put options ($\Delta\sigma^{P}_{do,a}$) does not yield statistically significant differences during market upswings. However, the results for the difference between the implied volatility

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[13] The results are presented for the difference between the levels of implied volatility across moneyness. Alternatively, relative implied volatility were used. The results of the relative implied volatility are available upon request and are not qualitatively different from the results presented below.

levels of DOTM put options and the related ITM put options ($\Delta\sigma^{P}_{do,i}$) is associated with a significant increase, at the 1% level, in the likelihood of a positive market jump of 3% and 4%. This finding is not compelling evidence for or against hypothesis 1b.

The overall result for the put implied volatility curve advances the idea that there is information embedded within the entire curve. In fact, the results are consistent with a general fear of a large devaluation in the market when the put implied volatility curve changes skewness. It seems that the short-termed nature of the 10-30 day to maturity options does not allow enough time for the market to correct itself in the event that a valuation fluctuation does occur. However, the empirics support that negative skewness in the OTM side of the put curve is associated with an increase in the probability of a market crash. The empirics also support that increase in the negative skewness in the ITM side is associated with a market valuation change, but whether the valuation change will be a market crash or an upward spike is unclear.

Examining the evidence for call options, the results are generally the opposite of those for put options. Note that the negative coefficients for the difference between an ITM call and a DOTM call is akin to a positive coefficient for the difference between a DOTM call and an ITM call, due to the construction of the variables. As such, the negative coefficients for $\Delta\sigma^{C}_{i,do}$ shown for the +3% and +4% jumps can be interpreted as an increase in the probability of an upward spike.

For the ITM side of the call option curve during market crashes, the coefficients for $\Delta\sigma^{C}_{i,do}$ are statistically insignificant. However, these coefficients are significant, at the 1% level, for upward spikes. For the difference between ATM call options and DOTM call options ($\Delta\sigma^{C}_{a,do}$), all coefficients are significant for both market crashes and upward spikes. Similar to the results for $\Delta\sigma^{P}_{do,i}$, the coefficients for $\Delta\sigma^{C}_{o,do}$ are statistically significant for both market crashes and market spikes upward. This suggests there is little to no information in the ITM call volatility skewness when there are market declines, consistent with the suggested weak or no pattern offered in hypothesis 2a, but it does contain information when there are upward market spikes as offered in hypothesis 2b.

For market crashes, the percentage bid-ask spread coefficients have a definitive pattern, although the level of significance is not clear. The coefficients are all negative for the –3% and –4% movements, but the only statistical significance is with the –3% calls. The evidence suggests that bid-ask spreads do not play an important role in forecasting market crashes and that market crashes are not associated with an increased uncertainty through a lack of liquidity that often is manifested within a widening of the spreads.

Bid-ask spreads seem to be more important for market spikes upward for both puts and calls. All coefficients for the bid-ask control are positive and significant at least at the 5% level, and nine of the twelve coefficients are significant at the 1% level. This suggests that a widening of the relative bid-ask spreads is associated with a higher probability of a market spike upward.

The coefficients for the open interest control variables are not consistent with their predicted signs. For put options, increases in open interest are associated with a significant decrease, at the 1% level, in the probability of a market crash or positive market jump. The opposite is true for call options, where increases in open interest are associated with small and insignificant decreases in the probability of a market and with small and sometimes significant increases in the probability of positive market jumps.

Note the sign and significance for the coefficients on $OI_{o,t}^{P}$ and $OI_{o,t}^{C}$ when the market crashes. The coefficient for $OI_{o,t}^{P}$ is negative and significant while for $OI_{o,t}^{C}$ it is positive and insignificant. The sign for $OI_{o,t}^{P}$ implies that hedgers and/or speculators are closing short positions, which is the opposite of the predicted behavior since buying a put would protect against a market crash.[14] This is consistent with the possibility that hedgers are having a hard time finding an opposing trading partner to increase their put positions, or speculators cannot unload their exposed position, such as Garleanu et al (2005) claim. The volume variable is insignificant in both cases, implying that few parties are willing to take the opposite of these contracts.[15]

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[14] The alternative is that the long positions are being closed out, but this seems unlikely given the option is currently OTM and is acting as a hedge.

[15] While volume and open interest are correlated, this suggests multicollinearity is not a problem

Conversely, open interest and volume coefficients have predictable signs and achieve significance when the market spikes upward for puts and calls. For puts there is a negative sign on open interest and a positive sign for volume. For calls it is reversed. These results are consistent with ex-ante expectations.

It is also noteworthy to point out the strength of the term structure of interest rates variable. For put and call options, the term structure of interest rates is negatively associated with negative and positive market jumps, significantly so in all cases except for the –3% jump. This result suggests that an increase in the term structure variable, which moves the yield curve farther away from an inverted state, is a stabilizing force in the option market, but is inconsistent with our ex-ante expectations of a negative sign for market crashes and a positive sign for spikes upward.

C. Intermediate and longer term maturities

Table 4 modifies the probit models in equation (1) and equation (2) by changing the maturity bin setting to 31-60 days. Table 5 reports the results for the same probit model regression modified to a maturity bin setting of 61-90 days. For brevity, only the results of ±3% jumps are reported.

For market crashes, the predictive power of the implied volatilities for put options is not supported by a preponderance of the evidence presented for the longer maturity structures. The statistically significant positive coefficients reported for $\Delta\sigma^{P}_{do,o}$ in the 10-30 day maturity options are not statistically significant for the 31-60 day or the 61-90 day maturity bins. The evidence suggests that the OTM side of the put implied volatility curve is not more skewed during periods of market crashes when compared to periods of non-crashes. While the coefficient for the ITM side of the curve ($\Delta\sigma^{P}_{do,i}$) is significant, at the 1% level, for 61-90 day options, the sign has changed from the 10-30 day bin and the coefficient for the 31-60 day options is insignificant. The results are consistent with a loss of predictive power for the put implied volatility curve for longer maturity options in the event of a market crash. The loss of predictive ability seems to hold for both the OTM side and the ITM side of the put curve.

These coefficient estimates are consistent with a market that is less concerned about the chances of a market crash, driving down the prices of OTM puts. This translates into a more positively sloped put implied volatility curve for longer maturities as compared to the 10-30 day skew. The evidence supports the conclusion that investors' fears of a possible crash are not reflected in longer maturity options as compared to 10-30 day options. The additional time to recover from a market crash seems to reduce the shift in skewness on the OTM portion of the put curve.

When the market upward spikes, the put curve has significantly less negative skewness compared to times without the upward movement. The coefficients for the OTM ($\Delta\sigma^{P}_{do,o}$) and ITM ($\Delta\sigma^{P}_{do,i}$) side of the volatility curve in both Tables 4 and 5 are significant at the 1% level. The negative coefficients are consistent with the findings for market crashes, suggesting cheaper OTM puts options if the market is going to spike upwards

For market crashes, the 31-60 day and 61-90 day call implied volatility curves appear to react similarly to the 10-30 day curve. The coefficients for the ITM side of the curve ($\Delta\sigma^{C}_{i,do}$) continue to have negative values, but are still insignificant. The coefficients for the OTM side of the curve ($\Delta\sigma^{C}_{o,do}$) continue to be negative. They are statistically significant for the 10-30 day and 61-90 day options but insignificant for the 31-60-day options.

For market spikes upward, the call curve shows little change when comparing the 31-60 day and 61-90 day options to the previously reported 10-30 day options. Both the ITM ($\Delta\sigma^{C}_{i,do}$) and the OTM ($\Delta\sigma^{C}_{o,do}$) coefficients remain negative and statistically significant. The call implied volatility curve shifts to a more positive skewness when there is a positive market jump.

The significance of the open interest variable for put options during market crashes vanishes with an increase in maturity. In fact, neither the open interest nor the volume variables are significant when the market experiences a crash (put or call) but the open interest is significant when the market has a revaluation for the 31-60 day maturity bin. Furthermore, when increasing to the 61-90 day maturity setting, the open interest variable is insignificant in every case. This suggests different trading strategies by hedgers when facing differing time horizons. The volume variable is insignificant in all cases except one for longer-term options, suggesting that speculators have little information at longer time horizons with which to change their portfolios.

The evidence for the longer-term maturities supports the claim in hypothesis 3 that the predictive ability of the skew weakens as maturity length increases, but only for the put volatility curve. Especially for positive market jumps, the call curve seems to retain its predictive skewness transformation. While it has been well documented that jumps and volatility are related, it interesting to note that the information within the tail of the skew is mitigated with an increase in option maturity, but the level of volatility is not. This may be related to the volatility risk premium versus the jump premium. As noted by Das and Sundaram (1999) and Doran and Ronn (2005), the volatility risk premium is a long-term effect, while jump premiums are a short-term phenomenon. Thus, this could explain some of the deterioration in the information content of the implied volatility curves over time.

