Cross-sectional analysis of risk-neutral skewness

by

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Abstract

We investigate the importance of various firm specific and market wide factors in explaining the risk-neutral skewness, estimated using the prices of individual stock options, for 149 U.S. firms. We find that the risk-neutral skewness of individual firms, which is less negative than the market index skewness, is negatively related with the firm's option trading volume, stock trading volume, size, systematic risk proportion, market sentiment ratio and the firm's own volatility, while it is positively related with the firm's leverage ratio, information asymmetry measure and the real-world volatility asymmetry. Also, the firm's risk-neutral skewness tends to be more negative during the periods when the market index skewness is more negative and when the stock index is more volatile.

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1 Introduction

The distribution of an asset price in the future is important in many areas of Finance. One important application is in option pricing. By defining the risk-neutral density function of the underlying asset, we can calculate the expected payoff of a European option contract. The option price equals the discounted value of the expected payoff in the risk-neutral pricing framework. Previous research studies have addressed different methods to extract the risk-neutral density from option prices, especially from index option prices, and examined its shape and properties. However, not many papers analyse the risk-neutral density of individual stocks.

Bakshi, Kapadia and Madan (BKM) (2003) and Dennis and Mayhew (2002) find that the risk-neutral skewness of individual stocks is much less negative than the index and depends on both market factors and firm specific factors, with the latter more important than the former. The difference between the risk-neutral skewness of individual stocks and the risk-neutral skewness of the stock index establishes the need for differential pricing of individual stock options versus the market index options. This makes it relevant to find out which, and to what extent, firm specific factors are determining the risk-neutral skewness of individual stocks.

1.1 Prior Literature

The risk-neutral moments of individual stocks has drawn far less scrutiny in empirical research than the corresponding moments of the stock index. One possible reason is due to data availability. Another possible reason is that the options of individual firms are far less liquid than index options.

BKM (2003) prove that, if individual stock returns are composed of a market component and an idiosyncratic component, then the skewness of stock returns can also be decomposed into a market component and an idiosyncratic component. Their empirical studies on 30 U.S. firms with the highest market capitalizations and the S&P500 index show that individual skews are nearly always negative but less negative than the index, and that there is not much information about the risk-neutral skewness of individual stocks, which can be extracted solely from the risk-neutral skewness of the index.

Their results are confirmed again by Dennis and Mayhew (2002), who directly examine the relation between risk-neutral skewness and six firm specific factors and two market-wide factors for 1,421 U.S. firms from April 1986 to December 1996. Their results show that the stock trading volume, firm size and the firm's market risk (measured by Beta) are all negatively related with the risk-neutral skewness of individual stocks. On the contrary, they do not find the leverage ratio and the ratio of put/call option trading volume, as a measure of market sentiment, are the driving forces behind the asymmetry in the risk-neutral distributions of individual stocks.

The insignificant relation between leverage ratio and risk-neutral skewness in Dennis and Mayhew (2002) is contrary to what Toft and Prucyk (1997) find for 138 U.S. firms from 1993 to 1994. However, Toft and Prucyk (1997)'s measure of risk-neutral skewness, which is the ratio of the slope of implied volatility curve over the at-the-money (ATM) implied volatility, is suspicious, as it includes effects from both the slope and the level of the implied volatility curve [Dennis and Mayhew (2002)].

Pena, Rubio and Serna (1999) test the determinants of various variables on the shape of implied volatility smiles, which is derived from the prices of Spanish index options. They find that the option transaction costs, underlying asset standard deviation, the long and short term interest rates and the option's time to maturity all influence the variation of the implied volatility smiles over time.

Following the work of BKM (2003) in examining the market wide effects, Duan and Wei (2006) find that, for the same 30 U.S. firms and the S&P100 index, the systematic risk proportion, defined as the ratio between the systematic variance of a stock returns and its total variance, is negatively and significantly related with risk-neutral skewness and positively and significantly related with risk-neutral kurtosis. Christoffersen, Jacobs and Vainberg (2006) theoretically derive that the risk-neutral skewness of individual firms is negatively related with the firms' beta and positively related with skewness of market returns, when assuming the skewness of idiosyncratic return is zero.

1.2 Scope

This paper firstly estimates the risk-neutral skewness for 149 U.S. firms, following the estimation method provided by BKM (2003). Secondly, we analyse the relations between a list of firm specific factors and the firm's risk-neutral skewness. Some of these factors have been examined by previous literature, while the others are addressed for the first time to explain the determinants of risk-neutral skewness. Our objective is to capture more properties of the risk-neutral skewness of individual firms and to find the sources of it.

Our study is closely related with Dennis and Mayhew (2002) but is different in three aspects. Firstly, the calculation of risk-neutral moments derived by BKM (2003) requires estimating the integrals function of option prices. Dennis and Mayhew (2002) who apply the same method use the market option prices, of which there are sometimes only a few observations for individual stocks. We choose to infer a lot more option prices from the implied volatility curve in order to better approximate the integral functions. Secondly, because days with only a few traded options are included, Dennis and Mayhew (2002) investigate nearly ten times the number of U.S. firms that we use. Thirdly, the option market is more mature for our sample period, which is from Jan 1996 to Dec 1999, compared to the earlier period.

For the firm specific variables that have been investigated in previous literature, we find consistent results that the risk-neutral skewness tend to be more negative for firms with higher stock trading volume, larger firm size, higher systematic risk proportion and lower leverage ratio. However, different to the results of Dennis and Mayhew (2002), our sample results in negative and significant coefficients for the put-to-all option volume and the firm's implied volatility.

As for the firm specific variables that have not been studied in the context of the risk-neutral skewness before, we find that the option trading volume is an important variable in explaining the risk-neutral distribution and is negatively related with skewenss. The information asymmetry measure, computed as the informed trader's profits in the stock market, increases with the risk-neutral skewness of individual firms. The real-world asymmetry in volatility is also positively related with the risk-neutral asymmetry. However, the book-to-market ratio that is positively related with the firms' risk-neutral skewness lost its significant in multivariable regressions.

For the market-wide variables, consistent with previous literature, our results suggest that the individual skewness moves in the same direction as the stock index skewness and becomes more negative when the stock index is more volatile. However, the effects from the stock index are limited for our data.

The remainder of the paper is organized as follows. The developments of hypothesis are described in Section 2. In Section 3, we introduce the BKM (2003) method to compute the risk-neutral skewness. Data sources and the constructions of all variables are discussed in Section 4. Section 5 presents the regression results. The last section contains conclusions.

2 Development of hypothesis

Most of the hypotheses that we make about the risk-neutral skewness of individual stocks are developed according to the existing literature, which also studies the individual risk-neutral skewness. Some other variables come from previous literature on risk-neutral distribution of stock indices, or the literature on the real-world distribution of individual firm prices.

The first explanatory variable for risk-neutral skewness is the *trading volume of the underlying stock*. The relation between it and the risk-neutral skewness can be motivated from two perspectives. Firstly, higher trading volume of stocks, as a proxy for liquidity, reduces the transaction costs. In an option pricing framework, lower transaction costs make it easier to implement dynamic arbitrage strategies and thus the arbitrage bounds on option prices are tighter [Figlewski (1989), Dennis and Mayhew (2002)]. Consistent with this insight, Dennis and Mayhew (2002) find that a higher trading volume of the underlying stock is associated with a less negative risk-neutral skewness or a more symmetric risk-neutral distribution.

On the other hand, Hong and Stein (1999) argue that investor heterogeneity is the central force creating return asymmetries. When assuming that there are differences of opinions among investors about stock values and that some investors face short-sale constrains, the Hong-Stein model suggests that the negative skewness is more pronounced in periods of heavy trading volume, where trading volume is a proxy for differences in opinions [Harris and Raviv (1993), Chen, Hong and Stein (2001)]. In the empirical tests of Chen, Hong and Stein (2001), the detrended level of turnover over six months, referring to differences in opinion, has some explanatory power to predict the conditional skewness measured by daily stock returns in the following six months, with a negative coefficient.

As the relation between trading volume and skewness is ambiguous, we test it directly. Following Dennis and Mayhew (2002), we adopt the logarithm of stock trading volume. Assuming some of the above arguments also apply to the trading volume of options, we include the logarithm of option trading volume as well.

Secondly, assuming the returns of a firm's stock are related with the market index returns. BKM (2003) show that the risk-neutral skewness for the stock returns can also be decomposed into two components reflecting market skewness and the skewness of unsystematic risk component, such that:

$$SKEW_i = (1+\frac{VAR_{\varepsilon,i}}{\beta_i^2 VAR_m})^{-2/3}\ SKEW_m\ +\ (1+\frac{\beta_i^2 VAR_m}{VAR_{\varepsilon,i}})^{-3/2}\ SKEW_{\varepsilon,i},$$

where $SKEW_i$, $SKEW_m$ and $SKEW_{\varepsilon,i}$, respectively, refer to firm i's stock returns skewness, market returns skewness and the skewness of the unsystematic risk component; VAR_m and $VAR_{\varepsilon,i}$ are the variance of market returns and the variance of the unsystematic proportion of firm i's stock returns; β_i estimates the comovements between firm i's stock returns and the market returns. As shown in the equation, the individual skew is positively linked to both components. When the risk-neutral distribution of the unsystematic risk component is symmetric or positively skewed, the individual skew will be less negative than the market [BKM (2003)].

Combining the theorem described by the above equation with the empirical findings that risk-neutral distribution of individual stocks is less negatively skewed than that of the index, we expect that a higher relation between the firms' stock return and the index return is associated with more negative risk-neural skewness. Dennis and Mayhew (2002) find a negative coefficient between beta and risk-neutral skewness for their data. However, Duan and Wei (2006) suggest another estimate equal to $\frac{\beta_i^2 VAR_m}{VAR_{\varepsilon,i}}$, namely systematic risk proportion, which is equivalent to the explanatory power, R^2, of the OLS regression for stock return: $R_{i,t} = \alpha_{i,t} + \beta_{i,t} R_{m,t} + \varepsilon_{i,t}$.

The systematic risk proportion is a better estimate than beta. Firstly, beta measures the systematic market risk but not the systematic risk that accounts for total risk [Duan and Wei (2006)]. For different firms with the same level of beta, the one with lower total risk and/or with a higher correlation with the market has a higher systematic risk proportion. Secondly, the systematic risk proportion ranges from zero to one, while beta can exceed one. Therefore, we estimate the effect of the systematic risk proportion on risk-neutral skewness and expect that there is a negative relation between them. *Beta* is used as an alternative measure to the systematic risk proportion in our study.

