Is Trading What Makes Prices Informative? Evidence from Option Markets

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Abstract

I investigate the information content in the implied volatility spread, which is the spread in implied volatilities between a pair of call and put options with the same strike price and time-to-maturity. I find that even volatilities implied from untraded options contain information about future stock performance. The trading strategy based on the information contained in the actively traded options does not necessarily outperform its counterpart derived from the untraded options. This is inconsistent with the previous research suggesting that the information contained in the implied volatility spread largely results from the price pressure induced by informed trading in option markets. Further analysis suggests that the magnitude of this spread is associated with the measures of option illliquidity and underlying risk-neutral higher moments. A larger spread is associated with higher option illiquidity, and smaller risk-neutral variance, more negative risk-neutral skewness, and seemingly larger risk-neutral kurtosis. I design a calibration study which reveals that the non-normality of the underlying risk-neutral return distribution relative to the Brownian motion can give rise to the implied volatility spread through the channel of early exercise premium.

I Introduction

It is generally agreed in the existing literature that option markets contain information that can predict future stock prices cross-sectionally.[1] The source of this information remains an open question. A stream of research treats observed option prices as equilibrium values. These option prices reflect the characteristics of the underlying stock's risk-neutral return distribution, such as risk-neutral skewness and kurtosis. Investors' risk preference embodied in these equivalent martingale measures relates to the shape of the pricing kernel, and in turn to the future stock returns. Another stream infers that observed option prices convey information about supply and demand conditions, and possibly incorporate the information about the underlying stocks channelled through informed trading in option markets. In this paper, I investigate the source of the information option prices consist of in the context of implied volatility spread (IV spread), which is the difference in implied volatilities between a pair of call and put options with the same time-to-maturity and strike price. I explore whether trading is what makes option prices informative, and the channel through which information that is closely related to future stock returns gets incorporated into option prices.

For European options, Black-Scholes IV spread should be zero as long as the put-call parity holds.[2] Cremers and Weinbaum (2010) suggest that the emergence of non-zero IV spread is driven by the price pressure induced by informed trading in option markets, and find that the magnitude of the IV spread can predict future stock returns. The intuition is that informed trading moves the prices of options in the direction consistent with the private information, which is not yet, but will be later on, reflected in stock market. Consistent with this account, they find the association between IV spread and PIN, which is usually considered a proxy for informed trading.

The evidence on the existence of trading induced price pressure in option markets, however, is mixed. Vijh (1990), for example, documents the absence of price

[1] See, for example, Sorescu (2000), Chakravarty, Gulen and Mayhew (2004), Pan and Poteshman (2006), Bali and Hovakimian (2009), Xing, Zhang and Zhao (2010), Cremers and Weinbaum (2010), Billings and Jennings (2011), Conrad, Dittmar and Ghysels (2013), and An et al. (2014), among others.

[2] Cremers and Weinbaum (2010).

effects surrounding large option trades for the CBOE options, and conclude that the information-related option trading is not prevalent on CBOE based on the examination of the options on NYSE-listed stocks during March and April of 1985. Muravyev (2016), on the other hand, finds that the price impact of trading activity in option markets is large, although the inventory effect is much stronger than the asymmetric information effect. Furthermore, recent literature suggests that PIN is more of a measure of liquidity than of private information. For example, Duarte and Young (2009) show that the component in PIN related to asymmetric information is not priced and does not contribute to PIN's explanatory power for the cross-sectional variation in stock returns. The persistence of the predictive power may also be too strong to be interpreted as the manifestation of informed trading. The IV spread can predict future stock returns on a weekly, even monthly basis, while whether price discovery in option markets exists is inconclusive in literature and the limited evidence mostly lies in high frequency trading (Easley, O'Hara and Srinivas (1998); Kane (2014)).

Bali and Hovakimian (2009), instead, associate the IV spread with jump risk. They show that the stocks in the quintile with the lowest IV spread are associated with the lowest jump risk, and that portfolio jump risk increases almost monotonically when moving from quintile 1 to quintile 5 during roughly the same period as Cremers and Weinbaum (2010). They, therefore, interpret the IV spread as a proxy for jump risk. They also show that this spread is associated with PIN. However, they do not demonstrate the channel through which jump risk is incorporated into the IV spread. The source of the information contained in the IV spread is still worth more examination.

In investigating this question, I conduct the analysis with several sets of options with no trading volume or no open interest. The purpose of examining these options is to isolate the information in option prices for future stock returns in the absence of trading activities. I find that the IV spread constructed from options with no trading volume or no zero interest can predict future stock return as well. More specifically, its ability to predict future stock return is comparable to its counterparts constructed from the actively traded options. These results suggest that there are factors that are not investigated in Cremers and Weinbaum (2010) but contribute to the predictive content in the IV spread.

To explore this idea, I first demonstrate the relationship between the measures of option illiquidity and the extent to which option prices deviate from put-call parity, as the illiquidity measures can mechanically give rise to such a deviation. Then, I estimate the model-free measures of risk-neutral moments for each stock from the option prices using the approach developed by Bakshi, Kapadia, and Madan (2003), and consider the risk-neutral profile of each portfolio characterized by the pre-formation IV spread. I find that the magnitude of the IV spread is associated with the risk-neutral distribution of the underlying stock return. Specifically, stocks with larger IV spreads display smaller risk-neutral variance and more negative risk-neutral skewness. I decompose the risk-neutral moments as in Conrad, Dittmar, and Ghysels (2010), and the decomposition suggests that the systematic components in these equivalent martingale measures drive this association. Stocks with larger IV spreads have smaller covariance, more negative co-skewness, and larger co-kurtosis in the q-measure.

As the Black-Scholes IV spread would be zero for European options as long as put-call parity holds, it is intuitive to consider the relation between non-zero IV spreads and the American feature of individual stock options. I design a calibration study in which the log-return of the underlying stock follows a jump-diffusion process to evaluate the size of the EEP relative to the non-normality of the underlying distribution. The results suggest that the size of the EEP can account for more than 72% of the variation in the magnitude of the IV spread, and varies across the risk-neutral return distribution of the underlying stock in a way that is consistent with my empirical findings.