D. Term Structure of Volatility

A possible concern with the prior estimation is that longer maturity option skews have information content, but the effect maybe diluted because the options are not near-term expiration. If there is a significant term structure of volatility (TSOV), then the effect of a possible crash/spike may be incorporated not only in the cross-section, but in the time-series as well. As such, control variables that account for the difference between the implied volatility for longer maturity options and the implied volatility of 10 to 30 day options are created for ATM options.[16] These variables are then added to equations (1) and (2). TSOV is measured for puts in equation (3) and for calls in equation (4).

The amended probit model is represented by the following for the put options:

$$\begin{aligned}\text{Prob}(\text{D}_{\text{j,t->t+}\tau} = 1) = \Phi(&\alpha + \beta_1 \Delta\sigma^P_{SKEW,t} + \beta_2 \sigma^P_{a.t} + \beta_3 BA^P_{o.t} \\ &+ \beta_4 V^P_{o.t} + \beta_5 OI^P_{o.t} + \beta_6 TS_t + \beta_7 TSOV^P_{a,t}) + e_t\end{aligned} \tag{3}$$

and for the call options:

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[16] For example, TSOV signifies the difference between the implied volatility of a 10-30 day maturity bin ATM put and the implied volatility of a 31-60 day maturity bin ATM put.

$$\text{Prob}(\text{D}_{\text{j,t->t+}\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^C_{SKEW,t} + \beta_2 \sigma^C_{a.t} + \beta_3 BA^C_{o.t} + \beta_4 V^C_{o.t} + \beta_5 OI^P_{o.t} + \beta_6 TS_t + \beta_7 TSOV^C_{a,t}) + e_t \qquad (4)$$

where

$TSOV^P_{a,t}$	is the difference between the average implied volatility of 10-30 day maturity ATM put options and longer-term ATM put options (31-60 or 61-90 days), and
$TSOV^C_{a,t}$	is the difference between the average implied volatility of 10-30 day maturity ATM call options and longer-term ATM call options (31-60 or 61-90 days).

The ex-ante expectations are that the TSOV variables are positively related to a market crash or spike upward for all options, since the jump fears should materialize in short-term options. It is unclear if there is information within the curves that is mitigated by TSOV, so the effect on the skewness on the OTM and ITM sides of the curves is unknown, ex-ante.

The columns labeled "with TSOV" in Tables 4 and 5 illustrate the results from the probit models in equations (3) and (4) for option maturity between 31-60 days and 61-90 days, respectively. Positive (market gains) and negative (market crashes) jumps are reported for the 3% threshold.[17] The results for both put and call options are presented.

For market crashes, the confounding significantly negative results reported for the coefficients for $\Delta\sigma^P_{do,i}$ in the 61-90 day maturity bin are negated when adding the TSOV control. While this coefficient remains negative, it is no longer statistically significant. This result strengthens the aforementioned evidence supporting hypothesis 3: predictive information within the put implied volatility skew weakens with longer maturities. This is consistent with the premise that the market fears a negative jump less when there is a longer remaining life of the option, since the market has a longer time to recover any lost value.

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[17] Results for the 4% threshold are available upon request, and do not deviate materially from the 3% threshold.

From the results in Tables 4 and 5, it appears that the inclusion of TSOV is necessary, especially for puts. Consistent with ex-ante expectations, the coefficient for TSOV is positive and significant at the 5% level or better in all eight put option regressions, and at the 1% level, for six of the eight call option regressions. Only the 31-60 day call options for market crashes result in an insignificant TSOV.

The results suggest that when looking at longer maturity options, it is necessary to account for TSOV effects, since jumps and volatility are related. TSOV does not, however, seem to mask information content in the put implied volatility curve during periods of crashes for longer maturity options. In fact, the overall shapes of the put and call curves are robust to the inclusion of the TSOV variable. Multiple authors have attempted to dissect the effect of volatility and jump premiums with limited success.[18] Currently there is much debate about the appropriate method, and while we make no qualitative statement about the correct methodology, it appears that cross-sectional and time-series data has to be jointly incorporated in estimation.

Our results suggest there is information contained within the volatility curves, but that the skewness is not uniform at all times. For put options, the OTM side of the curve is much more negative for short-term options during periods of market crashes than it is when there are no crashes. This negative skewness dissipates in longer-term options. The positive skewness that exists on the OTM side of the call options during market crashes also decreases with increases in the time to maturity. These results suggest that investors are leery of downward market moves when the options they hold are close to maturity. Market participants lose market crash fears as the option maturity increases, consistent with a widening time-window to rebound from a valuation decline. On the other hand, in the times of market upward spikes, the market loses any fear it may have had concerning a market crash short-term and turns much more bullish as the time-to-maturity bin increases.

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[18] Pan (2002), Eraker (2004), Doran (2005), and others have estimated parametric models by using both option and underlying prices to estimate multiple risk premia. As Broadie, Chernov, and Johannes (2006) point out, arriving at precise estimates is a quantitative challenge, since authors need to restrict either time-series or cross-sectional observations because the data is computationally intensive.

E. Robustness Checks: Alternative Specifications

i. Option's Delta

The initial specification defined moneyness using the option's strike price divided by the forward price of the underlying asset. While using this measure of moneyness is fairly intuitive, it ignores the fact that the likelihood of the option being exercised relies not only on the volatility, but the time to maturity as well. While we have accounted for the time to maturity aspect by separating the implied volatility into maturity bins, using an option's delta will allow all options to be grouped together. An option's delta accounts for both volatility and time to maturity. As Bollen and Whaley (2004) point out, an option's delta can be interpreted as the risk-neutral probability that the option will be exercised.

We adopt the five moneyness definitions given in Bollen and Whaley (2004), and shown in Table 6. Since most of the trading activity takes place between the DOTM options and ATM options, three measures of skewness are defined using these new moneyness categories as the difference between the implied volatility of,

$\Delta_{do,o}$ DOTM and OTM options,
$\Delta_{o,a}$ OTM and ATM options, and
$\Delta_{do,a}$ DOTM and ATM options.

Given our findings in the prior section suggesting a strong positive relationship between the shape of the put skew and a negative jump, we restrict our attention to this relationship. The revised probit model in equation (1) includes one of the three variables defined above and an additional control for the volatility between ATM and ITM options, defined as $\Delta_{a,i}$. The new model is then estimated using these new moneyness definitions assuming the same definition of a jump used previously. The results are reported in Table 7.

The findings in Table 7 for crashes of -4% or greater show a positive relationship between the shape of the put skew and a large negative jump; all three coefficients are significant at the 1% level. For the -3% crashes, the coefficients are positive but insignificant. This insignificance may be attributable to the negative relationship between the put skew for 31-60 and 61-90 day options, as shown in Tables 4 and 5. The coefficient on $\Delta_{a,i}$ is small and insignificant, suggesting no information in this part of the skew or that the infrequency of trading results in noisy estimates of volatility. The signs of all the other coefficients are as predicted. This suggests that our findings are robust to the definition of moneyness.

ii. Probability of a Crash/Spike

To test the implications our findings, the probability of a crash/spike is assessed using the marginal coefficients from the put and call probit model specified in equation (1) and (2).[19] The put skew variable, $\Delta\sigma_{do,o}^{P}$, is allowed to vary between 0% and 15%, the approximate minimum and maximum values for the put skew difference over the period. Additionally, the ATM implied volatility level varies between 10% and 30% while all other variables are kept at their mean values. To assess the probability of a spike upwards, the call skew variable, $\Delta\sigma_{o,do}^{C}$, is varied between -3% and 12%%, the approximate minimum and maximum values for the call skew difference over the period.. The probabilities of a crash/spike are reported in table 8.

The results show the informative nature of the put skew relative to the call skew, conditional on the level of implied volatility. At 10% levels of ATM implied volatility, the probability of a crash increases 10.22% when $\Delta\sigma_{do,o}^{P} = 0$ increases to $\Delta\sigma_{do,o}^{P} = 15\%$. At 30% ATM implied volatility the probability increase is 39.83%. This suggests that a negative jump is proportional not only to level of volatility, but also to the shape of the volatility skew.