Moreover, according to the above equation, the individual skewness should be positively related with the market skewness. Dennis and Mayhew (2002) find that the risk-neutral skewness of individual firms tends to move in the same direction with that of the S&P 500 index over time. We include the risk-neutral skewness of the market index into out analysis, expecting in the periods with more negative market skewness that the risk-neutral skewness individual firm also tends to be more negative. We adopt the S&P 100 index as the market index.

Except for market skewness, the market volatility and the firm's own volatility are also included in the above equation. Dennis and Mayhew (2002) find that the ATM implied volatility of the S&P500 index option is negatively related with the firm's risk-neutral skewness, while the ATM implied volatility of the firm's own stock option is positively related with the firm's risk-neutral skewness. Their findings imply that the firm's risk-neutral skewness is more negative when the market volatility is high and when the firm's own volatility is low. We test the relations by including both the *ATM option implied volatility of the S&P100 index* and the *ATM option implied volatility of the firm's stock* as independent variables and expect the relations to have the same sign.

Apart from the variables connecting the firms and the market, we also include the *firm size*, which helps ensure that we do not attribute more explanatory power to other variables than is appropriate, and the *book-to-market ratio*. In Chen, Hong and Stein (2001)'s test, book-to-market ratio is positively related with the next period's conditional skewness. Their explanation is the stochastic bubble model suggested by Blanchard and Watson (1982). A low book-to-market ratio implies that the bubble has been building up for a long time. When the bubble pops, the low-probability event might produce large negative returns.

The leverage effect [Black (1976)] is a popular explanation of the asymmetry in stock return distributions. It indicates that a drop in stock price raises the firm's *leverage ratio* and, as a result, the firm's stock becomes riskier. However, the resulted higher risk level does not necessarily relate with a more negative slope of the implied volatility curve. Therefore, it is difficult to say whether the relation between the risk-neutral skewness and the firm's leverage ratio is positive or negative. The positive relation, found by Dennis and Mayhew (2002) is consistent with the empirical results that the risk-neutral density of individual stocks is less negatively skewed than the index. We include the firm's leverage ratio and test whether firms with more leverage tend to have more or less risk-neutral skewness.

Another variable that has been examined by previous studies is the proxy for market sentiment or trading pressure. When the market is pessimistic, people might expect the stock price to decline and thus the shape of the future return distribution will appear to be left skewed. The ratio of put-to-call trading volume is commonly believed to be a sentiment index and Pan and Poteshman (2006) show that the ratio constructed from reliable data is negatively associated with future stock returns. Dennis and Mayhew (2002) do not find evidence that the ratio can explain the movements of risk-neutral skewness. We include the ratio of *put-to-all trading option volume* and expect that a higher demand for put options, compared to that for calls, indicates pessimism and implies a more negatively skewed risk-neutral distribution.

The relation between *information asymmetry* and the risk-neutral distribution has not been investigated in previous related literature. Investors with private information in the stock market can make profits by trading with those without. Easley, O'Hara and Srinivas (1998) and Bardong, Bartram and Yadav (2006) find that U.S. firms with options traded have lower information asymmetry at the stock market than those without. The information asymmetry should be able to influence the option prices and thus the option implied risk-neutral distribution. Both French and Roll (1986) and Bardong, Bartram and Yadav (2006) show that a higher information asymmetry is related with an increase in the firms' risk-neutral volatility.

Unfortunately, there is no theoretical research that provides the relation between information asymmetry and risk-neutral skewness. We conduct the empirical tests that may later motivate future theoretical research. If a firm has more private information, then the expectations of the future stock price from both informed and uninformed investors will be dispersed, because they are using different information. When these investors participate in the option market, they will trade options at a variety of strike prices based on their own expectations. Therefore, the option implied risk-neutral density might then appear to be more volatile and more symmetric. As, at most times, the risk-neutral skewness of individual firms is negative, we expect a higher information asymmetry is associated with less negative risk-neutral skewness. The measure of information asymmetry documented by Naik and Yadav (2003) and Bardong, Bartram and Yadav (2006) is adopted in our study.

The asymmetric volatility phenomenon (hereafter AVP) refers to the fact that negative return shocks tend to imply a higher volatility than do positive return shocks of the same magnitude [Nelson (1991)]. In the theory of stochastic volatility models, the stock price S_t and its variance $V_t = \sigma_t^2$ follow a pair of diffusion equations in the real world:

$$dS = \mu \, S \, dt + \sigma \, S \, dW$$

and

$$dV = \alpha \, dt + \eta \, dZ \, .$$

ρ refers to the correlation between the volatility shocks and price shocks in both the real-world and the risk-neutral processes. Taylor and Xu (1994) derive that, when $\rho \neq 0$, the option implied volatility is approximately a quadratic function of the option's moneyness and the minimum implied volatility does not occur at the forward price. This theoretical relation implies that the AVP, proxied by realistic negative values of ρ, can influence the slope of the implied volatility curve, which reflects the risk-neutral skewness. Based on the futures prices of the S&P500 index.

Taylor (2005) shows that the slope of the implied volatility curve, calculated from the option pricing formula of Heston (1993), is more negative when ρ is more negative,

According to prior theoretical work, Harvey and Siddque (1999) have noted a link between negative conditional skewness and the AVP. Blair, Poon and Taylor (2002) and Dennis, Mayhew and Stivers (2006) document that the AVP is stronger for the stock index than for individual firms. Dennis, Mayhew and Stivers (2006) further show that this 'index versus firms' difference in the AVP is consistent with the 'index versus firms' differences of the slopes of their implied volatility curves. It is thus plausible to suggest that firms with a stronger AVP tend to exhibit a more negative slope on their implied volatility curves. Therefore, we use the *asymmetric volatility ratio* that is defined by the GJR (1,1) model [Glosten, Jagannathan and Runkle (1993)] as the proxy for AVP.

3 Spanning and pricing risk-neutral skewness

The BKM (2003) method to find risk-neutral skewness and kurtosis is motivated by a theorem outlined in Bakshi and Madan (2000). Let $S(t)$ refer to the stock price at time t. For any claim payoff, $H[S(t+\tau)]$, that is integrable under risk-neutral pricing, the risk-neutral expectation of it at time $t+\tau$ is:

$$E_t^Q\{H[S(t+\tau)]\} = \int_0^\infty H[S(t+\tau)]q[S(t+\tau)]dS \qquad (1),$$

where $E_t^Q\{.\}$ refers to the risk-neutral expectation and $q[S(t+\tau)]$ is the risk-neutral density of S at time $t+\tau$.

Bakshi and Madan (2000) show that any payoff function with bounded expectation can be spanned by a continuum of out-of-the-money (OTM) European call and put option prices. They derive the arbitrage-free price of the claim at time t as:

$$E_t^Q\left\{e^{-r\tau}H[S]\right\} = (H[\bar{S}] - \bar{S}H_S[\bar{S}])e^{-r\tau} + H_S[\bar{S}]S(t) + \int_{\bar{S}}^{\infty} H_{SS}[K]C(t,\tau;K)dK + \int_0^{\bar{S}} H_{SS}[K]P(t,\tau;K)dK \qquad (2),$$

where r refers to the interest rate, $H_S[S]$ and $H_{SS}[S]$ are the first-order and second-order derivatives of the payoff with respective to S evaluated at any selected number $\bar{S}$. $C(t,\tau;K)$ and $P(t,\tau;K)$ are respectively the European call and put option prices at time t with strike price K and expiry date $t+\tau$.

BKM (2003) define the volatility contract, cubic contract and quartic contract to have the payoffs respectively equal to $R(t,\tau)^2$, $R(t,\tau)^3$ and $R(t,\tau)^4$, where the τ-period stock return is defined as: $R(t,\tau) \equiv \log(S(t+\tau)) - \log(S(t))$. The prices of these three contracts at time t are expressed respectively by $V(t,\tau) \equiv E_t^Q\left\{e^{-r\tau}R(t,\tau)^2\right\}$, $W(t,\tau) \equiv E_t^Q\left\{e^{-r\tau}R(t,\tau)^3\right\}$ and $X(t,\tau) \equiv E_t^Q\left\{e^{-r\tau}R(t,\tau)^4\right\}$.

BKM (2003) derive the value of $V(t,\tau)$, $W(t,\tau)$ and $X(t,\tau)$ when letting $H[S]$ in Equations (1) and (2) be equal to $R(t,\tau)^2$, $R(t,\tau)^3$ and $R(t,\tau)^4$. For the choice $\bar{S} = S(t)$, they are:

$$V(t,\tau) = \int_0^{\infty} \frac{2(1-\log[\frac{K}{S(t)}])}{K^2} Q(t,\tau;K)dK \qquad (3),$$

$$W(t,\tau) = \int_0^{\infty} \frac{6\log[\frac{K}{S(t)}] - 3(\log[\frac{K}{S(t)}])^2}{K^2} Q(t,\tau;K)dK \qquad (4),$$

$$X(t,\tau) = \int_0^{\infty} \frac{12(\log[\frac{K}{S(t)}])^2 - 4(\log[\frac{K}{S(t)}])^3}{K^2} Q(t,\tau;K)dK \qquad (5),$$

where $Q(t,\tau;K)$ is the call option price with strike price K when $K > S(t)$ and otherwise it is the put option price. Therefore, the value of each of these three contracts can be expressed by a portfolio of OTM option prices.

By Theorem (1) in BKM (2003), the skewness of the risk-neutral distribution of $\log(S)$ at time $t+\tau$, which is $SKEW(t,\tau)$, can be recovered from the above equations, such that:

$$\begin{aligned} SKEW(t,\tau) &\equiv \frac{E_t^Q\left\{(R(t,\tau) - E_t^Q[R(t,\tau)])^3\right\}}{\left\{E_t^Q(R(t,\tau) - E_t^Q[R(t,\tau)])^2\right\}^{3/2}} \\ &= \frac{e^{r\tau}W(t,\tau) - 3\mu(t,\tau)e^{r\tau}V(t,\tau) + 2\mu(t,\tau)^3}{[e^{r\tau}V(t,\tau) - \mu(t,\tau)^2]^{3/2}} \end{aligned} \qquad (6),$$

with $\mu(t,\tau) \equiv E_t^Q\left\{\log\left[\frac{S(t+\tau)}{S(t)}\right]\right\} \approx e^{r\tau} - 1 - \frac{e^{r\tau}}{2}V(t,\tau) - \frac{e^{r\tau}}{6}W(t,\tau) - \frac{e^{r\tau}}{24}X(t,\tau)$.