My investigation of the information content in the IV spread contributes to the understanding of information in option prices about the underlying stocks by demonstrating the association of magnitude of IV spread with trading activity as well as with the underlying stock return distribution. The second contribution of my paper is placing the informational role of securities with no trading activities under scrutiny. Previous literature generally puts more importance on actively traded options. Conrad, Dittmar, and Ghysels (2010) require that there be positive trading volume in out-of-money options for a stock to be included in their sample. Cremers and Weinbaum (2010) exclude option pairs for which either the call or put has zero open interest. Bali and Hovakimian (2009) also work with positive open interest options. Options with zero trading volume or zero open interest account for a significant portion of the full sample. Specifically, more than half of the listed options are not traded in my sample. Therefore, it is important to understand whether these options contain information about the underlying stock, and if they do, how much information there is. I provide evidence that the untraded options contain information about the underlying stock return as well.

My research also sheds light on the understanding of American feature of options. I embed the non-normality into the underlying risk-neutral distribution in my calibration study, and show that the size of the early exercise premium (EEP) varies across the degree of non-normality. The calibration also suggests that the EEP relates to the magnitude of the IV spread. Thus EEP can serve as a link between the risk-neutral return distribution of the underlying stock and the magnitude of the corresponding IV spread.

The rest of the paper is organized as followed. Section II describes the data used in this paper. Section III presents the main empirical results regarding the information content in the IV spread. Section IV explores the IV spread in terms of its associations with the option market illiquidity and with the underlying risk-neutral moments. Section V presents the calibration study. Section VI presents the additional discussion. Section VII concludes.

II Data

I obtain the option data from the company "Historical Option Data".[3] The underlying securities include stocks, indexes, and ETFs. The data set spans February 2002 to November 2013. It has end-of-the-day (4:00PM EST) information on each option contract, including the date, underlying symbol, root number, strike price, bid and ask prices, price of the underlying stock, and trading volume. Open Interest is always a day behind as the OCC changes this number at 3:00AM every morning.

[3] The company website: https://www.historicaloptiondata.com/

The number of underlying securities with options listed has increased over the years. The first day in the data (February 8th, 2002) has 1,956 unique underlying symbols; on the last day (November 25th, 2013), there are 4,079. The market has grown dramatically, with 107,296 quoted contracts on February 8th, 2002 and 600,390 on November 25th, 2013.

On each Wednesday, I calculate implied volatilities from individual options using the binomial tree model that accounts for the early exercise and the dividends expected to be paid over the lives of the options. I linearly interpolate Libor to obtain risk-free rates. When calculating the implied volatility spreads, I select options following the convention in the literature. I only include those options with moneyness (the ratio of the underlying price to the strike price) between 0.7 and 1.3. In addition, I filter out observations that violate the no-arbitrage constraints. I only include options with times-to-maturity (TTM) longer than a week and less than a year. I exclude options whose implied volatilities are not in the range of 0 to 150%. Both call and put have to satisfy these constraints to be included into the sample.

Note that I calculate the implied volatilities mostly in the way described in the Reference Manual of OptionMetrics,[4] which is a more commonly adopted database in current literature, but I do not smooth the implied volatility surface.

Cremers and Weinbaum (2010) calculate the IV spread by weighting the spread between each pair of call-implied and put-implied volatilities by average open interest. In order to take the information in the inactively traded options into account as well, I construct an alternative IV spread by equally weighting spreads across all strikes and times-to-maturity for each stock. I merge each calculated IV spread on each Wednesday with the underlying stock's next week return. The weekly returns are calculated by compounding the daily stock returns from each Thursday to the next Wednesday. The daily stock data is from CRSP, and I only include stocks with exchange code 10 or 11, and share code 1, 2, or 3. I calculate IV spreads in the monthly analysis in the same manner on the last trading day of each month. I then merge these with CRSP monthly data.

[4]See Chapter 3 (page 29 and beyond).

Table 1 presents the numbers of option pairs and firms by time-to-maturity and trading activity on all the Wednesdays between February 8th, 2002 and November 25th, 2013 in my sample. More than half of the listed option contracts are not traded. For example, there are 6,495,730 option pairs in the 1-to-3-month group, of which 3,538,440 have zero volume. If only one leg of the pair, either the call or the put, has zero volume, I do not include the pair in the second column. While fewer pairs have zero open interest in both call and put options, these still account for a material portion of the full sample. Most firms have experienced at least one Wednesday on which some of their listed options are not traded. The markets for shorter term options have grown significantly in terms of the number of firms with option listed, while the scale of the markets for longer term options slightly shrinks.

Table 2 reports summary statistics on the IV spreads. Each stock has a single IV spread calculated every Wednesday. The average IV spread is -0.38% and the median is -0.25% in the full sample, which indicates that the distribution of IV spread is left skewed. Its standard deviation is 7.44%, indicating considerable variation in the size of the IV spread. I calculate 1,266,070 IV spreads in the full sample. This number is 1,209,156 for the zero trading volume sample. Fewer stocks are included in the sample in which their options are ”inactively traded” by stricter eligibility criteria, but they still account for a notable portion of the full sample. The only sample that could be too small to perform a meaningful test on is the one in which the stocks have options listed but none of the options have positive open interest on that Wednesday; there are 11,376 IV spreads in this category over the entire test period–less than 1% of the entire sample.

Table 3 demonstrates the migration of stocks across IV spread portfolios. Panel A reports the transition frequency in a week for stocks in each portfolio. 44.49% of the stocks in portfolio 1 (with the smallest IV spreads) remain in the bottom portfolio the next week, while 40.65% of the firms in the top portfolio stay. Panels B, C, D, and E report these transitions at 4-week, 12-week, 26-week, and 52-week frequencies, respectively. The percentage of stocks that remain in the same portfolio declines with the horizon. Nevertheless the IV spreads of the stocks in two extreme portfolios are somewhat persistent and those stocks are more likely to stay in the same portfolio than to migrate into any of the other four portfolios even 52 weeks later.