The probabilities for the spikes upward using the call skew are only informative when the ATM implied volatility is at 30%. However, even the probabilities of a spike upward in the extreme case, $\Delta\sigma_{o,do}^{C} = -3\%$, is only 38.67%. This is approximately 50% of the probability of the put skew counterpart for the downward crash. This suggests that even though we document significant positive power for predicting a market spike

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[19] Results from the probit marginal effects model are available upon request

upward, the marginal effect of this prediction is very small. This result appears consistent with the one-sided notion that market fears and/or liquidity constraints about future precipitous price drops are reflected in higher implied volatility in OTM puts.

IV. Conclusion

Our findings suggest that there is predictive information content within the volatility skew, especially in the short-term. Consistent with prior literature and the notion of a negative jump premium, the put volatility skew has strong predictive power in forecasting short-term market declines. This result is robust to different definitions of moneyness and jump specifications. In addition, there is power in the call skew in predicting upward market spikes in the short-term; however, the magnitude of the prediction is quite small. The predictive power for both declines and increases appears to diminish as the time to maturity increases, even when a term-structure of volatility control is included. This general conclusion suggests that different risk premiums exist across time and the cross-section, and that negative jump concerns are stronger than positive jump concerns

We do not try to comment upon why there is a negative skew, but we accept that the market prices options with either an embedded jump premium, or that the skew is the result of market liquidity effects such as the cost of short-selling. However, regardless of the explanation for the skew, the shape of the skew contains information about future market movements. Our results are consistent with the possibility that there is both a positive and negative jump premium embedded in option prices, but the magnitude of the jump premium is much stronger for negative movements. This is interesting as it suggests our current single-price jump factor models are mis-specified.

There is information within the volatility curves and this information provides some predictive power in short-term options. We show that the predictive information for market crashes held in puts and calls dissipates rather quickly with increases in maturity. Given that it is a short-term phenomenon, and there are liquidity issues such as short-selling constraints, substantial barriers exist that limit the feasibility to dynamically hedge the potential crash/spike even if it can be forecast.

If liquidity is not a concern, then our results are of a practical importance, as the hedging implications for investors and companies are ample. If the volatility skew is the harbinger of bad or good news, then market participants can take an active role is protecting their market assets depending on their level of risk-aversion. Additionally, the skew may signal investment opportunities in the short-term for those willing to speculate on future market movements. This is not to say there are arbitrage opportunities, but a change in the volatility skew is more a reflection of a change in jump risk aversion. The traders willing to bear that risk can use the volatility skew ex-ante to profit from investors' increasing or decreasing risk attitudes.

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Figure 1
S&P 100 and Major Daily Moves

This figure shows the S&P 100 level from January 1996 through December 2002. The small circles document 3% or greater price drops over a given day. The large circles document 4% or greater price drops over a given day. The small squares document 3% or greater price increases over a given day. The large squares document 4% or greater price increases over a given day. The VIX index is included to show the relationship between jumps and high levels of volatility.

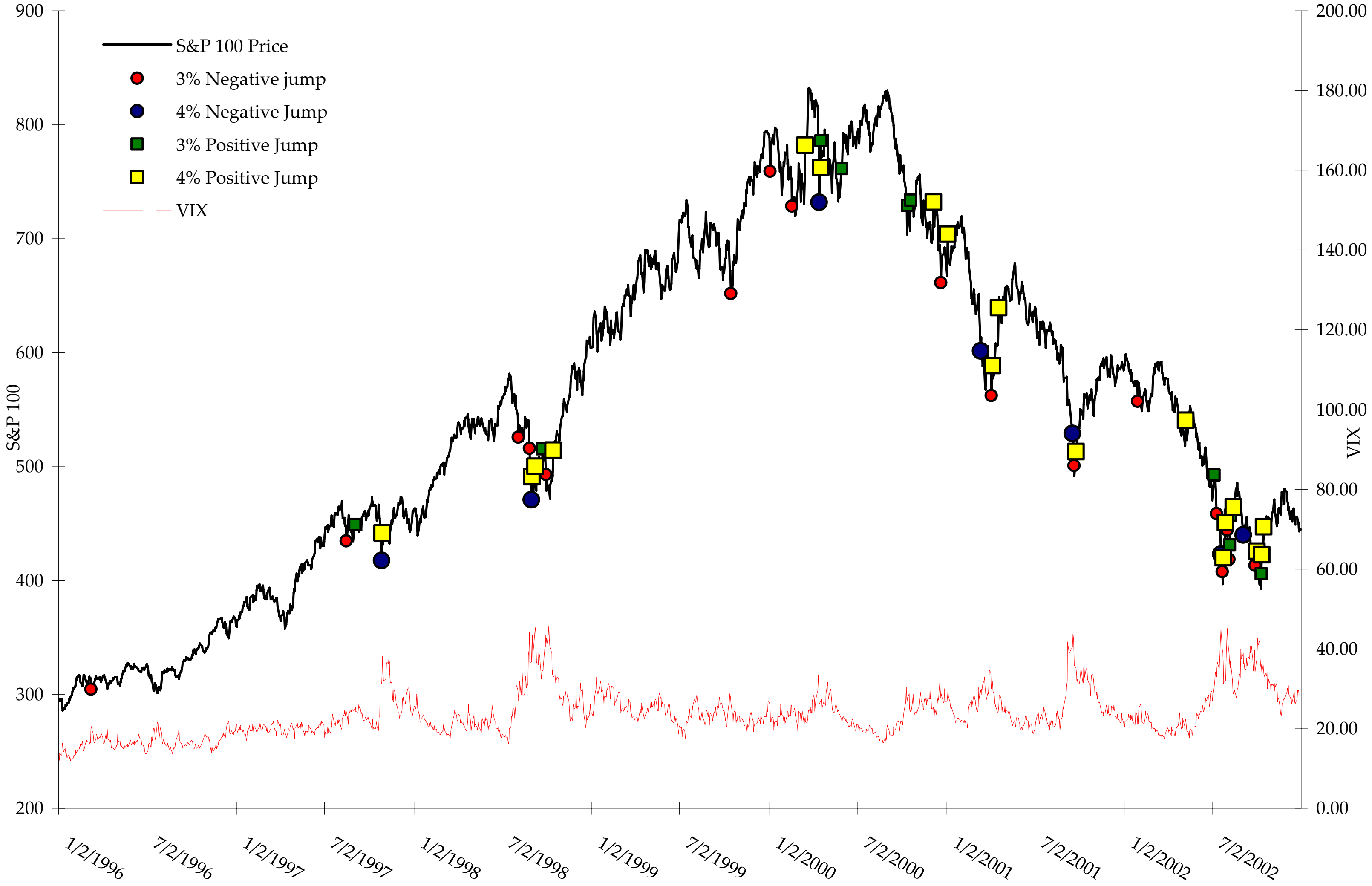

Figure 2

S&P 100 and Major Daily Moves: July 1998 through November 1998

This figure shows the S&P 100 level from July 1998 through November 1998. The small circles document 3% or greater price drops over a given day. The large circles document 4% or greater price drops over a given day. The small squares document 3% or greater price increases over a given day. The large squares document 4% or greater price increases over a given day.