This method shows that the risk-neutral skewness for a future time can be calculated from a continuum of current option prices with the same maturity. The method has been adopted, at least, by BKM (2003), Dennis and Mayhew (2002), Duan and Wei (2006), and Christoffersen, Jacob and Vainberg (2006) in measuring risk-neutral moments of individual stocks.

4 Data

Our sample includes 149 U.S. firms[1] with options listed on the CBOE and ranges from Jan 1996 to Dec 1999. Daily option data including both prices and trading volume for both firms and the S&P100 index are from the IvyDB Database provided by Option Metrics. Options with less than seven days to maturity are excluded. For most trading days, we choose the nearest-to-maturity options[2]. Daily data of the underlying stocks, including trading volume, closing price and shares outstanding in the market all comes from CRSP. Firm's financial reporting information used to estimate leverage and book-to-market ratio is from Computstat. The calculation of information asymmetry requires high-frequency stock data, which are obtained from TAQ. All variables, including risk-neutral skewness, are estimated daily and then averaged to obtain weekly measures.

4.1 Construction of explanatory variables

Daily trading volume of underlying stock measured in shares traded is collected directly from CRSP. Firm size equals the firm's market capitalization, calculated as the daily closing stock price multiplied by the shares outstanding in the market. In order to eliminate the effects from extremely high or low volume and size, we use the natural log of the firm's trading volume in thousands of shares and the natural log of firm size in thousands of dollars.

The indicator of market sentiment is estimated as the trading volume of put options divided by the trading volume of all options, where option trading volume is proxied by the number of traded contracts. In robustness tests, the ratio of daily put open

[1] The selection criteria of firms are same as in Taylor, Yadav and Zhang (2007).
[2] We switch to the second-nearest-to-maturity options when there are only a few observations for nearest-to-maturity options.

interests to daily overall open interests is used. Consistent with the variable of stock trading volume, we use the natural log of daily option trading volume as the indicator of option liquidity. The firm's at-the-money implied volatility is the average of the implied volatilities for the put and call options whose strike prices are closest to the stock price. As for the market volatility, we adopt the volatility index on the CBOE, VOX, which is the average of the volatilities implied by eight nearest-to-the-money and nearest-to-maturity options[3]. It represents the volatility level of the S&P 100 index with 22 days to maturity. The historical daily level of VOX index are downloaded from the CBOE's website.

The systematic risk proportion, defined by Duan and Wei (2006), is the ratio of the firm's systematic variance over the total variance. For stock i, it can be viewed as the R^2 of the OLS regression:

$$R_{it} = \alpha_{it} + \beta_{it} R_{mt} + \varepsilon_{it} \tag{7}$$

where R_{it} and R_{mt} refer to the stock i's return and the market return at time t. Following Duan and Wei (2006), we run the regression in Equation (7) for day t using daily stock returns from day $t-250$ to day t with the S&P100 index as a proxy for the market return. All returns are computed as continuously compounded

The measure of information asymmetry, presented by Naik and Yadav (2003), calculates, for each transaction, the gain or loss of a trader, who deals with a market maker, and correctly or incorrectly anticipates the direction of the movement of the

[3] For consistency, we also compute the at-the-money option implied volatility for the S&P100 index in the same way as we calculate the implied volatility for individual firms but find no significant difference in regression results.

stock price. For a transaction of stock i at time t'[4], the information asymmetry measure $IA_{it'}$ equals:

$$IA_{it'} = D_{it'} \frac{M_{i(t'+\tau)} - M_{it'}}{M_{it'}} \qquad (8),$$

where $D_{it'}$ is a direction indicator being +1 for a buy and −1 for a sell, $M_{it'}$ is the mid-quote corresponding to a transaction of stock i at time t' and $M_{i(t'+\tau)}$ is the mid-quote τ minutes after the reference trade. From the definition, a higher information asymmetry will lead to a higher value (or more positive value of IA). The daily measure is calculated as the average of all transactions within the day.

Bardong, Bartram and Yadav (2006) have tested various time intervals, τ, and both transaction-size weighted and equally weighted when averaging to compute the daily measure and find all generate consistent results. We choose τ equal to 15 minutes and daily measure equal to the equally weighted average of all transactions within the day[5].

To calculate the asymmetric volatility ratio, we use the GJR (1,1)-GARCH model that incorporates the asymmetric effect of positive and negative returns in the real world. Based on 1009 daily stock returns from Jan 1996 to Dec 1999, we estimate the parameters of the following equations once for each firm:

$$\begin{aligned} r_t &= \mu_i + \varepsilon_t + \theta\varepsilon_{t-1}, \\ \varepsilon_t &= \sqrt{h_t} z_t, \qquad z_t \sim i.i.d.N(0,1), \\ h_t &= \varpi + \alpha\varepsilon_{t-1}^2 + \alpha^- s_{t-1}\varepsilon_{t-1}^2 + \beta h_{t-1} \end{aligned} \qquad (9),$$

4 t' refers to a time within trading day t.
5 We are grateful to Florian Bardong for sharing the software used to calculate the information asymmetry.

by maximizing the log-likelihood value, where s_{t-1} is 1 if $\varepsilon_{t-1} < 0$, and is 0 otherwise. From the definition of the model, α and $\alpha + \alpha^{-}$ measure the respective effects of positive and negative shocks on the next-period conditional variance.

Following Blair, Poon and Taylor (2002), we define the asymmetric volatility ratio for firm i as:

$$A_i = \frac{\alpha}{\alpha + \alpha^{-}} \quad (10).$$

Therefore, a more pronounced AVP is consistent with a lower value of A_i.

Table 1 contains the summary statistics of the explanatory variables described above. For our data, on average there is less trading of put options than of call options, as the mean put-to-all trading volume, 0.319, is less than 50%. The average daily trading volume of underlying stock during our sample period across all firms is 924,336 ($e^{6.829} \times 1{,}000$) shares and the average firm size is 5.82 billion ($e^{15.577} \times 1{,}000$) dollars. The average level of the systematic risk proportion, which is 18.2%, shows that most risk of our sample firms comes from the firm specific component rather than the market component. Leverage lower than 50% means on average that our firms are financed more by equity than by debt. All weekly measures of information asymmetry are positive, indicating that "insider profits" exist in our sample firms. However, the average magnitude of 12.28 basis points is less than has appeared in Bardong, Bartram and Yadav (2006), where the mean of the information asymmetry is 58 basic points for about 2000 stocks in their sample. Since our firms on average are larger than theirs, our values of information asymmetry are consistent with their findings that larger firms have less information asymmetry.

4.2 Measuring risk-neutral skewness

To empirically estimate the risk-neutral skewness described in Equations (6), we need to evaluate the integrals that appear in Equation (3), (4) and (5). In order to reduce the errors coming from discrete option prices, we estimate implied volatility curves from small sets of observed option prices and then extract more option prices from it. We implement a variation of the practical strategy described by Malz (1997a, 1997b), who proposed estimating the implied volatility curve as a quadratic function of the Black-Scholes option's delta; previously a quadratic function of the strike price had been suggested by Shimko (1993). As stated by Malz (1997a), making implied volatility a function of delta, rather than of the strike price, has the advantage that the away-from-the-money implied volatilities are grouped more closely together than the near-the-money implied volatilities. Also, extrapolating a function of delta provides sensible limits for the magnitudes of the implied volatilities.

The quadratic specification is chosen because it is the simplest function that captures the basic properties of the volatility smile. Furthermore, there are insufficient stock option prices to estimate higher-order polynomials. Delta is defined here as the first derivative of the Black-Scholes call option price with respect to the underlying forward price, with a constant volatility level that permits a convenient one-to-one mapping between delta and the strike price. Following Bliss and Panigirtzoglou (2002, 2004), the constant volatility level is set as the volatility implied by the option observation whose strike price is nearest to the forward price.

We use the implied volatility of the observed options provided by the IvyDB directly. The quadratic function is fitted by minimizing the sum of weighted squared errors between the observed and the fitted implied volatilities. The weight of [delta * (1-delta)] ensure that most weight is given to near-the-money options. Introducing weights reduces the impact from any outliers of far-from-the-money options, which are the most susceptible to non-synchronicity errors.

For each trading day, we extract 1000 option prices from the estimated implied volatility curve with equal space in delta ranging from $\frac{e^{-r\tau}}{1001}$ to $\frac{1000e^{-r\tau}}{1001}$. If, following the above procedures, the lowest (highest) put (call) option price is still higher than 0.001 cents, we extrapolate option prices by assuming a constant implied volatility level and keep on reducing (increasing) moneyness, defined as the strike price divided by the forward price, by 0.01 each time until the minimum option prices reach 0.001 cents. However, such an extrapolation is not often necessary for our data, as almost always the extreme OTM option prices after interpolation are already too small to have any effect on the integral functions.

Daily risk-neutral skewness for 149 firms and the S&P100 index are estimated according to Equations (6). Each weekly estimate is the average of daily estimates. We also calculate the weekly estimate as the median value of daily estimates but the differences are small. For a few trading days, the market option prices imply first order arbitrage opportunities, which means the call (or put) option prices are not monotonically decreasing (increasing) with strike prices. These trading days are not included when calculating weekly risk-neutral moments.

Table 2 provides the summary statistics of the estimated risk-neutral skewness, the autocorrelations in skewness at lag 1 to 5 and the number of firms where Ljung-Box Q-statistics at that specific lag are significant at the 1% level. We also sort the firms according to different industry sectors[6] and report the summary statistics for the firms belonging to these sectors.

We find that, consistent with previous literature, our risk-neutral skewness of individual firms are negative overall, with the mean of –0.205. There is occasionally positive skewness. Although we include only relatively large firms, their risk-neutral distribution appears to be different from that of the stock index, which is always negatively skewed and with a higher magnitude [Dennis and Mayhew (2002), BKM (2003), Christoffersen, Jacobs and Vainberg (2006)]. Secondly, the skewness shows high persistence over time for our data. The average autocorrelation is 0.336 at lag 1 and then decreases monotonically from lag 1 to lag 5. These indicate that the period of a negative skewness tends to be followed by a period that also has a negative skewness. Finally, the summary statistics of risk-neutral skewness for firms in different industry sectors are close to each other.

Figure 1 plots the time series of risk-neutral skewness for both individual firms and the S&P100 index. For each out of 209 weeks over the four years, we calculate the median value of risk-neutral skewness across 149 firms. The figure shows that the median values of risk-neutral skewness are always negative during our sample period, ranging from –0.05 to –0.45. The risk-neutral skewness of the S&P100 index is

[6] The definitions of industry sectors are from Professor Kenneth French's website: http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html, when all U.S. firms are separated into five main industry sectors.

nearly always below the median values of individual firms. The time-series mean skewness of the S&P100 index is –1.08.