In order to explore whether IV spread has any implication for the underlying stock's risk-neutral profile, I apply the approach developed by Bakshi, Kapadia and Madan (2003) to recover the higher moments of each stock in the equivalent martingale (q-) measure from observed option prices. Each day I select OTM calls and puts used to calculate the risk-neutral higher moments by following Conrad, Dittmar, and Ghysels (2013). Options must meet the no-arbitrage criteria. The mid-point of bid-ask prices of each selected option is higher than \$0.5. The trading volume on the option must be positive. I use the trapezoidal rule to calculate the integral. A stock is selected only if it has at least two OTM calls or two OTM puts that meet all the inclusion criteria. The resulting sample consists of 33,130,112 daily observations of options across firms, strike, and times-to-maturity. I use options in this sample to calculate the daily risk-neutral variance, skewness, and kurtosis across maturities for each stock. This results in 2,992,415 sets of risk-neutral moments.

III Information Content in IV spread

As discussed in section I, IV spreads contain information about future stock returns during 1996-2005 (Cremers and Weinbaum (2010), Bali and Hovakimian (2009)). However, the extent to which this information gets incorporated into option prices through informed trading and possible market inefficiencies is an open question. In order to investigate this, I perform the analysis on various samples selected based on different criteria in the interest of decomposing the information content in the IV spread according to the source of the information.

III.1 Predictive Content in Untraded Options

Cremers and Weinbaum (2010) build their empirical work on the theory developed by Easley, O'Hara, and Srinivas (1998). Here, informed trading in options moves their prices, and this carries information about the underlying stock. Cremers and Weinbaum

(2010) subsequently show that the predictive content of IV spread is linked with the stock's PIN. Thus they interpret the information contained in the implied volatility spread as informed trading induced price pressure manifesting in option prices.

However, recent literature suggests PIN is more of a measure of liquidity than of private information (e.g., Duarte and Young (2009)). In addition, Vijh (1990) suggests that there is no trading induced price pressure in option markets. Moreover, if the predictive power for future stock returns from the implied volatility spread is due to the demand of the investors with private information, we should observe trading activities on the more expensive options. In order to examine whether this is the case, I perform the analysis on subsamples of options with zero trading volume or zero open interest. I examine whether price pressure does happen in option markets, where institutional features have changed dramatically since the period studied by Vijh (1990). I report equal-weighted portfolio returns in the rest of the paper.

III.1.1 Options with zero trading volume

In this section, I conduct the test on the subsample of options with zero trading volume. Each Wednesday, I select options that are not traded on that day so that their end-of-day prices are less likely to have been affected by trading-induced price pressure. In the first week of the sample period, there are 1,487 unique firms in this sub-sample. This number grows to 2259 in the last week of the sub-sample. Most firms in the option markets have at least one option with no trading volume. If a stock does not have any zero trading volume options, it would not be included into the sample for further analysis. I calculate the IV spread using the selected options for each stock. Then all the stocks are sorted into five portfolios based on the IV spreads calculated from options with zero trading volumes.

Table 4 Panel A reports the results of this analysis. It shows that almost all the measures of portfolio returns increase monotonically in IV spread. The spread between the raw returns on portfolio 5 and portfolio 1 is 36 basis points per week and this spread is 38 basis points after adjusting for all the five systematic risk factors.

As price pressure might be contagious across strike prices on the same underlying stock given the time-to-maturity, I further constrain the sample. I only select a stock if there is at least one time-to-maturity such that all the options with this time-to-maturity on this stock have zero trading volume. There are 940 unique firms selected into the sample in the first week, and 1413 unique firms in the last. Over two thirds of the firms in full sample are selected into this constrained set. I sort stocks based on the quintiles of their IV spreads and form portfolios each Wednesday.

Table 4 Panel B presents the subsequent portfolio returns. The raw return and all the abnormal returns increase in the IV spread. The spread in raw returns between the top portfolio (with the highest IV spread) and the bottom portfolio (with the lowest IV spread) is 34 basis points with a t-statistic of 10.31, and the spread in abnormal returns is even larger.

In the same manner, I further constrain the sample in case the price pressures are not only contagious across strikes, but also across times-to-maturity. I only include a stock into this sample if the firm has options listed but there is no trading volume on any of its option on the sample selection day (Wednesday). With restriction there are 311 unique firms on the first Wednesday, and 550 by the end of the sample period. As suggested in Table 4 Panel C, all the return measures monotonically increase in pre-formation IV spread, and the return on the portfolio with the highest pre-formation IV spread exceeds the return on the portfolio with the lowest by 44-47 basis points. The magnitude of the spread is even larger than its counterpart in the analysis in which IV spreads are constructed from the full sample.

In summary, portfolios sorted based on the pricing of options that are not traded at all on the portfolio formation day also demonstrate increasing returns in the IV spread. If the predictive power of IV spread for future stock returns largely comes from the informed trading, options that are not traded would contain much less information about future stock returns. This is not the case.

III.1.2 Options with zero open interest

Another measure of the trading activeness in option markets is open interest. The option prices on each Wednesday, even for the options on which there is not any trading activity, may have potentially been influenced by informed trading that had happened before. Therefore I also examine the information in options with zero open interest.

The first analysis in this section is conducted on the sample in which all the options used to calculate IV spreads have zero open interest. This sample contains 747 unique firms at the beginning, and 1783 firms at the end of the sample period. As in the previous section, I calculate the IV spread for each stock each Wednesday by equal-weighting the implied volatility spreads between pairs of call and put across all the strikes and times-to-maturity. I sort stocks into five portfolios each Wednesday based on the IV spread constructed from zero open interest options.