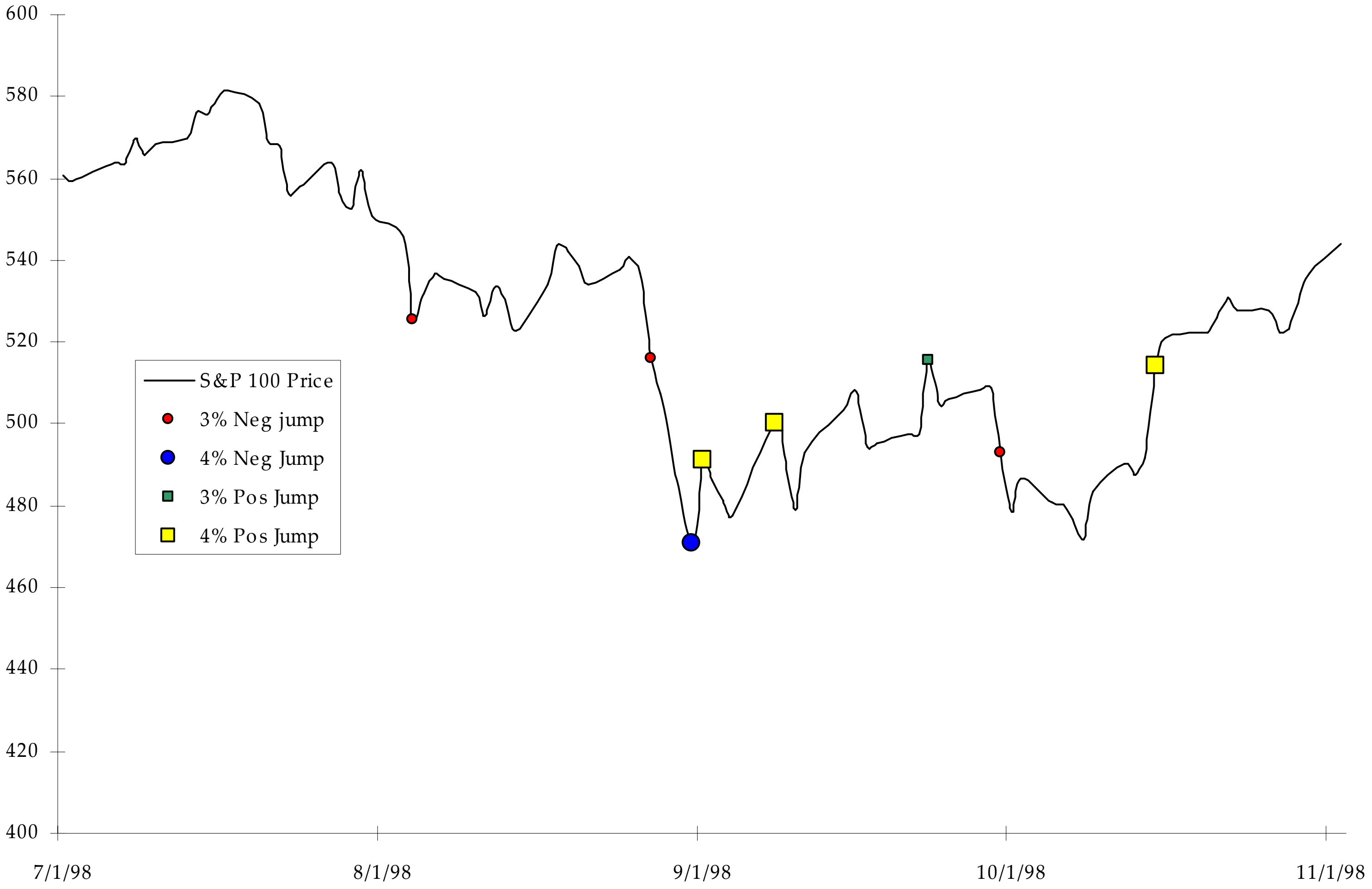

Figure 3

S&P 100 and Major Daily Moves: June 2002 through November 2002

This figure shows the S&P 100 level from June 2002 through November 2002. The small circles document 3% or greater price drops over a given day. The large circles document 4% or greater price drops over a given day. The small squares document 3% or greater price increases over a given day. The large squares document 4% or greater price increases over a given day.

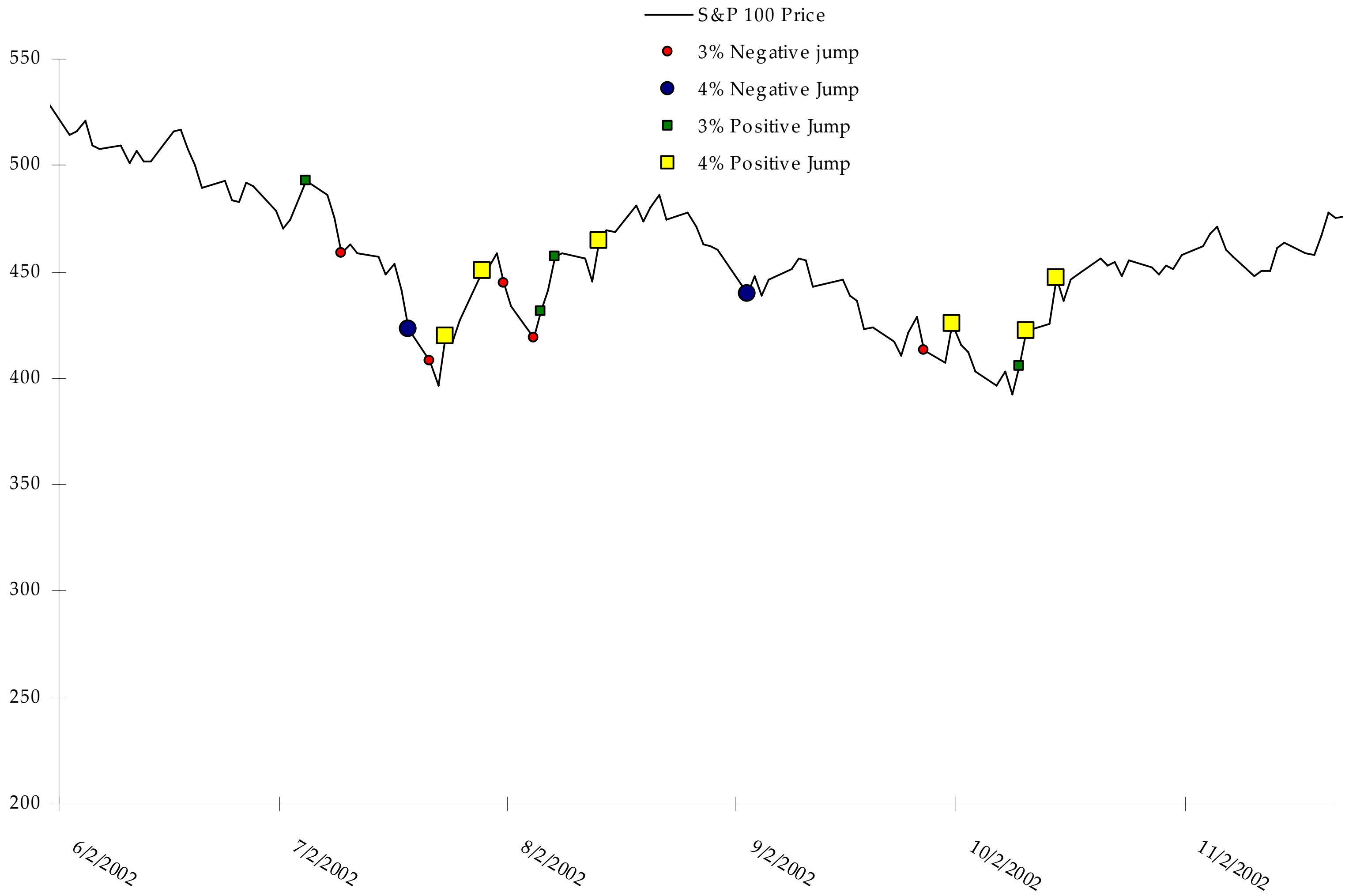

Table 1

Descriptive Statistics of Sample

This table reports summary statistics for the seven volatility bins for the three maturity classifications. Panel A reports the average implied volatility (Mean), standard deviation (SD), and number of observations (N), for each volatility bin over the 1996-2002 that qualified using the data screen. Panel B reports the average option percentage bid-ask spread (BA), volume (V), and open interest (OI) for each maturity/implied volatility bin.

Panel A		Call							Put						
Moneyness	K/Se^{rT}	< .875	.875 - .925	.925 - .975	.975 - 1.025	1.025 - 1.075	1.075 – 1.125	> 1.125	< .875	.875 - .925	.925 - .975	.975 – 1.025	1.025 – 1.075	1.075 – 1.125	> 1.125
		DDITM	DITM	ITM	ATM	OTM	DOTM	DDOTM	DDOTM	DOTM	OTM	ATM	ITM	DITM	DDITM
30 day	Mean	59.81%	39.24%	29.74%	22.97%	19.89%	20.70%	25.38%	37.15%	31.62%	27.34%	23.19%	23.87%	32.96%	54.32%
	SD	26.78%	13.40%	8.25%	6.21%	5.52%	4.91%	4.93%	7.18%	6.61%	6.31%	6.25%	8.05%	13.71%	24.78%
	N	1493	1686	1758	1760	1753	1111	241	1220	1677	1760	1760	1754	1337	893
60 day	Mean	35.99%	29.38%	25.93%	22.98%	20.60%	19.59%	20.30%	33.41%	28.75%	25.80%	23.16%	21.30%	21.48%	29.37%
	SD	7.61%	5.88%	5.53%	5.25%	4.97%	4.33%	3.79%	5.98%	5.43%	5.27%	5.14%	5.00%	4.52%	6.76%
	N	1488	1737	1757	1760	1760	1625	1039	1492	1739	1758	1760	1759	1588	980
90 day	Mean	33.84%	28.67%	25.54%	23.19%	21.20%	20.10%	20.02%	32.30%	28.16%	25.46%	23.32%	21.63%	20.91%	24.50%
	SD	6.02%	5.08%	5.08%	4.93%	4.72%	4.17%	3.44%	5.04%	4.88%	4.92%	4.81%	4.70%	4.29%	4.87%
	N	1163	1600	1753	1760	1760	1643	1119	1173	1614	1754	1760	1760	1630	1054