Table 3 presents the correlations of all the explanatory variables used in the following regressions with the estimated risk-neutral skewness. It appears that option liquidity, underlying stock liquidity and systematic risk proportion are the most important variables in explaining risk-neutral skewness. The market skewness has some influences on the individual skewness, with correlation of 10%. The market volatility also has some effect on the firm's risk-neutral skewness. When the market volatility is high, the firm's risk-neutral skewness tends to be more negative.

It is not surprising to find that the option trading volume, stock trading volume, firm size and systematic risk proportion have high positive correlations with each other. Firstly, larger firms tend to have more liquid option trading and are more correlated with market movements. At the same time, firms with higher market values of equity are normally actively traded by the market. We also find that the information asymmetry is negatively related with firm size and positively related with book-to-market ratio and the firm's volatility. This is consistent with the findings in Bardong, Bartram and Yadav (2006).

5 Regression analysis and the results

In this section, we show the regression results when using firm specific factors to explain the dynamics in risk-neutral skewness. The first subsection introduces two regression specifications that are used for our analysis. One is the Fama-Macbeth

(1973) type of cross-sectional regressions; the other is the time-series cross-sectional pooled regression. The results of univariate regressions are presented in the second subsection. From univariate regressions, we can find the unique effect of each factor on the risk-neutral skewness. The results of multivariate regressions test relative effects form our main results and are presented in the subsequent subsections.

5.1 Regression specifications

Our analysis starts from the Fama-MacBeth (1973) type of cross-sectional approach. Each week, we run the following multivariate regression and the univariate special cases across 149 firms:

$$\text{SKEW}_i = \beta_0 + \beta_1 \text{PUT/ALL}_i + \beta_2 \text{TV\_OP}_i + \beta_3 \text{TV\_STOCK}_i + \beta_4 \text{SIZE}_i + \beta_5 \text{SRP}_i + \beta_6 \text{VOL}_i + \beta_7 \text{LEVERAGE}_i + \beta_8 \text{B/M}_i + \beta_9 \text{IA}_i + \beta_{10} \text{A}_i + \varepsilon_i \qquad (11),$$

where SKEW_i is the risk-neutral skewness for firm i; PUT/ALL_i is the ratio of put to all option trading volume; TV_OP_i is the option trading volume; TV_STOCK_i is the trading volume of underlying stocks; SIZE_i is the market value of firm i's equity; SRP_i is the systematic risk proportion; VOL_i is the ATM option implied volatility of the firm's stock; LEVERAGE_i is the leverage ratio; B/M_i is the book-to-market ratio; IA_i is the measure of information asymmetry; A_i is the real-world asymmetric volatility ratio .

These regressions investigate the cross-sectional relations between the dependent and the independent variables and generate time-series coefficients throughout 209 weeks during our sample period. For each weekly regression, the significance of the estimated slope coefficient is tested using the White (1980) t-statistic taking account of heteroscedasticity. The averages of these weekly coefficients are presented for each variable and the null hypothesis that the mean slope coefficient over time equals zero is tested by the t-statistic adjusted for the autocorrelations in the weekly coefficients up to the 10th lag.

Secondly, we run the pooled regressions, which test the cross-sectional and the time-varying relations simultaneously between risk-neutral skewness and various firm specific factors. The multivariate model specification is as follows:

$$\begin{aligned}\text{SKEW}_{i,t} = {} & \beta_0 + \beta_1 \text{PUT/ALL}_{i,t} + \beta_2 \text{TV\_OP}_{i,t} + \beta_3 \text{TV\_STOCK}_{i,t} + \beta_4\ \text{SIZE}_{i,t} \\ & + \beta_5 \text{SRP}_{i,t} + \beta_6 \text{VOL}_{i,t} + \beta_7 \text{LEVERAGE}_{i,t} + \beta_8 \text{B/M}_{i,t} + \beta_9 \text{IA}_{i,t} + \beta_{10} \text{A}_i \\ & + \beta_{11}\ \text{SKEW\_M}_t + \beta_{12} \text{VOX\_M} + \varepsilon_{i,t} \qquad (12),\end{aligned}$$

where i indexes for firm and t indexes for week of the observation. In these pooled regressions, we add two market-wide variables, where SKEW_M_t refers to the risk-neutral skewness of the market index at time t and VOX_M_t refers to the CBOE's volatility index, VOX, on the S&P100 index at time t. The number of weekly observations for our sample is 31,141. The hypothesis tests are based on the heteroscedasticity and autocorrelation consistent standard errors presented by Newey and West (1987).

5.2 Results of univariate regressions

Table 4 shows the univariate regression results of both regression specifications described in the last subsection. The left four columns are the results for cross-sectional univariate regressions, defined from Equation (11). The mean coefficients are the time-series averages of the coefficients obtained from weekly cross-sectional regressions. The null hypothesis that the time-series mean of weekly coefficients equals zero is tested using the t-statistics shown in the parentheses. The column labelled "% t-stat n/p" counts the percentages of weeks when the coefficient of the explanatory variable is negatively (n)/positively (p) significantly different from zero at the 5% level, based on the White t-statistics. The mean R^2 and mean adj. R^2 are the time-series averages of the R^2 values from weekly cross-sectional regressions.

The regressions with option trading volume, firm size and underlying stock trading volume generate the highest average values of R^2, compared with other regressions. Moreover, the coefficients of option trading volume and stock trading volume are negatively significant at the 5% level for respectively 58.0% and 60.3% out of 209 weeks but both have never been positively significant. The results indicate that firms with higher trading volume of options, higher trading volume of underlying stocks and/or higher market value of equity, compared to other firms, tend to have more negative skewness.

The last three columns on the right in Table 4 show the coefficient estimates and explanatory powers of the univariate pooled regressions, defined in Equation (12). The Newey-West t-statistics, taking account of both heteroscedasticity and autocorrelation, are presented in the parentheses. The sign and significance of the estimated coefficient for the firm specific variables are, in general, similar to the time-series averages of the cross-sectional coefficients reported in the left hand side of the table. The R^2 values are slightly lower than the mean R^2 values in the cross-sectional regressions for most variables. The systematic risk proportion has a higher explanatory power than firm size in the pooled regressions and becomes the third most important among all variables.

The risk-neutral skewness of the S&P100 index is positively related with that of the individual firms, with the coefficient estimate equal to 0.13. The volatility index of the S&P100 index, VOX, is also significantly related with the firms' risk-neutral skewness but with a negative coefficient equal to –0.92.

From the cross-sectional regressions and the pooled regressions, all the explanatory variables are significant in explaining the movements in risk-neutral skewness at a univariate level. However, as there is collinearity between many pairs of explanatory variables, it is difficult to state more conclusions about the effects coming from these variables, solely based on the univariate regression results.

5.3 Results of multivariate regressions

Results of cross-sectional regressions

Table 5 presents the results of the multivariate cross-sectional regression defined in Equation (11). The regression is run once a week and the means of the weekly coefficient estimates are shown. Initially all variables are including, labelled *Model I* in Table 5. From the regression results, firstly we find that the coefficient on put to all trading volume of options, PUT/ALL, is negative and significant. This is consistent with our hypothesis that when investors are pessimistic and trade more on put options relative to the overall option trading volume, the probability of a lower price level on the risk-neutral distribution might be driven up. However, based on the same hypothesis, Dennis and Mayhew (2002) do not find any consistent evidence for their data. One possible reason is that their sample is too large and the values of the variable, measured as the put trading volume over call trading volume, is volatile so that their regression results might be influenced by some extreme values.

Secondly, we find a negative and significant relation between the options' trading volume and the risk-neutral skewness of individual firms. The index options are much more liquid than options on individual firms. If the index is viewed as a firm with the highest trading volume in options, our results are consistent with the empirical findings that the option implied risk-neutral distribution of index returns is much more negatively skewed than that of individual firms.

Thirdly, in univariate regressions presented in Table 4, the negative mean coefficient on stock trading volume indicates that firms with more actively traded stocks tend to have more negative skewness. However, in the encompassing regression, stock trading volume loses its significance at almost all levels. It is possible that the information provided by it are all subsumed by other variables that have high correlations with stock trading volume but which remain significant in multivariate regression. To assess the collinearity effects, we estimate the regression again by omitting firm size. The parameter estimates are reported in the two middle columns of Table 5, as *Model II*. When firm size is ignored, there is almost no change to the coefficients for the other variables except that stock trading volume now becomes significant at very low levels ($t = -3.9$).

The systematic risk proportion, as expected, is negatively and significantly related with risk-neutral skewness. Firms that contain a higher proportion of systematic risk within their overall risk tend to exhibit more negative risk-neutral skewness. The results are consistent with Duan and Wei (2006) and Dennis and Mayhew (2002), while the latter uses beta as the proxy of systematic risk. Our mean coefficient of –0.12 is much smaller than the coefficient of Duan and Wei (2006)'s cross-sectional regressions, which is –1.34. This is perhaps because they use the S&P 500 index as the proxy for the market portfolio and, their sample is from Jan 1991 to Dec 1995 and contains the 30 U.S. firms with highest market capitalizations and the S&P100 index. The risk-neutral skewness of their firms is overall more negative than ours.

Also consistent with the finding of Dennis and Mayhew (2002), we find the coefficient on debt-to-equity ratio, D/E, is positive and significant. Therefore, the leverage effect can not be used to explain the relation between leverage and risk-neutral skewness. One possible explanation of our positive coefficient is that firms with a symmetric risk-neutral distribution or even positive risk-neutral skewness are able to take more debt in their capital structure.

The mean coefficient on the information asymmetry measure, IA, is negative and significant in the multivariate regression. In both the correlation analysis in Table 3 and the univariate regression results in Table 4, the relation between it and the risk-neutral skewness appear to be positive. The negative coefficient might be a result of the negative correlations between the information asymmetry measure and the option trading volume, stock trading volume, firm size and systematic risk proportion. All these values are always positive according to their definitions and the negative correlations between them and IA are all below –30%.

To assess this negative colinearity problem, we estimate the regression again by omitting the four covarying variables, which are option trading volume, underlying stock trading volume, firm size and systematic risk proportion. The coefficient estimates are presented in the last two columns in Table 5, as *Model III*. As expected, the mean coefficient estimate of IA is positively significant after the variables negatively correlated with it are dropped. The adjusted explanatory power, 3.36%, is much lower than before, because the four important variables are not included in the regressions. The results imply that when the firm contains more insider information in the underlying market, the firm's risk-neutral distribution tends to be more symmetric or more positively skewed. However, after controlling for option and stock trading volume, firm size and systematic risk proportion, the coefficient becomes negative and significant. We also find that the coefficient estimate of book-to-market ratio becomes significant when these four variables are omitted. In the all-inclusive regression, information provided by book-to-market ratio is subsumed by the other explanatory variables.