Table 5 Panel A reports the post-formation portfolio returns. They generally increase in pre-formation IV spreads. The spread between portfolio 5 and portfolio 1 is 23 to 26 basis points. This is about half of the size in the case of full sample, but still statistically and economically significant.

In order to eliminate the possible price pressure contagion, I constrain the analysis samples as in the previous section. I only select the options with zero open interest across strikes and sort the stocks into portfolios based on IV spreads constructed from those options. This sample consists of 125 unique firms in the first week, and 702 of them in the last week. Table 5 Panel Bshows that all the return measures increase in the IV spread, and the spread between the two extreme portfolios is 32 to 35 basis points per week. With the further stricter sample selection criterion (i.e., a stock would be selected only if it has options listed and the open interests on them are all zero), the size of the selected option sample is very small. There is only one firm that meets the criterion in the sample in the first week. Forty-nine firms meet the criterion in the last week. Table 5 Panel C presents the results. Not surprisingly, the pattern is much less obvious. The return on the portfolio in which stocks have the highest IV spreads is still higher than the return on the portfolio in which stocks have the lowest IV spreads, but the spread is statistically insignificant.

Generally, the prices of options with zero open interest also contain information about future stock returns. To summarize, inactively traded and untraded options, despite the fact that they are less likely to be affected by price pressure, contain a comparable amount of information about future stock returns as the more actively traded options. This implies that the predictive power of the IV spread for future stock returns is not completely driven by informed trading. Other factors not discussed by Cremers and Weinbaum (2010) may play roles in the information content in the IV spread.

III.2 Comparison between Actively and Untraded Options

In this section, I compare the predictive power of the IV spreads emerging from the actively traded options with those in which there is zero trading volume or zero open interest. The purpose of this comparison is to investigate whether trading activity plays a role in the IV spread's predictive content, and if it does, how important the role is. The fact that options that are very unlikely to be affected by price pressure also contain information about future stock returns indicates that other things contribute to the predictive content in the IV spread. The comparison to be conducted in this section reveals whether trading induced price pressure has contribution, too.

I conduct the test described in the previous sections using the sample of options with positive volume or with positive open interest. I examine whether the IV spread derived from options with more trading activity is more informative about future stock returns. More specifically, I subtract the return on the long-short portfolio when pre-formation IV spread is calculated from a certain type of inactively traded options from the return on the long-short portfolio when this spread is derived from the actively traded options; if the more actively traded options are more informative, we would expect the differences to be significantly positive.

Table 6 reports the results. It shows that the difference in the IV spread between the top and the bottom quintile is always larger when IV spread is calculated from options with zero trading volume or with zero open interest, as all the numbers in the first column are negative. Options with positive trading volume have stronger predictive power for future stock returns than those with zero volume, or those with zero volume across strikes at a given time-to-maturity, as the return on the long-short portfolio formed based on the actively traded options is significantly higher than the return on the long-short portfolio formed based on those two types of options with "zero activity". Options with positive open interest also display similarly stronger predictive power. However, the long-short portfolio formed based on positive volume options does not outperform its counterpart formed using options on those stocks with no option volumes across strikes and times-to-maturity. Similarly, the long-short portfolio constructed from positive open interest options does not statistically significantly outperform the long-short portfolio constructed based on options with zero open interest across strikes at a given time-to-maturity.

Options with positive trading volume or positive open interest seem to be more informative about future stock returns than the inactively traded options whose prices are possibly affected by the contagion in price pressure, but do not necessarily contain more information than the untraded options. A possibility is that trading induced price pressure in option markets moves the option prices from the equilibrium determined by the risk-neutral return distribution of the underlying stock. Thus inactively traded options, whose prices are less likely to be moved from equilibrium, contain more information about the underlying risk-neutral density, while the heavily traded options contain more information about the informed trading. Another possibility is that the stocks with least actively traded options are exposed to some specific risk, which is captured by the variation in IV spread. The exact reason is worth exploring.

IV IV Spread, Option Liquidity, and Risk-neutral Distribution

IV.1 Option Illiquidity

In this section I investigate the nature of IV spreads. I first analyze the association of IV spread with bid-ask spread, as larger size of the latter mechanically allows more room for the deviation of option prices from put-call parity, which happens to be an interpretation of the former. I also consider the trading volume of options, as another measure for the option illiquidity. I regress the absolute value of the IV spread on the bid-ask spread and trading volume in various specifications, controlling for timing of the observation (time fixed effect), underlying firm (firm fixed effect), time-to-maturity of the option, and option moneyness either by the variable or by the corresponding fixed effect. For the time-to-maturity fixed effect and moneyness fixed effect, I catogorize options based on their moneyness (0.7 - 0.85; 0.85 - 0.95; 0.95 - 1.05; 1.05 - 1.15; 1.15 - 1.3) and time-to-maturity (<45 days; 45 - 105 days; 106 - 195 days; 196 - 365 days).

Table 7 reports the results, which suggest a robust positive relation between the size of the bid-ask spread and the absolute value of the IV spread. Both call and put tradings reduce this absolute value, which is inconsistent with the argument put forward in prior literature that (informed) trading induced price pressure results in the deviation from put-call parity, and in turn gives rise to the IV spread. As a matter of fact, Table 7 suggests that more trading activities push the option prices closer to the put-call parity. Overall, the IV spread is associated with option illiquidity measures.

IV.2 Risk-Neutral Distribution

I have shown that the predictive power of the IV spread is not necessarily driven by trading activity as suggested by Cremers and Weinbaum (2010). Another stream of literature interprets the information in option prices as a reflection of the representative investor's risk preference embodied in the underlying asset's risk-neutral distribution. Thus I explore if this interpretation is associated with the information content in the

IV spread. I recover the stock return distribution in the equivalent martingale measures using the approach developed by Bakshi, Kapadia and Madan (2003), and examine the risk-neutral profile of the portfolios characterized by the size of the IV spread.