Panel B		Call							Put						
		DDITM	DITM	ITM	ATM	OTM	DOTM	DDOTM	DDOTM	DOTM	OTM	ATM	ITM	DITM	DDITM
30 day	BA	1.6%	2.5%	3.8%	4.8%	9.1%	20.5%	37.3%	23.5%	14.6%	8.4%	5.0%	4.3%	3.0%	1.9%
	V	3	32	224	2178	1735	651	303	480	696	1611	2500	175	32	4
	OI	62	378	1570	4199	4259	2880	2144	3241	3820	4795	4092	814	210	49
60 day	BA	1.7%	2.4%	3.3%	4.9%	7.4%	13.5%	33.1%	19.3%	10.4%	7.5%	5.7%	4.1%	3.0%	2.1%
	V	1	4	16	100	114	104	93	98	111	143	134	21	6	4
	OI	51	142	426	943	1075	968	1003	1153	1300	1341	934	334	126	49
90 day	BA	1.8%	2.4%	3.0%	4.2%	6.0%	8.7%	22.0%	14.3%	8.6%	6.9%	5.5%	3.9%	3.1%	2.2%
	V	0	2	4	31	43	39	28	36	41	46	62	14	3	1
	OI	77	86	159	413	499	450	505	443	540	573	557	244	103	46

Table 2

Descriptive Statistics of Volatility Skew

This table reports summary statistics of the difference between volatility skews of puts and calls given jump (D=1) and non-jump (D=0) periods for the 30-day maturity bin. $\Delta\sigma^{P}_{do,o}$, $\Delta\sigma^{P}_{do,a}$, and $\Delta\sigma^{P}_{do,i}$ denote the difference between the implied volatility of DOTM puts and OTM puts, ATM puts, and ITM puts, respectively. $\Delta\sigma^{C}_{o,do}$, $\Delta\sigma^{C}_{a,do}$, and $\Delta\sigma^{C}_{i,do}$ denote the difference between the implied volatility of DOTM calls and OTM calls, ATM calls, and ITM calls, respectively. (Mean) is the average difference between the implied volatility of the relevant two option groups, expressed in percentage difference. (SD) is the standard deviation of the implied volatility difference. (N) denotes the number of trading days that satisfy the binary jump variable. t-statistics test the difference in means between periods of jumps and non-jumps using unequal variances.

		Put			Call			Put			Call		
		$\Delta\sigma^{P}_{do,o}$	$\Delta\sigma^{P}_{do,a}$	$\Delta\sigma^{P}_{do,i}$	$\Delta\sigma^{C}_{o,do}$	$\Delta\sigma^{C}_{a,do}$	$\Delta\sigma^{C}_{i,do}$	$\Delta\sigma^{P}_{do,o}$	$\Delta\sigma^{P}_{do,a}$	$\Delta\sigma^{P}_{do,i}$	$\Delta\sigma^{C}_{o,do}$	$\Delta\sigma^{C}_{a,do}$	$\Delta\sigma^{C}_{i,do}$
		-3% Jump						+3% Jump					
D=0	Mean	4.04%	8.15%	7.33%	1.12%	4.37%	11.67%	4.10%	8.24%	7.51%	1.15%	4.41%	11.62%
	SD	1.68%	2.67%	6.45%	0.97%	2.40%	7.23%	1.67%	2.72%	6.46%	0.93%	2.24%	6.98%
	N	1271	1271	1271	774	774	774	1360	1360	1359	826	826	826
D=1	Mean	4.95%	9.34%	8.57%	1.73%	5.33%	10.86%	4.04%	8.06%	8.63%	1.80%	5.58%	11.31%
	SD	2.04%	3.44%	7.75%	1.40%	2.38%	4.90%	2.23%	3.15%	7.14%	1.47%	2.94%	5.32%
	N	238	238	237	181	181	181	155	155	155	138	138	138
	t-statistic	(5.90)**	(3.99)**	(1.82)	(4.34)**	(3.66)*	(1.30)	(0.25)	(0.55)	(1.49)	(4.17)**	(3.56)**	(0.44)
		-4% Jump						+4% Jump					
D=0	Mean	4.07%	8.21%	7.53%	1.22%	4.56%	11.63%	4.09%	8.22%	7.59%	1.19%	4.47%	11.49%
	SD	1.74%	2.77%	6.57%	1.02%	2.40%	6.90%	1.67%	2.70%	6.41%	1.02%	2.26%	6.82%
	N	1488	1488	1488	929	929	929	1464	1464	1463	916	916	916
D=1	Mean	5.00%	9.12%	9.11%	1.57%	4.86%	9.94%	4.08%	8.16%	8.63%	1.96%	5.86%	11.59%
	SD	1.70%	2.76%	6.00%	1.68%	2.46%	4.17%	2.40%	3.45%	7.63%	1.52%	3.09%	5.23%
	N	91	91	90	87	87	87	134	134	134	120	120	120
	t-statistic	(5.90)**	(2.52)*	(1.97)*	(1.62)	(0.87)	(2.51)*	(0.04)	(0.17)	(1.25)	(4.48)**	(3.90)**	(0.14)

** denotes statistical significance at the 1% level;
* denotes statistical significance at the 5% level.

Table 3

Probit Model Estimation Results for 10-30-Day Maturity Window

The results shown in this table are the parameter estimates for the 10-30 day maturity bin for call and put options. The put results come from the probit regression of equation 1; the call results are from equation 2. The dependent variable equals one if the option window contains a daily jump below(above) –3%(+3%) or –4%(+4%), zero otherwise. Standard errors are corrected by Newey-West procedures. The reported parameter values for $\Delta\sigma^P_{do,o}$, $\Delta\sigma^P_{do,a}$, and $\Delta\sigma^P_{do,i}$ represent the coefficients for the difference between the implied volatility of DOTM puts and OTM puts, ATM puts, and ITM puts, respectively . $\Delta\sigma^C_{i,do}$, $\Delta\sigma^C_{a,do}$, and $\Delta\sigma^C_{o,do}$ represent the coefficients for the difference between the implied volatility of DOTM calls and ITM calls, ATM calls, and OTM calls, respectively. σ^P_a and σ^C_a represent the coefficients for implied volatility of ATM put and call options. BA^P_o and BA^C_o represent the coefficients for the percentage OTM put and call bid/ask options. V^P_o and V^C_o represent the coefficients for the volume of OTM put and call options, and are expressed in 100,000s. OI^P_o and OI^C_o represent the coefficients for the open interest of OTM put and call options, and are expressed in 100,000s. TS represents the coefficients of the difference between the 10-year U.S. Treasury Bond rate and the 1-year U.S. Treasury Note rate. Absolute values of z-scores for the parameter estimates are reported in parentheses.

$$\text{Put Model} \; : \text{Prob}(D_{j,t->t+\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^P_{SKEW,t} + \beta_2 \sigma^P_{a.t} + \beta_3 BA^P_{o.t} + \beta_4 V^P_{o.t} + \beta_5 V^P_{o.t} + \beta_6 TS)_t + e_t$$

$$\text{Call Model} \; : \text{Prob}(D_{j,t->t+\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^C_{SKEW,t} + \beta_2 \sigma^C_{a.t} + \beta_3 BA^C_{o.t} + \beta_4 V^C_{o.t} + \beta_5 V^C_{o.t} + \beta_6 TS)_t + e_t$$