The asymmetric volatility ratio, A, is positively related with the risk-neutral skewness. A higher value of A implies a less pronounced asymmetric volatility phenomenon. So our finding is consistent with the hypothesis that, when the effects coming from negative shocks of stock returns are small relative to that from positive shocks in the real world, the risk-neutral distribution tends to be more positively skewed or more symmetric.

Overall the percentages of weeks when each coefficient estimate is negatively or positively significant are low in Table 5. This might be caused by the relatively small number of observations each week, which is 149 firms, compared to the number of explanatory variables in the regression model.

Results of pooled regressions

The first column of Table 6 shows the results of the multivariate pooled regression *I*, defined by Equation (12). The numbers below each coefficient estimate are the Newey-West t-statistics. The F-statistic tests the null hypothesis that the all coefficients of the explanatory variables in the regression model are zero. In the pooled regression, we add two market-related variables, market skewness and market volatility, to capture the time-series properties of risk-neutral skewness.

Nearly all the coefficient estimates of regression *I* have a similar magnitude to the average coefficients obtained from the cross-sectional approach in Table 5. The adjusted R^2 is 7.75% and the null hypothesis that all coefficient estimates are equal to zero is strongly rejected according to the F-statistic. Consistent with the cross-sectional regression results, the coefficients of stock trading volume, book-to-market ratio and asymmetric volatility ratio are not significant at the 5% level. For regression *II* in Table 6, when we omit firm size, the coefficient of stock trading volume becomes negative and significant. The asymmetric volatility ratio is not significant probably because we fix the measure for each firm throughout the sample period.

In regression *I* in Table 6, the risk-neutral skewness of the S&P100 index, which is viewed as the market skewness by us, positively and significantly helps to explain individual firm skewness over time, as expected. The market volatility is negatively significant, indicating the individual risk-neutral skewness tends to be more negative when the overall market is more volatile. The firm's ATM implied volatility is also significantly and negatively related with the risk-neutral skewness. This result is different from that of Dennis and Mayhew (2002) and thus solves the puzzle in their paper that the individual risk-neutral skewness has a conflicting relationship between the market volatility and the firm's own volatility. Our results suggest that when the market volatility or/and the firm's volatility is high, the individual risk-neutral skewness tends to be more negative.

It is found again that the information asymmetry measure appears to be negatively related with risk-neutral skewness. The reason, as discussed before, lies in the strong negative correlations between it and some other explanatory variables, which are option trading volume, stock trading volume, firm size and systematic risk proportion. Therefore, in regression *III* of Table 6, we show the results of the pooled regression when omitting those four variables and find that the coefficient estimate of the information asymmetry measure changes sign and is significant in explaining risk-neutral skewness at low levels.

It is also interesting to isolate the effects coming from the market skewness and those from the firms themselves and test which is more important. Dennis and Mayhew (2002) prove that the risk-neutral skewness of the market index explains some of the time-series variation in individual skewness but is much less important than the firm specific factors. For regression *IV* shown in Table 6, we drop the market variables, which are the risk-neutral skewness of the S&P100 index and the volatility index of the S&P100 index. Comparing the results with those in regression *I*, there is not much difference in the sign and significance of all the other explanatory variables. The adjusted R^2 is 6.89%, which is only 0.86% lower than that of regression *I*. Therefore, the risk-neutral skewness and the option implied volatility of the S&P100 index captures only a small proportion of the time-series variation in the risk-neutral skewness of individual firms.

From the summary statistics presented in Table 2, we find that the firm's risk-neutral skewness has high autocorrelations at the first few lags. Therefore, we add the lagged risk-neutral skewness as an additional independent variable and show the regression results in the fifth column in Table 6.

The coefficient of the lagged skewness in regression *V* is positive and highly significant. The adjusted R^2 increases to 21.09%, which is about three times the adjusted R^2 of regression *I*. This is consistent with the results of Dennis and Mayhew (2002) that also find the inclusion of lagged skewness improves the explanatory power of their regression model greatly. Their explanation of the highly significant coefficient on lagged skewness is that the lagged estimates subsume the omitted firm specific factors. Another possible reason, which maybe more credible, is the overlapping problem existing in both their and our samples.

The coefficient on lagged skewness for our sample is 0.38 in regression *V*, which is about a half of that in Dennis and Mayhew (2002). In their sample, they fix the risk-neural skewness with 22 days to maturity and estimate the risk-neutral skewness once a day. The maturity date is fixed in each month in our sample, which means after every four weekly observations the subsequent measure does not overlap with the previous observations. In Table 2, the autocorrelations in risk-neutral skewness become small at the fifth lag.

To reduce the overlapping effects, we run all the pooled regressions using data collected after each month's option maturity date. The results of the regressions, with the same specifications as those in Table 6, are shown in Table 7. The number of observations reduces to 7,152 for 149 firms over 48 months. Overall, the economic and statistical significance of the results are similar to those in Table 6. The trading volume of stocks is not significant but the signs of all the other explanatory variables are nearly the same as before. In regression *V*, after adding lagged skewness, the difference between the adjusted R^2 and the adjusted R^2 of regression *I* is much less than the corresponding difference in Table 6. This implies that the monthly sample eliminates most of the effects from overlapping data in the weekly sample. The coefficient estimate of the lagged skewness, 0.19, is still positive and significant but with a lower magnitude. Therefore, we may conclude that there is some information contained in the previous monthly observation of risk-neutral skewness.

In summary, we find that the put to all option trading volume, trading volume of options, firm size, systematic risk proportion, implied volatility of the firm's ATM options, leverage, information asymmetry measure and asymmetric volatility phenomena, are all important in explaining the movements in risk-neutral skewness. The coefficient estimates for them are all negative, except for the leverage ratio.

Secondly, the information about risk-neutral skewness provided by stock trading volume and book-to-market ratio is subsumed by other variables and thus their coefficients lose significance at the 5% level in the multivariate regressions. Thirdly, the risk-neutral skewness and the ATM implied volatility of the S&P100 index capture some proportion of the movements of individual skewness over time. However, the proportion is small compared to that explained by firm-specific factors. Finally, the previous skewness contains important information about the current risk-neutral skewness.

5.4 Alternative measures of variables

To investigate the robustness of the results of our regression analysis, we repeat the pooled regressions defined by Equation (12), using some alternative measures of variables. The results are shown in Table 8.

Firstly, in our main results, the weekly risk-neutral skewness is calculated as the mean of daily observations. As sometimes the mean and median of daily values within the week can deviate from each other because of the existence of extreme values, we estimate again the weekly risk-neutral skewness using the median value of daily observations. The mean of the weekly risk-neutral skewness, measured as median values of daily observations, across all firms, is –0.210. The correlation between it and that measured by the daily mean is 93.68%. The results of the pooled regression with risk-neutral skewness measured as median values of daily observations are shown in the first column of Table 8. Comparing the results with those in regression *I* of Table 6, there is not much difference in both the coefficient estimates and the explanatory powers.

Secondly, as the trading volume of options might not be able to capture the number of open contracts, we estimate the market sentiment index as the ratio between the open interests of put options and the open interests of all options. The mean of the ratio measured by open interests for all firms is 35.01%, which is 3% higher than the mean of the ratio measured by trading volume. The pooled regression is performed again by substituting the ratio of put open interest to all open interest for the variable PUT/ALL. The results are presented in Table 8, under the column of regression *II*. We can not find much change in the significance, sign and magnitude in the coefficient estimates. The market sentiment index measured by options' open interests is negatively related with risk-neutral skewness. The adjusted explanatory power of the regression is 0.2% less than that of regression *I* in Table 6.

Thirdly, the results of the pooled regression when substituting beta for systematic risk proportion are shown in regression *III* of Table 8. Beta at time t is computed as the coefficient estimate of Equation (7), when regressing the firm's daily stock returns onto the returns of the S&P100 index from day $t-250$ to day t. Different from the systematic risk proportion, a higher beta does not always mean a higher correlation between the firm's return and the market return. The average beta for firms during our sample period is 1.122 and the correlation between it and the systematic risk proportion is 26.69%. As the value of beta is overall higher than that of systematic risk proportion, the coefficient estimate of beta, -0.03, is less negative than that of the systematic risk proportion shown in regression *I* of Table 6.

Finally, we estimate the pooled regression using different measures of information asymmetry. Different time intervals of 5, 15, 60 minutes and 24 hours, combined with different weighting methods, of transaction-size weighted average and equally weighted average, all generate consistent results. To save space, we only present the regression result when using the information asymmetry measure calculated as the transaction-sized weighted daily averages of traders' profits over 15 minutes intervals, under the column of regression *IV* of Table 8. The results are nearly identical to those of regression *I* of Table 6.

6 Conclusion

In this paper, we estimate the risk-neutral skewness of 149 U.S. firms, according to the method in BKM (2003). We investigate the relations between various firm specific variables and the risk-neutral skewness, in order to point out which variables are important in determining the prices of individual options.

First of all, we confirm again that there are cross-sectional differences in the risk-neutral skewness of individual firms. Variables that represent sentiment (proxied by put-to-all option trading volume), liquidity (proxied by option and stock trading volume), firm size, firm's volatility, leverage ratio, information asymmetry, and volatility asymmetry are all important in explaining the cross-sectional variation in risk-neutral skewness. Consistent with Dennis and Mayhew (2002), but different from Toft and Prucyk (1997), our results imply that the leverage ratio is not negatively but positively related with risk-neutral skewness. The information asymmetry measure, which has not been connected with risk-neutral skewness before, is proved to be helpful in explaining the variation in risk-neutral skewness.

Secondly, consistent with Dennis and Mayhew (2002), our results address the importance of market risk components when pricing individual options. The importance is reflected by the negative and significant relation between the firm's risk-neutral skewness and the firm's systematic risk proportion. In addition, the volatility and risk-neutral skewness of the stock index are also proved to contain some information about the risk-neutral distribution of individual firms.

There might be additional factors that remain uncovered in our study that can be evaluated in a future research study. It would be also interesting to incorporate more cross-sectional differences in the developments, tests and comparisons of option pricing models when the underlying assets are individual stocks. Our findings, consistent with BKM (2003) and Dennis and Mayhew (2002), establish the differences between the risk-neutral distribution of individual stocks and that of the market index. The differences might carry over to theoretical research on the differential pricing in individual options versus index options.