Note that the IV spread would be zero for European options as long as the put-call parity holds, regardless of the choice of option pricing model or the related assumptions about the underlying stock return in p- or q- measures (Cremers and Weinbaum (2010)). For an American option, though, EEP is incorporated as a part of its value; this part is especially significant for a put option. As accounting for the EEP can be technically demanding and tends to be inaccurate, the IV spread does not necessarily indicate an arbitrage relation for an American option, and is likely to emerge from the EEP. The risk-neutral higher moments may work through the American feature of options, and associate with the measure of the deviation from the put-call parity: IV spread.

IV.2.1 Risk-neutral higher moments and co-moments

The risk-neutral probability distribution provides the probabilities of outcomes adjusted for risk such that observed price of each security exactly equals the discounted expectation of the price under the equivalent martingale measure. Under this measure, all assets earn the same return as the risk-free rate. Therefore the risk-neutral distribution contains information about the prices of risks.

While it is hard to recover a stock's risk-neutral distribution without making strict assumptions, its characteristics can be described by its moments, namely, the risk-neutral mean, variance, skewness, and kurtosis. Bakshi, Kapadia and Madan (2003) develop an approach to estimate these equivalent martingale measure moments using observed prices of OTM options. They show that in general, the payoff to any security can be constructed from the prices of a set of options on the security. They define volatility contract $V_{i,t}(\tau)$, cubic contract $W_{i,t}(\tau)$ and quartic contract $X_{i,t}(\tau)$ as the contracts that have the payoffs of squared, cubic, and quartic security returns, respectively. Then they show that risk-neutral moments can be written as functions of these contracts, in turn as functions of observed options prices. Formally,

$$VAR^Q_{i,t}(\tau) = e^{r\tau}V_{i,t}(\tau) - \mu_{i,t}(\tau)^2 \tag{1}$$

$$SKEW^Q_{i,t}(\tau) = \frac{e^{r\tau}W_{i,t}(\tau) - 3\mu_{i,t}(\tau)e^{r\tau}V_{i,t}(\tau) + 2\mu_{i,t}(\tau)^3}{(e^{r\tau}V_{i,t}(\tau) - \mu_{i,t}(\tau)^2)^(3/2)} \tag{2}$$

$$KURT^Q_{i,t}(\tau) = \frac{e^{r\tau}X_{i,t}(\tau) - 4\mu_{i,t}(\tau)W_{i,t}(\tau) + 6\mu_{i,t}(\tau)^2e^{r\tau}V_{i,t}(\tau) - \mu_{i,t}(\tau)^4}{(e^{r\tau}V_{i,t}(\tau) - \mu_{i,t}(\tau)^2)^2} \tag{3}$$

where the prices of volatility, cubic, and quartic contracts can be expressed as

$$V_{i,t}(\tau) = \int_{S_{i,t}}^{\infty} \frac{2(1 - ln(\frac{K_i}{S_{i,t}}))}{K_i^2} C_{i,t}(\tau; K_i)dK_i + \int_0^{S_{i,t}} \frac{2(1 + ln(\frac{K_i}{S_{i,t}}))}{K_i^2} P_{i,t}(\tau; K_i)dK_i \tag{4}$$

$$W_{i,t}(\tau) = \int_{S_{i,t}}^{\infty} \frac{6(ln(\frac{K_i}{S_{i,t}})) - 3ln((\frac{K_i}{S_{i,t}}))^2}{K_i^2} C_{i,t}(\tau; K_i)dK_i + \int_0^{S_{i,t}} \frac{6(ln(\frac{K_i}{S_{i,t}})) + 3ln((\frac{K_i}{S_{i,t}}))^2}{K_i^2} P_{i,t}(\tau; K_i)dK_i \tag{5}$$

$$X_{i,t}(\tau) = \int_{S_{i,t}}^{\infty} \frac{12(ln(\frac{K_i}{S_{i,t}}))^2 - 4ln((\frac{K_i}{S_{i,t}}))^3}{K_i^2} C_{i,t}(\tau; K_i)dK_i + \int_0^{S_{i,t}} \frac{12(ln(\frac{K_i}{S_{i,t}}))^2 + 4ln((\frac{K_i}{S_{i,t}}))^3}{K_i^2} P_{i,t}(\tau; K_i)dK_i \tag{6}$$

and

$$\mu_{i,t} = e^{r\tau} - 1 - e^{r\tau}V_{i,t}(\tau)/2 - e^{r\tau}W_{i,t}(\tau)/6 - e^(r\tau)X_{i,t}(\tau)/24 \tag{7}$$

Conrad, Dittmar, and Ghysels (2013) extend the application of this approach by decomposing the risk-neutral moments into systematic and idiosyncratic components. With the single factor model

$$r_{i,t} = a_i + b_i r_{m,t} + e_{i,t} \tag{8}$$

co-skewness can be expressed as

$$COSKEW^Q_t(r_{i,t+\tau}, r_{m,t+\tau}) = b_i SKEW^Q_{m,t}(\tau) \frac{VAR^Q_{m,t}(\tau)}{\sqrt{VAR^Q_{i,t}(\tau)}} \tag{9}$$

and co-kurtosis can be expressed as

$$COKURT_t^Q(r_{i,t+\tau}, r_{m,t+\tau}) = b_i KURT_{m,t}^Q(\tau)\frac{VAR_{m,t}^Q(\tau)}{VAR_{i,t}^Q(\tau)} \tag{10}$$

Conrad, Dittmar, and Ghysels (2013) estimate b_i using the procedure in Coval and Shumway (2001):

$$b_i = \frac{S_i}{C_{i,t}}\left(\frac{ln(\frac{S_{i,t}}{K_i}) + (r - \delta + 0.5\sigma^2)\tau}{\sigma\sqrt{\tau}}\right)\beta_i \tag{11}$$

Note that this is an approximate estimation of b_i in that Coval and Shumway (2001) work under the framework of Black-Scholes model, which does not consider higher moments of the underlying return. I leave the correction of this estimation to future examination.

Furthermore, Conrad, Dittmar, and Ghysels (2013) regress the total higher moments in q-measure on the co-moments to estimate the idiosyncratic components.