Puts	-3% Jump			-4% Jump			+3% Jump			+4% Jump		
$\Delta\sigma^P_{do,o}$	**7.08**			**8.92**			**5.65**			**6.47**		
	(2.76)**			**(3.27)****			**(1.88)**			**(2.01)***		
$\Delta\sigma^P_{do,a}$		**4.03**			**3.90**			**2.32**			**2.61**	
		(2.68)**			**(2.31)***			**(1.30)**			**(1.36)**	
$\Delta\sigma^P_{do,i}$			**2.84**			**3.75**			**3.12**			**2.64**
			(4.14)**			**(4.01)****			**(3.63)****			**(2.73)****
σ^P_a	9.62	9.63	9.90	7.07	7.07	7.39	10.94	10.89	11.11	12.83	12.72	12.85
	(13.45)**	(13.34)**	(13.49)**	(9.98)**	(10.23)**	(10.05)**	(13.20)**	(13.10)**	(13.86)**	(12.27)**	(12.05)**	(12.53)**
BA^P_o	-2.53	-3.07	-2.44	-0.40	-1.20	-0.55	4.29	3.72	4.78	6.19	5.40	6.26
	(1.80)	(2.23)*	(1.77)	(0.23)	(0.69)	(0.32)	(2.59)**	(2.31)*	(3.00)**	(3.87)**	(3.34)**	(3.95)**
V^P_o	8.48	6.71	7.45	-0.63	-2.27	-4.04	18.48	17.72	18.47	20.50	19.64	20.31
	(1.69)	(1.30)	(1.39)	(0.12)	(0.43)	(0.73)	(4.64)**	(4.39)**	(4.27)**	(4.68)**	(4.48)**	(4.30)**
OI^P_o	-6.38	-6.61	-6.12	-10.53	-10.66	-10.40	-11.29	-11.38	-11.89	-7.22	-7.39	-7.53
	(4.00)**	(4.17)**	(3.71)**	(5.86)**	(5.85)**	(5.49)**	(5.42)**	(5.32)**	(5.32)**	(2.97)**	(3.02)**	(2.99)**
TS	-16.38	-15.59	-15.31	-4.19	-3.38	-2.40	-19.15	-18.55	-18.40	-19.71	-18.89	-18.72
	(3.98)**	(3.78)**	(3.73)**	(0.80)	(0.65)	(0.46)	(2.86)**	(2.74)**	(2.71)**	(2.58)**	(2.43)*	(2.39)*
Constant	-3.03	-3.01	-3.06	-3.18	-3.05	-3.19	-4.20	-4.09	-4.30	-5.33	-5.17	-5.28
	(11.21)**	(11.04)**	(12.18)**	(10.63)**	(9.73)**	(10.91)**	(13.12)**	(13.27)**	(14.65)**	(15.61)**	(15.88)**	(16.51)**
Observations	1509	1509	1508	1579	1579	1578	1515	1515	1514	1598	1598	1597
Calls												
$\Delta\sigma^C_{i,do}$	**-6.86**			**-10.20**			**-25.86**			**-43.16**		
	(1.09)			**(1.31)**			**(3.34)****			**(5.07)****		
$\Delta\sigma^C_{a,do}$		**-10.99**			**-13.23**			**-18.64**			**-26.79**	
		(3.77)**			**(4.37)****			**(4.49)****			**(4.78)****	
$\Delta\sigma^C_{o,do}$			**-6.15**			**-7.32**			**-8.56**			**-12.41**
			(5.53)**			**(7.54)****			**(5.98)****			**(6.64)****
σ^C_a	9.83	12.16	12.11	6.68	8.75	8.40	15.59	17.35	16.32	23.08	24.39	22.46
	(6.82)**	(8.05)**	(9.60)**	(5.48)**	(7.45)**	(8.43)**	(9.38)**	(9.52)**	(10.85)**	(10.72)**	(9.73)**	(9.41)**
BA^C_o	-3.91	-4.24	-4.41	-0.55	-0.79	-0.53	7.33	6.51	6.49	8.90	7.16	6.37
	(2.23)*	(2.43)*	(2.57)*	(0.28)	(0.40)	(0.28)	(3.02)**	(2.57)*	(2.65)**	(4.06)**	(2.82)**	(2.52)*
V^C_o	30.16	26.76	25.91	25.14	23.21	24.03	-32.98	-36.90	-37.47	-25.53	-30.93	-30.49
	(1.56)	(1.37)	(1.39)	(1.80)	(1.71)	(1.71)	(2.65)**	(3.02)**	(3.16)**	(2.40)*	(2.73)**	(2.50)*
OI^C_o	12.06	12.06	9.86	-4.11	-2.98	-4.80	22.52	23.71	21.65	10.78	13.74	11.45
	(1.80)	(1.76)	(1.47)	(0.82)	(0.59)	(0.90)	(3.76)**	(3.97)**	(3.62)**	(1.86)	(2.42)*	(2.00)*
TS	-8.90	-14.02	-13.04	7.81	3.29	4.85	-31.10	-35.40	-32.72	-44.40	-52.05	-47.48
	(1.83)	(2.88)**	(2.80)**	(1.30)	(0.58)	(0.86)	(4.27)**	(4.76)**	(4.44)**	(4.86)**	(5.05)**	(4.40)**
Constant	-3.05	-3.11	-2.92	-3.04	-3.02	-2.81	-5.37	-5.17	-4.87	-7.38	-6.82	-6.26
	(9.38)**	(10.59)**	(10.70)**	(9.83)**	(10.01)**	(9.63)**	(10.88)**	(10.65)**	(11.01)**	(14.54)**	(14.52)**	(13.38)**
Observations	954	954	954	1015	1015	1015	963	963	963	1035	1035	1035

* significant at 5%; ** significant at 1%

Table 4

Probit Model Estimation Results for 31-60 Day Maturity Window

The results shown in this table are the parameter estimates for the 31-60 day maturity bin for call and put options. The put results come from the probit regression of equations 1 and 3; the call results are from equations 2 and 4. The dependent variable equals one if the option window contains a daily jump below(above) –3%(+3%), zero otherwise. Standard errors are corrected by Newey-West procedures. The reported parameter values for $\Delta\sigma^{P}_{do,o}$, $\Delta\sigma^{P}_{do,a}$, and $\Delta\sigma^{P}_{do,i}$ represent the coefficients for the difference between the implied volatility of DOTM puts and OTM puts, ATM puts, and ITM puts, respectively . $\Delta\sigma^{C}_{i,do}$, $\Delta\sigma^{C}_{a,do}$, and $\Delta\sigma^{C}_{o,do}$ represent the coefficients for the difference between the implied volatility of DOTM calls and ITM calls, ATM calls, and OTM calls, respectively. σ^{P}_{a} and σ^{C}_{a} represent the coefficients for implied volatility of ATM put and call options. BA^{P}_{o} and BA^{C}_{o} represent the coefficients for the percentage OTM put and call bid/ask options. V^{P}_{o} and V^{C}_{o} represent the coefficients for the volume of OTM put and call options, expressed in 100,000s. OI^{P}_{o} and OI^{C}_{o} represent the coefficients for the open interest of OTM put and call options, expressed in 100,000s. TS represents the coefficients of the difference between the 10-year U.S. Treasury Bond rate and the 1-year U.S. Treasury Note rate. $TSOV^{P}_{a}$ and $TSOV^{C}_{a}$ represent the coefficients of the difference between the ATM 30-day and 60-day implied volatility for the put and the call options, respectively. Absolute values of z-scores for the parameter estimates are in parentheses

Put Model : $\text{Prob}(D_{j,t\text{->}t+\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^{P}_{SKEW,t} + \beta_2 \sigma^{P}_{a.t} + \beta_3 BA^{P}_{o.t} + \beta_4 V^{P}_{o.t} + \beta_5 V^{P}_{o.t} + \beta_6 TS_t) + e_t$

Call Model : $\text{Prob}(D_{j,t\text{->}t+\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^{C}_{SKEW,t} + \beta_2 \sigma^{C}_{a.t} + \beta_3 BA^{C}_{o.t} + \beta_4 V^{C}_{o.t} + \beta_5 V^{C}_{o.t} + \beta_6 TS_t) + e_t$

Put Model with TSOV : $\text{Prob}(D_{j,t\text{->}t+\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^{P}_{SKEW,t} + \beta_2 \sigma^{P}_{a.t} + \beta_3 BA^{P}_{o.t} + \beta_4 V^{P}_{o.t} + \beta_5 V^{P}_{o.t} + \beta_6 TS_t + \beta_7 TSOV^{P}_{a,t}) + e_t$

Call Model with TSOV : $\text{Prob}(D_{j,t\text{->}t+\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^{C}_{SKEW,t} + \beta_2 \sigma^{C}_{a.t} + \beta_3 BA^{C}_{o.t} + \beta_4 V^{C}_{o.t} + \beta_5 V^{C}_{o.t} + \beta_6 TS_t + \beta_7 TSOV^{P}_{a,t}) + e_t$