Reference

Bakshi, Gurdip, Nikunj Kapadia, and Dilip Madan, 2003, Stock Return Characteristics, Skew Laws, and the Differential Pricing of Individual Equity Options, *The Review of Financial Studies* 16, 101-143.

Bakshi, Gurdip, and Dilip Madan, 2000, Spanning and derivative-security valuation, *Journal of Financial Economics* 55, 205-238.

Bardong, Florian, Söhnke M. Bartram, and Pradeep K. Yadav, 2006, Informed Trading, Information Asymmetry, and Pricing of Information Risk: Empirical Evidence from the NYSE, *Working Paper*.

Black, Fisher, 1976, Studies of stock price volatility changes, *Proceedings of the American Statistical Association, Business and Economic Statistics Section* 177-181.

Blair, Bevan J., Ser-Huang Poon, and Stephen J. Taylor, 2002, Asymmetric and crash effects in stock volatility for the S&P 100 index and its constituents, *Applied Financial Economics* 12, 319 - 329.

Bliss, Robert R., and Nikolaos Panigirtzoglou, 2002, Testing the stability of implied probability density functions, *Journal of Banking & Finance* 26, 381-422.

Bliss, Robert R., and Nikolaos Panigirtzoglou, 2004, Option-Implied Risk Aversion Estimates., *Journal of Finance* 59, 407-446.

Chen, Joseph, Harrison Hong, and Jeremy C. Stein, 2001, Forecasting crashes: trading volume, past returns, and conditional skewness in stock prices, *Journal of Financial Economics* 61, 345-381.

Christoffersen, Peter, Kris Jacobs, and Gregory Vainberg, 2006, Forward-Looking Betas, *Working Paper*.

Dennis, Patrick, Stewart Mayhew, and Chris Stivers, 2006, Stock Returns, Implied Volatility Innovations, and the Asymmetric Volatility Phenomenon., *Journal of Financial & Quantitative Analysis* 41, 381-406.

Duan, Jin-chuan, and Jason Z. Wei, 2006, Is Systematic Risk Priced in Options?, *Rotman School of Management Working Paper No. 06-05*.

Easley, David, Maureen O'Hara, and P. S. Srinivas, 1998, Option Volume and Stock Prices: Evidence on Where Informed Traders Trade, *The Journal of Finance* 53, 431-465.

Fama, Eugene F., and James D. MacBeth, 1973, Risk, Return, and Equilibrium: Empirical Tests, *The Journal of Political Economy* 81, 607-636.

Figlewski, Stephen, 1989, Options Arbitrage in Imperfect Markets, *The Journal of Finance* 44, 1289-1311.

French, Kenneth R., and Richard Roll, 1986, Stock return variances: The arrival of information and the reaction of traders, *Journal of Financial Economics* 17, 5-26.

Glosten, Lawrence R., Ravi Jagannathan, and David E. Runkle, 1993, On the Relation between the Expected Value and the Volatility of the Nominal Excess Return on Stocks, *The Journal of Finance* 48, 1779-1801.

Harris, Milton, and Artur Raviv, 1993, Differences of Opinion Make a Horse Race, *The Review of Financial Studies* 6, 473-506.

Harvey, Campbell R., and Akhtar Siddique, 1999, Autoregressive Conditional Skewness, *The Journal of Financial and Quantitative Analysis* 34, 465-487.

Hong, Harrison G., and Jeremy C. Stein, 1999, Differences of Opinion, Rational Arbitrage and Market Crashes, *Working Paper*.

Malz, Allan M, 1997a, Estimating the probability distribution of the future exchange rate from option prices, *Journal of Derivatives* 5, 18.

Malz, Allan M., 1997b, Option-Implied Probability Distributions and Currency Excess Returns, *Working Paper*.

Naik, Narayan Y., and Pradeep K. Yadav, 2003, Trading Costs of Public Investors with Obligatory and Voluntary Market-Making: Evidence from Market Reforms, *Working Paper*.

Nelson, Daniel B., 1991, Conditional Heteroskedasticity in Asset Returns: A New Approach, *Econometrica* 59, 347-370.

Newey, Whitney K., and Kenneth D. West, 1987, A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix, *Econometrica* 55, 703-708.

Pan, Jun, and Allen M. Poteshman, 2006, The Information in Option Volume for Future Stock Prices, *Review of Financial Studies* 19, 871-908.

Pena, Ignacio, Gonzalo Rubio, and Gregorio Serna, 1999, Why do we smile? On the determinants of the implied volatility function, *Journal of Banking & Finance* 23, 1151-1179.

Shimko, D., 1994, Bounds of Probabiltiy, *Risk* 6, 33-37.

Taylor, Stephen J., and Gary X. Xu, 1994, The magnitude of implied volaitlty similes: theory and empirical evidence for exchange rates, *Review of Futures Markets* 13, 355-380.

Taylor, Stephen J., Yadav, Pradeep K. and Zhang, Yuanyuan, 2007, The information content of implied volatilities and model-free volatility expectations: Evidence from options written on individual stocks, *Working paper*.

Toft, Klaus Bjerre, and Brian Prucyk, 1997, Options on Leveraged Equity: Theory and Empirical Tests, *The Journal of Finance* 52, 1151-1180.

White, Halbert, 1980, A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity, *Econometrica* 48, 817-838.

Figure 1 Time-series plot of risk-neutral skewness

The figure plots the weekly risk-neutral skewness of the S&P100 index and the median values of the weekly risk-neutral skewness across 149 firms, observed from January 1996 to December 1999. The risk-neutral moments are computed using the method in BKM (2003).

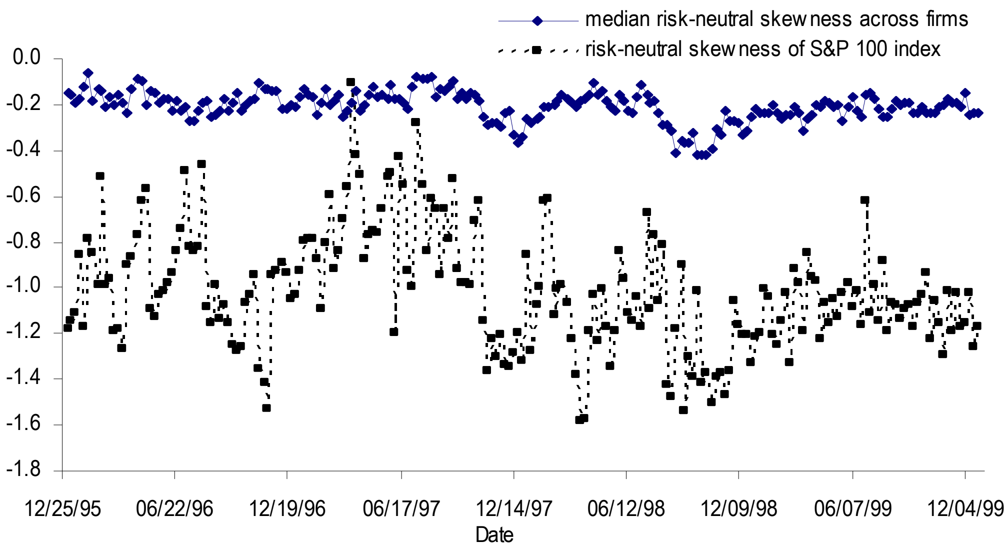

Table 1 Summary statistics for independent variables

The table contains the summary statistics for independent variables used in the following regressions. There are 31,141 weekly observations for 149 firms, during the sample period from January 1996 to December 1999. PUT/ALL is the ratio of put to all trading volume of options on the firm's stock. TV_OP is the natural logarithm of option trading volume in number of contracts. TV_STOCK is the natural logarithm of underlying stock trading volume in thousands of shares. SIZE is the natural logarithm of the firm's market capitalization in thousands of dollars. SRP refers to the systematic risk proportion, which is the R^2 when regressing the firm's daily stock returns onto the S&P100 index returns. VOL is the at-the-money option implied volatility. Leverage and B/M respectively refer to the firm's leverage and book-to-market ratio. IA is the information asymmetry measure defined by Naik and Yadav (2003), calculated as the equally weighted daily average of positioning spread over a 15 minutes interval; *bp* refers to basis points. A is the asymmetric volatility ratio obtained from the GJR (1,1) model estimated by using daily stock returns, the statistics of it are across 149 firms. Days-to-Maturity is the weekly average days to maturity of options used in our study. SKEW_M is the risk-neutral skewness of the S&P 100 index, computed using the method in BKM (2003) and VOX_M is the CBOE's volatility index, VOX, on the S&P100 stock index.

	Mean	Lower Quartile	Median	Upper Quartile	Standard deviation
PUT/ALL	0.319	0.188	0.307	0.432	0.191
TV_OP	5.729	4.433	5.740	6.947	1.794
TV_STOCK	6.829	6.059	6.881	7.662	1.239
SIZE	15.577	14.285	15.459	16.862	1.720
SRP	0.182	0.087	0.151	0.246	0.128
VOL	0.486	0.341	0.476	0.604	0.179
LEVERAGE	0.122	0.002	0.038	0.157	0.189
B/M	0.313	0.142	0.247	0.395	0.281
IA (*bp*)	11.051	5.591	8.855	14.124	8.167
A	0.366	0.040	0.220	0.493	0.529
SKEW_M	-1.018	-1.190	-1.038	-0.861	0.258
VOX_M	0.231	0.197	0.224	0.255	0.054

Table 2 Summary statistics of risk-neutral skewness

The table contains the summary statistics of the risk-neutral skewness, calculated using the method provided by BKM (2003). The sample consists of 149 firms, each of which has 209 weekly observations during the sample period from January 1996 to December 1999. ρ_τ is the autocorrelation of the time-series risk-neutral moment at lag τ. We have τ equal to 1 to 5 lags. The last column counts the number of firms when the Ljung-Box Q-statistics at lag τ is significant at the 1% level. In each panel, the firms are sorted by five different industry sectors, defined by Ken French, with Cnsmr representing Consumer, Manuf referring to manufacturing, HiTech referring to High technology and Hlth referring to Health. The number in parentheses after each sector's name is the number of firms within each industry sector.