IV.2.2 Risk-neutral profile of portfolios characterized by IV spread

I select options by the criteria described in the data section, and calculate the daily risk-neutral moments of each stock across maturities using the approach described above. I also decompose these higher moments into systematic and idiosyncratic components. I average the daily moments and their components over a week starting from each Thursday and ending with the next Wednesday to obtain the estimations of these equivalent martingale measures on a weekly basis. Then I sort stocks into quintiles based on the IV spread each Wednesday and consider the risk-neutral profile of the stocks in each portfolio. The q-measures have horizons that correspond to the times-to-maturity of the options used in the estimation procedure. I use options that have times-to-maturity closest to 1 month and 12 months, and the results are consistent across choices of option maturities.

Table 8 presents the results when I work with the options with maturities closest to 1 month. The IV spreads are calculated using options with zero trading volume (Panel A), zero open interest (Panel B), positive trading volume (Panel C), or positive open interest (Panel D). It shows that as one goes from quintile one to quintile five, the risk-neutral variances of the stocks in the portfolio on average decline. Stocks with larger IV spreads are associated with smaller risk-neutral variance. With IV spread constructed from zero volume options, the average risk-neutral variance of stocks with the smallest IV spread is 0.0216, while this measure for the portfolio with the largest IV spread is 0.0156. The difference is 0.0060 and statistically significant. This difference is larger when the stocks are sorted into quintiles based on actively traded options (with positive volume or positive open interest). The pattern with risk-neutral skewness is not clear when stocks are sorted by the IV spreads emerging from inactively traded options, but the results suggest that options with positive volume or open interest also contain information about the third moment q-measure. The skewness becomes more negative as one goes from quintile one to quintile five in Panel C and D, and the differences between the top and bottom quintiles are significantly negative.

Table 8 also presents the systematic components of the risk-neutral moments. I decompose each risk-neutral moments into systematic and idiosyncratic components as Conrad, Dittmar, and Ghysels (2013). The results suggest consistent pattern in the systematic components of risk-neutral variance and skewness, especially with IV spread emerging from actively traded options (Panel C and D). Though the measure of risk-neutral kurtosis does not display any pattern associated with IV spread, its systematic component does increase in the size of the spread. The difference in the co-kurtosis between the top and bottom quintile is statistically significant.

Table 9 presents the results when I work with the options with maturities closest to 12 months. All the patterns observed in Table 8 still hold. In contrast, the idiosyncratic components in general do not display any clear pattern in their association with IV spread except for idiosyncratic component of risk-neutral skewness. Table 10 reports the behavior of the idiosyncratic components in the risk-neutral moments.

These results are related with Conrad, Dittmar, and Ghysels (2013). They find a negative relation between ex ante volatility and subsequent returns cross-sectionally, while this relation is positive for kurtosis. They also find more negative skewness is related with higher subsequent returns. My results are consistent in that I show that larger IV spread, which predicts higher future returns, is associated with smaller risk-neutral variance, more negative skewness, and arguably larger kurtosis. Moreover, I show that the primary drive of this association is the systematic components in these higher moments.

V Calibration Study

I conduct a calibration study to further demonstrate the relation between the risk-neutral distribution of the underlying stock return and the magnitude of the corresponding IV spread. I also explore the potential channel through which the risk-neutral higher moments impact the magnitude of the IV spread. As I study American options, and put-call parity strictly holds only for European options, the deviation from put-call parity can intuitively be attributed to the options' American features (EEP), which the evidence in prior literature supports (Kamara and Miller (1995)). The magnitude of the EEP is unobservable and can only be estimated. The estimation would depend on the underlying option pricing model. In order to show the exact relationships among the IV spread, the EEP, and the underlying risk-neutral distribution, I calibrate the dynamics in stock prices under a jump-diffusion process based on the model developed by Hilliard and Schwartz (2005). The jump process introduces non-normality relative to the Brownian motion, and provides a window for studying the potential channel through which the risk-neutral higher moments give rise to the IV spread.

V.1 The Jump-Diffusion Process

In Hilliard and Schwartz (2005), the stock price follows a jump-diffusion process, and they describe this process using a bivariate tree. One dimension of the tree that models $ln\frac{S}{dS}$ is the smooth arithmetic Brownian motion, while the other dimension is jumps that are normal under Poisson compounding. Namely, the risk-neutral version of the underlying jump-diffusion is

$$\frac{dS}{S} = (r - q - \lambda\bar{k})dt + \sigma dz + kdq \tag{12}$$

where r is the risk-free rate, q is the continuous dividend yield, σ is the volatility of the smooth diffusion process, λ is the intensity of the jumps in the Poisson process, and k is the random jump magnitude with the average size of $\bar{k} = e^{\gamma} - 1$ where $ln(1 + k) \sim N(\gamma', \delta^2)$. Then we have

$$V_t = ln\frac{S_t}{S_0} = X_t + Y_t \tag{13}$$

where

$$X_t = (r - q - \lambda\bar{k} - \frac{\sigma^2}{2})t + \sigma z(t) \tag{14}$$

which is arithmetic Brownian motion and

$$Y_t = \sum_i ln(1 + k_i) \tag{15}$$

which is a normal random variable under Poisson compounding.

For the smooth diffusion, the probability of going up is

$$p = 0.5(1 + \frac{dt}{\sigma}(r - q - \lambda\bar{k} - \frac{\sigma^2}{2})) \tag{16}$$

where dt is the length of the time step, and for each discontinuous jump, the probability $q(j)$ is given by the equation system

$$\sum_{j=-m}^{m} (jh)^{i-1} q(j) = \mu'_{i-1}, i = 1, 2, ..., 2m + 1 \tag{17}$$

for a $2m + 1$ jump grid, where h is the jump spacing, and μ'_{i-1} is the ith local moment of Y. Then the probability of each node on the bivariate tree is pq.