Puts	-3% Jump				+3% Jump			
$\Delta\sigma^{P}_{do,o}$	**2.28**	**10.44**			**-40.39**	**-26.83**		
	(0.38)	**(1.61)**			**(4.54)****	**(2.88)****		
$\Delta\sigma^{P}_{do,i}$			**-0.98**	**3.02**			**-14.99**	**-8.32**
			(0.41)	**(1.12)**			**(4.40)****	**(2.25)***
σ^{P}_{a}	6.18	5.01	6.45	5.09	12.71	10.27	13.32	10.53
	(5.90)**	(5.05)**	(6.08)**	(5.03)**	(10.15)**	(7.83)**	(10.18)**	(7.52)**
BA^{P}_{o}	6.75	4.51	6.41	4.37	17.31	13.53	17.34	13.90
	(3.26)**	(2.08)*	(3.05)**	(2.00)*	(6.47)**	(4.77)**	(6.47)**	(4.92)**
V^{P}_{o}	8.23	3.84	8.03	3.68	16.89	15.20	18.08	14.83
	(0.63)	(0.31)	(0.61)	(0.30)	(0.80)	(0.72)	(0.87)	(0.71)
OI^{P}_{o}	2.77	0.03	3.43	0.52	-34.59	-40.70	-34.05	-40.56
	(0.69)	(0.01)	(0.85)	(0.13)	(4.19)**	(4.60)**	(4.09)**	(4.56)**
$TSOV^{P}_{a}$		**7.79**		**7.74**		**13.25**		**12.86**
		(3.25)**		**(3.11)****		**(4.34)****		**(4.04)****
TS	-17.34	-19.52	-17.83	-18.88	-6.39	-10.35	-11.28	-12.89
	(4.51)**	(4.74)**	(4.49)**	(4.52)**	(1.19)	(1.82)	(2.11)*	(2.31)*
Constant	-2.28	-2.00	-2.18	-1.94	-3.53	-2.92	-3.67	-3.13
	(6.73)**	(5.97)**	(6.36)**	(5.73)**	(7.54)**	(5.85)**	(7.91)**	(6.34)**
Observations	1508	1508	1507	1507	1438	1438	1437	1437
Calls								
$\Delta\sigma^{C}_{i,do}$	**-8.40**	**-6.74**			**-40.89**	**-29.76**		
	(0.98)	**(0.79)**			**(3.69)****	**(2.52)***		
$\Delta\sigma^{C}_{o,do}$			**-4.02**	**-3.52**			**-13.58**	**-10.72**
			(1.53)	**(1.35)**			**(3.85)****	**(2.80)****
σ^{C}_{a}	8.22	7.70	8.33	7.86	16.04	12.58	15.47	12.24
	(5.42)**	(5.20)**	(6.19)**	(6.03)**	(8.86)**	(6.45)**	(9.50)**	(6.74)**
BA^{C}_{o}	1.98	1.73	2.16	1.88	15.35	12.54	16.29	13.22
	(0.96)	(0.83)	(1.08)	(0.93)	(5.75)**	(4.76)**	(6.31)**	(5.23)**
V^{C}_{o}	62.97	62.02	71.13	69.86	60.08	72.29	72.85	90.91
	(2.21)*	(2.19)*	(2.43)*	(2.41)*	(0.87)	(1.06)	(1.08)	(1.32)
OI^{C}_{o}	-5.07	-5.00	-4.57	-4.55	-61.17	-63.10	-59.10	-62.23
	(1.05)	(1.04)	(0.95)	(0.94)	(5.35)**	(5.48)**	(5.27)**	(5.40)**
$TSOV^{C}_{a}$		**2.63**		**2.60**		**17.80**		**18.31**
		(1.10)		**(1.09)**		**(5.01)****		**(5.07)****
TS	-17.12	-17.64	-17.45	-18.03	-13.06	-14.34	-12.39	-14.40
	(3.91)**	(3.94)**	(4.08)**	(4.09)**	(2.39)*	(2.59)**	(2.26)*	(2.59)**
Constant	-2.15	-2.02	-2.05	-1.94	-4.37	-3.51	-4.07	-3.24
	(6.78)**	(6.42)**	(6.87)**	(6.54)**	(10.43)**	(8.01)**	(9.94)**	(7.62)**
Observations	1394	1394	1391	1391	1327	1327	1324	1324

. * significant at 5%; ** significant at 1%.

Table 5
Probit Model Estimation Results for 61-90 Day Maturity Window

The results shown in this table are the parameter estimates for the 61-90 day maturity bin for call and put options. The put results come from the probit regression of equations 1 and 3; the call results are from equations 2 and 4. The dependent variable equals one if the option window contains a daily jump below(above) –3%(+3%), zero otherwise. Standard errors are corrected for Newey-West procedures. The reported parameter values for $\Delta\sigma^P_{do,o}$, $\Delta\sigma^P_{do,a}$, and $\Delta\sigma^P_{do,i}$ represent the coefficients for the difference between the implied volatility of DOTM puts and OTM puts, ATM puts, and ITM puts, respectively. $\Delta\sigma^C_{i,do}$, $\Delta\sigma^C_{a,do}$, and $\Delta\sigma^C_{o,dio}$ represent the coefficients for the difference between the implied volatility of DOTM calls and ITM calls, ATM calls, and OTM calls, respectively. σ^P_a and σ^C_a represent the coefficients for implied volatility of ATM put and call options. BA^P_o and BA^C_o represent the coefficients for the percentage OTM put and call bid/ask options. V^P_o and V^C_o represent the coefficients for the volume of OTM put and call options, expressed in 100,000s. OI^P_o and OI^C_o represent the coefficients for the open interest of OTM put and call options, expressed in 100,000s. TS represents the coefficients of the difference between the 10-year U.S. Treasury Bond rate and the 1-year U.S. Treasury Note rate. $TSOV^P_a$ and $TSOV^C_a$ represents the coefficients of the difference between the ATM 30-day and 60-day implied volatility for the put and the call options, respectively. Absolute values of z-scores for the parameter estimates are reported in parentheses.

Put Model : $\text{Prob}(D_{j,t->t+\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^P_{SKEW,t} + \beta_2 \sigma^P_{a.t} + \beta_3 BA^P_{o.t} + \beta_4 V^P_{o.t} + \beta_5 V^P_{o.t} + \beta_6 TS)_t + e_t$

Call Model : $\text{Prob}(D_{j,t->t+\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^C_{SKEW,t} + \beta_2 \sigma^C_{a.t} + \beta_3 BA^C_{o.t} + \beta_4 V^C_{o.t} + \beta_5 V^C_{o.t} + \beta_6 TS_t) + e_t$

Put Model with TSOV : $\text{Prob}(D_{j,t->t+\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^P_{SKEW,t} + \beta_2 \sigma^P_{a.t} + \beta_3 BA^P_{o.t} + \beta_4 V^P_{o.t} + \beta_5 V^P_{o.t} + \beta_6 TS_t + \beta_7 TSOV^P_{a,t}) + e_t$

Call Model with TSOV : $\text{Prob}(D_{j,t->t+\tau} = 1) = \Phi(\alpha + \beta_1 \Delta\sigma^C_{SKEW,t} + \beta_2 \sigma^C_{a.t} + \beta_3 BA^C_{o.t} + \beta_4 V^C_{o.t} + \beta_5 V^C_{o.t} + \beta_6 TS_t + \beta_7 TSOV^P_{a,t}) + e_t$