	Mean	Lower Quartile	Median	Upper Quartile	Standard Deviation	No. of firms with significant Ljung-Box Q-statistic at 1% level
All firms	-0.205	-0.390	-0.205	-0.029	0.328	
ρ_1	0.336	0.252	0.339	0.419	0.128	134
ρ_2	0.186	0.099	0.176	0.255	0.121	133
ρ_3	0.133	0.049	0.115	0.215	0.120	127
ρ_4	0.118	0.044	0.102	0.188	0.119	127
ρ_5	0.097	0.030	0.081	0.149	0.107	126
Sorted by different industry sectors:						
Cnsmr (13)	-0.194	-0.406	-0.183	0.002	0.375	
Manuf (21)	-0.196	-0.381	-0.192	-0.014	0.326	
HiTec (69)	-0.213	-0.390	-0.212	-0.048	0.311	
Hlth (23)	-0.212	-0.397	-0.215	-0.026	0.336	
Other (23)	-0.189	-0.382	-0.193	-0.004	0.342	

Table 3 Correlation between variables

This table contains the correlation coefficients between the variables that appear in the following regressions. The number of weekly observations is 31,141 for 149 firms during the period from January 1996 to December 1999. SKEW is the risk-neutral skewness of individual firms; PUT/ALL is the ratio of put to all options' trading volume; TV_OP, TV_STOCK and SIZE, are respectively the natural logarithms of option trading volume in number of contracts, of stock trading volume in thousands of shares and of the firm's equity value in thousands of dollars; SRP refers to the systematic risk proportion, which is the R^2 when regressing the firm's daily stock returns onto the S&P100 index returns; VOL is the at-the-money option implied volatility; D/E and B/M respectively refer to the firm's leverage ratio and book-to-market ratio; IA is the information asymmetry calculated as the equally weighted daily average of positioning spread over a 15 minutes interval; A is the asymmetric volatility ratio defined as the effect from positive shocks on the next conditional variance divided by the effect from both positive and negative shocks; SKEW_M is the risk-neutral skewness of the S&P100 index; VOX_M is the CBOE's volatility index on the S&P 100 index. The risk-neutral skewness for firms and the S&P 100 index are computed using the method in BKM (2003). All correlations are stated as percentages.

	SKEW	PUT/ALL	TV_OP	TV_STOCK	SIZE	SRP	VOL	D/E	B/M	IA	A	SKEW_M
PUT/ALL	-8.0											
TV_OP	-19.0	11.5										
TV_STOCK	-19.3	9.8	82.0									
SIZE	-15.7	11.4	63.0	70.3								
SRP	-17.2	11.6	40.3	45.5	67.3							
VOL	-4.6	-3.7	-8.9	-11.1	-60.4	-31.5						
D/E	8.9	3.8	-6.2	-14.8	0.5	7.7	-20.8					
B/M	7.8	2.1	-15.7	-21.4	-25.7	-11.4	-1.1	45.3				
IA	4.6	-7.3	-37.8	-41.1	-65.0	-39.1	53.7	-8.6	8.8			
A	3.9	1.0	-6.2	-11.5	-9.5	-16.5	-4.0	-3.4	1.4	1.5		
SKEW_M	10.0	-2.5	-3.2	-5.2	-4.1	-16.6	-9.4	0.0	0.5	3.0	0.0	
VOX_M	-15.1	9.3	6.1	12.8	7.0	28.8	22.2	-0.1	0.1	4.6	0.0	-25.2

Table 4 Results of univariate regressions

The table shows the univariate regression results when regressing risk-neutral skewness on various factors. The left 4 columns show the results of cross-sectional regressions that run the regressions once a week across 149 firms for 209 weeks. Mean coef. and Mean R^2, adj. R^2 are respectively the time-series averages of the weekly coefficients and of weekly explanatory powers; the numbers in parentheses are t-statistics computed from time-series coefficients and adjusted for autocorrelations; the column labelled " % t-stat n/p" counts the percentages of weeks when the coefficient is negatively (n)/ positively (p) significant at the 5% level based on the White t-statistics. The last 3 columns are the pooled regressions results, with n=31,141. The numbers in parentheses are the Newey-West t-statistics. PUT/ALL is the ratio of put to all options' trading volume; TV_OP, TV_STOCK and SIZE are respectively the natural logarithms of option trading volume in number of contracts, of stock trading volume in thousands of shares and of the firm's equity value in thousands of dollars; VOL is the at-the-money option implied volatility; SRP is the systematic risk proportion that is the explanatory power when regressing the firm's daily stock returns on the S&P100 index returns; D/E and B/M are the firm's leverage and book-to-market ratio; IA is the information asymmetry calculated as the equally weighted daily average of positioning spread over a 15 minutes interval; A is the asymmetric volatility ratio defined as the effect from positive shocks onto the next conditional variance divided by that from both positive and negative shocks; SKEW_M and VOX_M are respectively the risk-neutral skewness and the CBOE's volatility index of the S&P 100 index. The asterisk * indicates a significant estimate at the 5% level.

	Cross-sectional regressions				**Pooled Regressions**		
	Mean Coef.	% t-stat n/p	Mean R^2	Mean adj. R^2	Coef.	R^2	adj. R^2
PUT/ALL	-0.11* *(-11.6)*	11.5/0.5	1.15%	0.48%	-0.14* *(-9.3)*	0.64%	0.64%
TV_OP	-0.03* *(-9.3)*	58.0/0	4.91%	4.26%	-0.03* *(-17.9)*	3.60%	3.60%
TV_STOCK	-0.05* *(-11.5)*	60.3/0	4.66%	4.01%	-0.05* *(-18.4)*	3.73%	3.73%
Size	-0.03* *(-4.9)*	47.4/0	4.73%	4.09%	-0.03* *(-13.0)*	2.46%	2.46%
SRP	-0.35* *(-6.1)*	40.7/0	3.31%	2.66%	-0.44* *(-13.4)*	2.95%	2.94%
VOL	0.00 *(0.1)*	10.5/9.6	1.61%	0.95%	-0.08* *(-4.1)*	0.21%	0.21%
D/E	0.16* *(6.6)*	0.0/19.6	1.69%	1.02%	0.15* *(6.8)*	0.79%	0.79%
B/M	0.10* *(12.8)*	0.5/14.8	1.59%	0.92%	0.09* *(5.9)*	0.61%	0.61%
IA	27.67* *(2.9)*	0.5/18.2	1.57%	0.90%	20.89* *(4.8)*	0.32%	0.31%
A	0.02* *(3.2)*	1.4/10.0	0.88%	0.20%	0.02* *(3.5)*	0.15%	0.15%
SKEW_M					0.13* *(11.1)*	1.01%	1.00%
VOX_M					-0.92* *(-14.0)*	2.29%	2.29%

Table 5 Results of multivariate cross-sectional regressions

This table contains the time-series averages of the results from weekly multivariate cross-sectional regressions. The model is defined as: $\text{SKEW}_i = \beta_0 + \beta_1 \text{PUT/ALL}_i + \beta_2 \text{TV\_OP}_i + \beta_3 \text{TV\_STOCK}_i + \beta_4 \text{SIZE}_i + \beta_5 \text{SRP}_i + \beta_6 \text{VOL}_i + \beta_7 \text{LEVERAGE}_i + \beta_8 \text{B/M}_i + \beta_9 \text{IA}_i + \beta_{10} \text{A}_i + \varepsilon_i$. SKEW is the risk-neutral skewness at time t, computed based on the method in BKM (2003). All the explanatory variables are defined in the same way as in Table 4. The regression is run once a week across 149 firms over 209 weeks. Mean coef. is the mean of weekly coefficient estimates; the numbers in parentheses are the t-statistics computed from weekly coefficients and adjusted for autocorrelations; the column labelled " % t-stat n/p" counts the percentages of weeks when the coefficient is negatively (n)/ positively (p) significant at the 5% level according to the White t-statistics; Mean R^2 and adj. R^2 are the averages of the weekly explanatory powers. The asterisk * indicates a significant estimate at the 5% level using a two tailed t-test.

	Model I		*Model II*		*Model III*	
	Mean Coef.	% t-stat n/p	Mean Coef.	% t-stat n/p	Mean Coef.	% t-stat n/p
Intercept	0.63* *(6.3)*	0.5/17.2	0.09 *(3.2)*	0.5/3.8	-0.23* *(-6.0)*	45.9/0
PUT/ALL	-0.07* *(-5.0)*	8.1/1.0	-0.07* *(-5.9)*	8.1/0.5	-0.10* *(-9.2)*	10.5/0.5
TV_OP	-0.01* *(-3.2)*	7.7/1.4	-0.02* *(-4.3)*	16.3/1.0		
TV_STOCK	-0.00 *(-0.0)*	3.8/4.3	-0.02* *(-3.9)*	6.2/1.0		
Size	-0.04* *(-4.8)*	18.2/0.5				
SRP	-0.12* *(-2.9)*	4.8/0	-0.24* *(-5.4)*	9.1/0		
VOL	-0.24* *(-7.8)*	10.5/0.5	-0.06 *(-1.3)*	4.8/3.3	-0.05 *(-1.4)*	6.2/3.8
D/E	0.10* *(4.4)*	0.5/8.1	0.11* *(4.7)*	0.5/9.1	0.12* *(4.6)*	0.5/10.0
B/M	-0.01 *(-0.9)*	2.4/1.9	0.02* *(2.1)*	1.4/2.9	0.05* *(4.5)*	1.0/6.7
IA	-9.46* *(-3.0)*	7.2/1.0	-10.27 *(-1.9)*	6.2/1.0	34.67* *(4.9)*	1.4/12.0
A	0.01 *(1.0)*	2.4/4.8	0.01 *(1.4)*	2.4/5.3	0.02* *(3.5)*	1.4/11.5
Mean R^2	13.85%		12.57%		7.28%	
Mean Adj. R^2	7.61%		6.19%		3.36%	

Table 6 Results of multivariate pooled regressions

The table shows the multivariate pooled regressions results, defined as: $\text{SKEW}_{i,t} = \beta_0 + \beta_1 \text{PUT/ALL}_{i,t} + \beta_2 \text{TV\_OP}_{i,t} + \beta_3 \text{TV\_STOCK}_{i,t} + \beta_4 \text{SIZE}_{i,t} + \beta_5 \text{SRP}_{i,t} + \beta_6 \text{VOL}_{i,t} + \beta_7 \text{LEVERAGE}_{i,t} + \beta_8 \text{B/M}_{i,t} + \beta_9 \text{IA}_{i,t} + \beta_{10} \text{A}_i + \beta_{11} \text{SKEW\_M}_t + \beta_{12} \text{VOX\_M}_t + \beta_{13} \text{SKEW}_{i,t-1} + \varepsilon_{i,t}$, where i and t index the firm and week. SKEW is risk-neutral skewness at time t, computed based on the method in BKM (2003). All variables are defined in the same way as in Table 4. There are 31,141 weekly sets of observations, calculated as the mean of daily observations, from January 1996 to December 1999 for 149 firms. The numbers in parentheses are the Newey-West t-statistics computed from the heteroscedasiticity and autocorrelation consistent standard errors. R^2, Adj. R^2, F-statistic and the number of observations of each regression model are shown in the last four rows. The asterisk * indicates a significant estimate at the 5% level using a two tailed t-test. Columns *I* to *V* are for five separate pooled regression specifications.