As the approximation of μ_{i-1} is given by Stuart and Ord (1994), I can calibrate the jump-diffusion process provided the values of the parameters. Consistent with Hilliard and Schwartz (2005), I adopt the spot price $S_0 = 40$, risk-free rate $r = 0.08$, volatility of the smooth diffusion $\sigma = \sqrt{0.05}$, $m = 3$, and volatility of the jump $\delta = \sqrt{0.05}$. In order to consider the dynamics in EEP and risk-neutral higher moments (RNM) across moneyness, time-to-maturity, jump intensity, and jump size, I create variations in strike price (K: 30, 35, 40, 45, 50), time-to-maturity (T: 1 month, 3 months, 6 months, 1 year), jump intensity (λ: 0.01, 1, 2, 3, 4, 5, 6), and average jump size (γ: -0.05, 0, 0.05). As prior literature is not conclusive about the relative sizes of σ and δ, I also calibrate stock and option prices using (σ, δ) = (0.2040, 0.0633) (Eraker (2004)) and (σ, δ) = (0.1404, 0.2646) (Bakshi, Cao and Chen (1997)). There are 1260 American option prices and their corresponding European option prices calibrated. I then calculate the exact EEP under the Hillard and Schwartz (2005) model and the corresponding risk-neutral higher moments given by Bates (1991). The underlying stock in the calibration does not pay a dividend during the life of the options, thus the EEP is the difference in option prices between the American put and the European put.

V.2 IV Spread, Early Exercise Premium, and Underlying Risk-Neutral Distribution

First, I analyze the relationship between the risk-neutral higher moments of the underlying stock return and the EEP of the options. I regress EEP on the risk-neutral moments while controlling for the time-to-maturity and the moneyness of the option:

$$EEP = b_0 + b_1 * T + b_2 * var + b_3 * skew + b_4 * kurt + b5 * moneyness \tag{18}$$

where var, $skew$, and $kurt$ are the risk-neutral variance, skewness, and kurtosis, and $moneyness$ is $\frac{S_0 e^{rT}}{K}$.

Table 11 presents the results. It suggests that larger EEP is associated with smaller risk-neutral variance and skewness, and larger risk-neutral kurtosis after controlling for the option's moneyness and time-to-maturity, and the relation is statistically significant. Note that the relation between the kurtosis and the EEP appears to be negative when variance and skewness are not controlled. This can be largely attributed to the association of kurtosis with skewness and variance when the higher moments get embedded into the underlying risk-neutral distribution through jumps.

Second, I construct the IV spread and the EEP for each set of parameter values of σ, λ, γ, and δ. The IV spread is calculated as done for each stock in the previous empirical study, and the EEP is the EEP in the last calibration analysis averaged across times-to-maturity and strikes. Then I regress IV spread on EEP. Table 12 presents the results. They suggest that the size of EEP is significantly positively related to the magnitude of the IV spread, and the explanatory power of EEP for the cross-sectional variation in the IV spread is more than 72%.

Next I discuss the intuition behind these relationships. As the number of jumps (λ) and the average jump size (γ) shape the underlying risk-neutral return distribution, I focus on the impact of λ and γ on the magnitude of EEP and IV spread. In order to demonstrate such an impact more clearly, I calibrate a second set of option prices with spot 100, strikes 90 and 110, when the number of jumps (λ) increases from 1 to 6, while the average jump size (γ) is either 0.1 or -0.1.

Table 13 presents this second set of calibration. As the number of jumps λ increases, both the calls and the puts get more expensive. It is consistent with the intuition that more jumps bring in larger uncertainty, which in turn makes the options more valuable. When the average jump size switches from 0.1 to -0.1, however, the calls and the puts get more expensive only for the strike price 90; for the strike price 110, both get cheaper instead. This can be attributed to at least three effects that a negative jump can have on the underlying distribution as suggested in Table 15. One, provided that the other parameter values stay the same, as the Brownian motion is positively skewed, a negative jump can offset a part of the volatility from the Brownian motion therefore making the underlying distribution less volatile. Two, a negative jump can shift the initially right-skewed underlying distribution (Brownian motion) towards the left. Finally, the negative jump makes the tail of the distribution less fat as well. Each effect can push the value of an option moving in opposite directions. The overall impact applies asymmetrically on the options with different moneyness.

Table 14 presents how the IV spread and the EEP change in the number of jumps and the average jump size, which suggests the following patterns. First, jumps cause the option holders less likely to exercise early, thus the EEP decreases as the number of jumps gets larger. Second, although more jumps always make the options more valuable, the effects on calls and puts differ in terms of the magnitude of the implied volatility. Third, the magnitude of the IV spread does not always move in one direction as the number of jumps grows. That being said, when averaged across strikes, the positive correlation tends to dominate. And fourth, the EEP tends to be larger in the presence of the negative jumps. This helps explain the relationship between the risk-neutral higher moments as shown in Table 15 and the EEP: a larger EEP is associated with smaller risk-neutral variance and skewness. As for the kurtosis, such an association is more complex since it is a fourth order moment and nests in the first three moments in some degree. Table 14 also suggests that overall, the size of the EEP and the magnitude of the IV spread are positively associated stock-wise.

The calibration study shows that the non-normality of the underlying risk-neutral return distribution relative to the Brownian motion can mechanically give rise to the non-zero IV spread through the channel of EEP, which can account for a large portion of the variation in the IV spread. Given the well documented relation between the risk-neutral higher moments and the future stock return, the predictive power of the IV spread can well be due to the information it contains about those higher moments.

VI Additional Discussion

I perform additional exercises to further explore the nature of the information content in the IV spread. First, I analyze the impact of dividend payment on the predictive content in the IV spread. Second, I examine the predictive power of the IV spread for future cross-sectional returns on a longer horizon.