Puts	-3% Jump				+3% Jump			
$\Delta\sigma^P_{do,o}$	**-0.05**	**4.50**			**-35.41**	**-31.47**		
	(0.01)	**(0.69)**			**(3.62)****	**(3.19)****		
$\Delta\sigma^P_{do,i}$			**-8.24**	**-4.16**			**-34.57**	**-30.83**
			(2.82)**	**(1.31)**			**(6.54)****	**(5.63)****
σ^P_a	5.15	4.24	5.75	4.74	11.57	9.77	13.94	12.45
	(4.98)**	(4.27)**	(5.39)**	(4.67)**	(8.13)**	(6.75)**	(8.63)**	(7.62)**
BA^P_o	6.50	3.02	5.41	2.77	28.21	23.64	24.99	22.39
	(3.46)**	(1.48)	(2.82)**	(1.35)	(9.81)**	(8.20)**	(8.78)**	(7.88)**
V^P_o	-7.56	-8.04	-3.20	-5.41	-34.77	-32.41	-21.96	-21.39
	(0.29)	(0.28)	(0.12)	(0.20)	(1.19)	(1.04)	(0.78)	(0.74)
OI^P_o	-3.85	-2.46	-1.24	-0.93	-15.08	-11.05	-10.08	-7.98
	(0.67)	(0.43)	(0.21)	(0.16)	(1.81)	(1.36)	(1.20)	(0.97)
$TSOV^P_a$		**7.02**		**6.14**		**9.45**		**6.17**
		(3.43)**		**(2.88)****		**(3.75)****		**(2.41)***
TS	-4.87	-9.37	-8.46	-10.96	10.66	5.01	0.88	-1.71
	(1.19)	(2.19)*	(1.96)*	(2.48)*	(2.29)*	(1.02)	(0.19)	(0.36)
Constant	-1.55	-1.12	-1.09	-0.86	-4.40	-3.65	-3.37	-3.01
	(5.13)**	(3.74)**	(3.46)**	(2.74)**	(9.29)**	(7.80)**	(6.66)**	(6.07)**
Observations	1336	1336	1336	1336	1145	1145	1145	1145
Calls								
$\Delta\sigma^C_{i,do}$	**-7.20**	**-0.50**			**-49.80**	**-42.86**		
	(0.90)	**(0.06)**			**(3.47)****	**(2.79)****		
$\Delta\sigma^C_{o,do}$			**-9.01**	**-6.73**			**-36.40**	**-33.55**
			(3.16)**	**(2.38)***			**(6.94)****	**(6.11)****
σ^C_a	6.04	4.72	6.97	5.84	12.82	10.73	15.73	13.65
	(4.62)**	(3.69)**	(5.59)**	(4.82)**	(7.83)**	(6.12)**	(9.30)**	(7.70)**
BA^C_o	1.69	-0.87	1.26	-1.21	23.50	18.66	22.55	18.05
	(0.77)	(0.38)	(0.59)	(0.55)	(6.96)**	(5.45)**	(7.00)**	(5.46)**
V^C_o	-17.69	-26.13	-15.88	-23.97	-152.86	-162.31	-153.82	-161.52
	(0.56)	(0.85)	(0.50)	(0.77)	(1.55)	(1.57)	(1.48)	(1.53)
OI^C_o	-3.54	-3.19	-2.34	-2.37	-11.07	-8.56	-6.61	-4.46
	(0.72)	(0.64)	(0.47)	(0.47)	(1.54)	(1.36)	(0.98)	(0.74)
$TSOV^C_a$		**8.00**		**7.25**		**13.49**		**12.72**
		(3.70)**		**(3.41)****		**(5.02)****		**(4.54)****
TS	-7.74	-11.30	-10.47	-13.39	-10.64	-14.17	-17.42	-20.38
	(1.68)	(2.34)*	(2.26)*	(2.76)**	(2.00)*	(2.50)*	(3.28)**	(3.75)**
Constant	-1.26	-0.82	-1.00	-0.65	-3.83	-3.07	-3.05	-2.38
	(4.75)**	(3.08)**	(3.86)**	(2.47)*	(9.51)**	(7.20)**	(7.28)**	(5.22)**
Observations	1355	1355	1349	1349	1171	1171	1165	1165

* significance at 5% ; ** significance at the 1%

Table 6

Descriptive Statistics of Volatility Skew using Delta Bins

This table reports the summary statistics for the 5 Delta bins for calls and puts. The table reports the means for implied volatility (IV), the average option percentage bid-ask spread (BA), volume (V), and open interest (OI) for each maturity/implied volatility bin over the 1996-2002 period.

Option	Moneyness	Label	Δ Range	IV	BA	V	OI
Call	Deep in-the-money	DITM	.875<Δ≤.98	42.67%	2.04%	47.33	278.92
	In-the-money	ITM	.625<Δ≤.875	27.15%	3.23%	160.04	827.44
	At-the money	ATM	.375<Δ≤.625	22.25%	5.08%	598.89	1501.69
	Out-the-money	OTM	.125<Δ≤.375	19.72%	8.60%	721.20	1871.52
	Deep out-the-money	DOTM	.02<Δ≤.125	18.43%	21.87%	691.62	2506.31
Put	Deep out-the-money	DOTM	-.125<Δ≤-.02	32.17%	15.52%	623.69	2891.74
	Out-the-money	OTM	-.375<Δ ≤-.125	26.34%	7.36%	660.52	2007.23
	At-the money	ATM	-.625<Δ ≤-.372	22.63%	4.87%	625.08	1332.29
	In-the-money	ITM	-.875<Δ ≤-.625	21.92%	3.60%	129.74	458.90
	Deep in-the-money	DITM	-.98<Δ ≤-.875	31.52%	2.54%	42.53	125.98

Table 7

Probit Model Results for Negative Jumps using Option Deltas

The results shown in this table are the resulting parameter estimates for negative jumps using put option deltas. The puts results come from the revised probit regression of equation 1 shown below. The dependent variable equals one if the option window contains a daily jump below –3% or -4%, zero otherwise. Standard errors are corrected by Newey-West procedures. The reported parameter values for $\Delta_{do,o}$, $\Delta_{o,a}$, and $\Delta_{do,a}$ represent the coefficients for the difference between the implied volatility of DOTM and OTM put deltas, OTM and ATM put deltas, and DOTM and ATM put deltas, respectively. $\Delta_{a,i}$ represents the coefficient for the difference between the implied volatility of ATM and ITM put deltas. σ^P_a represents the coefficient for implied volatility of ATM put options. BA^P_o represents the coefficient for the percentage OTM put bid/ask options. V^P_o represents the coefficient for the volume of OTM put options, expressed in 100,000s. OI^P_o represents the coefficient for the open interest of OTM put options, expressed in 100,000s. TS represent the coefficient of the difference between the 10-year U.S. Treasury Bond rate and the 1-year U.S. Treasury Note rate. Absolute values of z-scores for the parameter estimates are reported in parentheses.

$$\text{Put Model} \quad : \text{Prob}(\text{D}_{\text{j,t->t+}\tau} = 1) = \Phi(\alpha + \beta_1\Delta^P_{SKEW,t} + \beta_1\Delta^P_{a\_i,t} + \beta_3\sigma^P_{a.t} + \beta_4 BA^P_{o.t} + \beta_5 V^P_{o.t} + \beta_6 V^P_{o.t} + \beta_7 TS_t) + e_t$$

	-4% Jump			-3% Jump		
$\Delta_{do,o}$	**12.320**			**3.003**		
	(5.37)**			**(1.67)**		
$\Delta_{o,a}$		**12.403**			**2.147**	
		(2.24)*			**(0.54)**	
$\Delta_{do,a}$			**8.733**			**1.967**
			(4.78)**			**(1.45)**
$\Delta_{a,i}$	1.347	0.624	0.203	0.038	0.059	-0.151
	(0.95)	(0.45)	(0.15)	(0.04)	(0.05)	(0.15)
σ^P_a	6.887	8.795	6.400	11.811	12.479	11.729
	(6.92)**	(6.92)**	(5.79)**	(12.29)**	(11.80)**	(11.39)**
BA^P_o	-15.158	-14.860	-14.011	-6.960	-6.871	-6.709
	(3.61)**	(3.66)**	(3.38)**	(2.03)*	(1.96)	(1.95)
V^P_o	16.794	18.938	17.849	6.143	6.627	6.375
	(4.45)**	(4.83)**	(4.61)**	(2.26)*	(2.43)*	(2.36)*
OI^P_o	-97.58	-68.36	-94.38	-26.48	-22.23	-26.01
	(5.52)**	(3.84)**	(5.35)**	(2.26)*	(1.97)*	(2.22)*
TS	29.51	23.96	27.24	19.84	19.25	19.6
	(3.86)**	(3.00)**	(3.53)**	(3.76)**	(3.72)**	(3.72)**
Constant	-4.456	-4.799	-4.508	-3.981	-4.075	-3.987
	(15.21)**	(16.03)**	(15.25)**	(17.80)**	(18.80)**	(17.98)**
Observations	1751	1760	1751	1751	1760	1751

* significant at 5%; ** significant at 1%

Table 8
Probability of a Crash/Spike

This table reports the predicted probability of a crash given the level of ATM implied volatility and the difference in implied volatility between a DOTM and OTM option, as defined in table 1, for both call and put options. The mean value for all other variables including the bid-ask spread, open interest, volume, and term-structure, are used. The probabilities are inferred from multiplying the coefficients from a marginal effects probit regression, given the same specification as in equations 1 and 2, to the given values of the variables. The probit regression is run using -3% crash for the put options and a 3% spike upward for the call options.

	ATM Implied Volatility Level		
	10%	20%	30%
Put Skew	Probability of Crash		
0%	1.17%	9.57%	36.51%
3%	1.99%	13.70%	44.73%
6%	3.26%	18.90%	53.19%
9%	5.15%	25.17%	61.50%
12%	7.80%	32.39%	69.32%
15%	11.39%	40.35%	76.34%
Call Skew	Probability of Spike Upward		
-3%	0.03%	3.24%	38.67%
0%	0.00%	0.44%	14.37%
3%	0.00%	0.03%	3.29%
6%	0.00%	0.00%	0.45%
9%	0.00%	0.00%	0.03%
12%	0.00%	0.00%	0.00%