	I	*II*	*III*	*IV*	*V*
Intercept	0.59*	0.27*	0.05*	0.54*	0.42*
	(7.7)	*(9.5)*	*(2.5)*	*(5.9)*	*(8.0)*
PUT/ALL	-0.08*	-0.09*	-0.12*	-0.09*	-0.07*
	(-6.1)	*(-6.3)*	*(-8.1)*	*(-6.6)*	*(-6.5)*
TV_OP	-0.02*	-0.02*		-0.01*	-0.01*
	(-5.7)	*(-7.0)*		*(-4.3)*	*(-5.0)*
TV_STOCK	0.00	-0.01*		0.00	0.00
	(0.3)	*(-2.4)*		*(0.0)*	*(1.5)*
Size	-0.03*			-0.03*	-0.02*
	(-4.7)			*(-4.7)*	*(-5.3)*
SRP	-0.15*	-0.24*		-0.26*	-0.08*
	(-4.0)	*(-6.5)*		*(-6.5)*	*(-3.3)*
VOL	-0.17*	-0.07*	-0.06*	-0.26*	-0.13*
	(-4.6)	*(-3.3)*	*(-2.7)*	*(-5.9)*	*(-4.8)*
D/E	0.12*	0.12*	0.13*	0.12*	0.08*
	(5.4)	*(5.3)*	*(5.4)*	*(5.1)*	*(5.4)*
B/M	-0.01	0.01	0.05*	-0.01	-0.01
	(-0.4)	*(1.0)*	*(2.9)*	*(-0.9)*	*(-0.6)*
IA	-16.13*	-9.71*	26.20*	-16.14*	-9.65*
	(-4.2)	*(-2.7)*	*(5.7)*	*(-4.1)*	*(-3.2)*
A	0.01	0.01	0.02*	0.00	0.00
	(1.3)	*(1.5)*	*(4.0)*	*(0.1)*	*(1.3)*
SKEW_M	0.07*	0.07*	0.08*		0.04*
	(6.5)	*(6.6)*	*(7.3)*		*(6.0)*
VOX_M	-0.48*	0.51*	-0.76*		-0.33*
	(-7.4)	*(-8.2)*	*(-11.6)*		*(-7.6)*
Lagged SKEW					0.38*
					(38.0)
R^2	7.79%	7.56%	4.63%	6.92%	21.12%
Adj. R^2	7.75%	7.53%	4.61%	6.89%	21.09%
F-statistic	219.01	231.42	188.92	231.29	638.06
No.of observations	31,141	31,141	31,141	31,141	30,992

Table 7 Results of multivariate pooled regressions with monthly observations

The table shows the multivariate pooled regressions results, defined as: $SKEW_{i,t} = \beta_0 + \beta_1 PUT/ALL_{i,t} + \beta_2 TV\_OP_{i,t} + \beta_3 TV\_STOCK_{i,t} + \beta_4 SIZE_{i,t} + \beta_5 SRP_{i,t} + \beta_6 VOL_{i,t} + \beta_7 LEVERAGE_{i,t} + \beta_8 B/M_{i,t} + \beta_9 IA_{i,t} + \beta_{10} A_i + \beta_{11} SKEW\_M_t + \beta_{12} VOX\_M_t + \beta_{13} SKEW + \varepsilon_{i,t}$, where i and t index the firm and week. SKEW is the risk-neutral skewness at time t, computed based on the method in BKM (2003). All variables are defined in the same way as in Table 4. There are 7152 monthly sets of observations, collected after the option's maturity date in each month from January 1996 to December 1999 for 149 firms. The numbers in parentheses are the Newey-West t-statistics computed from the heteroscedasiticity and autocorrelation consistent standard errors. R^2, Adj. R^2, F-statistic and the number of observations of each regression model are presented in the last four rows. The asterisk * indicates a significant estimate at the 5% level using a two tailed t-test. Columns *I* to *V* are for five separate pooled regression specifications.

	I	*II*	*III*	*IV*	*V*
Intercept	0.61*	0.26*	0.09*	0.51*	0.53*
	(5.3)	*(5.6)*	*(2.8)*	*(4.1)*	*(5.5)*
PUT/ALL	-0.07*	-0.08*	-0.11*	-0.08*	-0.06*
	(-3.1)	*(-3.2)*	*(-4.4)*	*(-3.3)*	*(-2.5)*
TV_OP	-0.02*	-0.02*		-0.01*	-0.02*
	(-3.5)	*(-4.4)*		*(-2.5)*	*(-3.7)*
TV_STOCK	0.01	0.00		0.01	0.02*
	(1.1)	*(-0.4)*		*(1.0)*	*(2.3)*
Size	-0.03*			-0.03*	-0.03*
	(-3.4)			*(-3.8)*	*(-3.9)*
SRP	-0.15*	-0.24*		-0.29*	-0.11*
	(-2.7)	*(-4.6)*		*(-5.0)*	*(-2.2)*
VOL	-0.14*	-0.03	-0.01	-0.26*	-0.12*
	(-2.7)	*(-0.9)*	*(-0.3)*	*(-4.5)*	*(-2.7)*
D/E	0.12*	0.12*	0.12*	0.11*	0.10*
	(3.2)	*(3.2)*	*(3.2)*	*(3.0)*	*(3.4)*
B/M	-0.02	0.00	0.03	-0.03	-0.02
	(-1.1)	*(-0.1)*	*(1.3)*	*(-1.6)*	*(-1.3)*
IA	-14.78*	-7.58	22.53*	-12.95	-13.38*
	(-2.1)	*(-1.1)*	*(3.4)*	*(-1.8)*	*(-2.0)*
A	0.01	0.01	0.03*	0.00	0.01
	(1.4)	*(1.6)*	*(3.1)*	*(0.3)*	*(1.6)*
VOX_M	0.07*	0.08*	0.09*		0.07*
	(4.2)	*(4.3)*	*(5.0)*		*(4.3)*
VOX_M	-0.75*	-0.79*	-1.04*		-0.69*
	(-7..6)	*(8.2)*	*(-10.1)*		*(-8.0)*
Lagged SKEW					0.19*
					(12.6)
R^2	8.86%	8.57%	5.71%	7.30%	12.29%
Adj. R^2	8.71%	8.43%	5.61%	7.17%	12.12%
F-statistic	57.83	60.83	54.10	51.40	75.32
No.of observations	7,152	7,152	7,152	7,152	7,003

Table 8 Results of multivariate pooled regressions with alternative measure of variables

The table shows the multivariate pooled regressions results, defined as: $\text{SKEW}_{i,t} = \beta_0 + \beta_1 \text{PUT/ALL}_{i,t} + \beta_2 \text{TV\_OP}_{i,t} + \beta_3 \text{TV\_STOCK}_{i,t} + \beta_4 \text{SIZE}_{i,t} + \beta_5 \text{SRP}_{i,t} + \beta_6 \text{VOL}_{i,t} + \beta_7 \text{LEVERAGE}_{i,t} + \beta_8 \text{B/M}_{i,t} + \beta_9 \text{IA}_{i,t} + \beta_{10} \text{A}_i + \beta_{11} \text{SKEW\_M} + \beta_{12} \text{VOX\_M}_t + \beta_{13} \text{SKEW}_{i,t-1} + \varepsilon_{i,t}$,where i and t index the firm and week. SKEW is the risk-neutral skewness computed according to BKM (2003); PUT_oi/ALL_oi is the ratio of put to all options' open interests; BETA is the coefficient when regressing the firm's daily stock returns on the S&P100 index returns; IA_TW is the information asymmetry calculated as the transaction-size weighted daily average of positioning spread over a 15 minutes intervals. All the other variables are defined in the same way as in Table 4. The weekly sets of observations are calculated as the mean of daily values, except that the dependent variable of the regression in the 1st column is the weekly risk-neutral skewness computed as the median of daily values. Number of observation is 31,141 from January 1996 to December 1999, for 149 firms. The numbers in parentheses are the Newey-West t-statistics from the heteroscedasiticity and autocorrelation consistent standard errors. R^2, Adj. R^2, and F-statistic of each regression model are presented in the last three rows. The asterisk * indicates a significant estimate at the 5% level using a two tailed t-test. Columns *I* to *IV* are for five separate pooled regression specifications.

	I	*II*	*III*	*IV*
Intercept	0.54*	0.59*	0.75*	0.56*
	(6.3)	*(7.6)*	*(10.5)*	*(7.4)*
PUT/ALL	-0.09*		-0.08*	-0.08*
	(-6.3)		*(-6.0)*	*(-6.0)*
PUT_oi /ALL_oi		-0.03		
		(-1.6)		
TV_OP	-0.02*	-0.02*	-0.02*	-0.02*
	(-6.0)	*(-5.8)*	*(-5.5)*	*(-5.4)*
TV_STOCK	0.00	0.00	0.01	-0.00
	(0.6)	*(0.4)*	*(1.2)*	*(-0.0)*
Size	-0.02*	-0.03*	-0.04*	-0.02
	(-3.8)	*(-4.7)*	*(-7.2)*	*(-4.2)*
SRP	-0.16*	-0.16*		-0.16*
	(-4.2)	*(-4.0)*		*(-4.1)*
Beta			-0.03*	
			(-3.0)	
VOL	-0.14*	-0.17*	-0.16*	-0.18*
	(-3.1)	*(-4.5)*	*(-4.3)*	*(-4.7)*
D/E	0.13*	0.12*	0.11*	0.13*
	(5.5)	*(5.3)*	*(5.0)*	*(5.6)*
B/M	-0.00	-0.01	-0.01	-0.00
	(-0.3)	*(-0.4)*	*(-0.6)*	*(-0.1)*
IA	-17.09*	-16.20*	-16.93*	
	(-4.3)	*(-4.2)*	*(-4.4)*	
IA_TW				-11.23*
				(-3.0)
A	0.01	0.01	0.01	0.01
	(1.7)	*(1.2)*	*(1.4)*	*(1.3)*
SKWE_M	0.07*	0.07*	0.07*	0.07*
	(6.4)	*(6.4)*	*(7.0)*	*(6.4)*
VOX_M	-0.48*	-0.49*	-0.59*	-0.48*
	(-7.2)	*(-7.6)*	*(-8.9)*	*(-7.5)*
R^2	7.31%	7.58%	7.70%	7.76%
Adj. R^2	7.27%	7.55%	7.67%	7.73%
F-statistic	204.44	212.77	216.52	218.25