VI.1 Predictive Content in IV Spread and Dividend Payment

I have discussed the EEP in put options in the previous section. Although it is usually thought that early exercise is more commonly-seen with put options, it can also be optimal to exercise an American call option just before the ex-dividend date to capture the dividend. A call option on a dividend-paying stock tends to be relatively more expensive as its value possibly consists of an EEP if there is ex-dividend date between the valuation date and the expiry date. However, my calculation of the IV spread does not recognize this premium, and instead, the positive EEP would manifest in a larger call-implied volatility. Cremers and Weinbaum (2010), in turn, would attribute this apparent larger IV spread to informed trading induced price pressure. In other words, a larger IV spread can simply arise as the underlying stock has ex-dividend dates during the life of the call option. Thus the profitability of the trading strategy based on the magnitude of the IV spread may result from the dividend-capture nature of the strategy. I explore this idea by looking into the information content in those options that expire before ex-dividend dates of the underlying stocks in comparison with options on stocks that have ex-dividend dates between now and the expiry date. I perform the analysis using two sets of options: those that will expire in 15 to 45 days, and those that will mature in 75 to 105 days.

Table 16 presents results using options with positive open interest. The IV spread tends to be larger when there are ex-dividend date(s) of the underlying stock between now and the expiry date of the option. The top and bottom quintiles where the underlying stocks have ex-dividend date(s) during the lives of the options almost always have larger IV spreads and higher subsequent weekly returns than the corresponding quintiles where the options expire before the ex-dividend dates of the underlying stocks. Such a difference is specifically obvious for options with shorter terms; investors using this dividend-capturing strategy are more likely to exploit shorter-term options. This indicates that the profitability of holding the long-short portfolio constructed from the pre-formation IV spread can be partially attributed to going after the stocks which will make dividend payments soon. Table 17 presents the same analysis with the options with zero open interest. The pattern in general holds, although the size of each subsample shrinks by more than half and the results get noisier.

VI.2 Longer-horizon Analysis

I conduct the analysis on a monthly basis and sort stocks into deciles as a robustness check. If the return predictability of the IV spread is primarily driven by the informed trading, such a predictability would be less likely to be observed on a longer horizon, especially if the information existing in the untraded options is left there because of price pressure contagions in the first place.

VI.2.1 Options with zero trading volume and monthly returns

In this section, I perform the tests on the subsamples of options with zero trading volume. In the first month of the testing time period, there are 1,499 unique firms in this sub-sample. This number grows to 2,278 in the last month of the sub-sample. Most firms in the option markets have at least one option with no trading volumes. I take the simple average of the spreads across strike prices and times-to-maturity.

I sort stocks into ten portfolios based on the IV spreads calculated from options with zero trading volumes on the last trading day of each month. Table 18 shows that portfolio returns increase in the IV spread. The spread between the raw returns on portfolio 10 and portfolio 1 is 141 basis points and this spread is 111 basis points after adjusting for all the five systematic risk factors.

Table 18 Panel A presents the results for the set of stocks with no trading volume on options across strike prices given the time-to-maturity. In the first month of the testing time period, there are 1,083 unique firms in the sample. This number grows to 1,511 in the last month of the sub-sample. More than half of the firms in the full sample have options with no trading volume across strike prices for a given time-to-maturity. Portfolio returns increase in the IV spread. The return on the portfolio in which stocks have the most expensive call options relative to the put options is 0.87% after adjusting for all the five systematic risk factors, and the return on the portfolio in which stocks have the least expensive call options relative to the put options is -0.55%. The spread between them is 1.42% per month and statistically significant.

In the same manner, I perform the analysis on a further smaller subset. I only include a stock into the sample if it has options listed but there is no trading volume on the options at all across all strike prices and times-to-maturity. There are 277 unique firms at the end of the first month in this sub-sample, and this number grows to 524 by the end of the sample period. Table 18 Panel B suggests that the results still hold. The difference between the risk-adjusted returns from Fama-French-Carhart-Harvey-Siddique 5-factor model on portfolio 10 and portfolio 1 is 1.41% per month and statistically significant.

In unreported analysis, I also perform tests on subsamples with only positive call option trading volume or only positive put option trading volume, and the results hold as well.

VI.2.2 Options with zero open interest and monthly returns

In this section, I perform the analysis on the subsamples of options with zero open interest. As in the previous section, I construct the implied volatility spread weighting the implied volatility spreads between each pair of call and put across all the strikes times-to-maturity equally so that each stock has a single implied volatility spread each month. Then, I examine whether this spread has predictive power for future stock returns.

On the last trading day of each month, I sort the stocks into ten portfolios based on IV spreads constructed from options with zero open interest as of this date. Table 19 Panel A shows that portfolio returns increase in the IV spread. The raw monthly return on the portfolio with the smallest implied volatility spread (i.e., with the most expensive put options and least expensive call options) is 0.41%, while the raw monthly return on the portfolio with the largest implied volatility spread is 1.38%. The spread between them is 0.97% per month. It is statistically significant but smaller than the spread from the full sample. After adjusted for the systematic risks, including market risk, HML, SMB, Momentum, and Harvey and Siddique's co-skewness factor, the difference between the returns on the tenth portfolio and the first is 0.57% per month and statistically significant.

It is possible that price pressure in some options may be contagious to other options with the same time-to-maturity. For this reason, I perform the analysis on a smaller subsample. This sub-sample only includes options that have zero open interest across all strike prices for a given time-to-maturity. Table 19 Panel B presents the results. Portfolio returns still generally increase in the IV spread. The return on the portfolio in which stocks have the most expensive call options relative to the puts is 1.03% after adjusted for all the five systematic risk factors, and the return on the portfolio in which stocks have the least expensive call options and the most expensive put options is -0.73%. This difference is 176 basis points per month and has a t-statistic of 4.5.

In unreported analysis, I also consider the stocks on which the listed options have no open interest at all. However, there is no significant result, potentially due to the small sample size (only 6 stocks in the first month and 44 in the last).

VII Conclusion

In this paper I investigate the information content in the IV spread, defined as the difference in implied volatilities between a pair of call and put options with the same time-to-maturity and strike price. Cremers and Weinbaum (2010) and Bali and Hovakimian (2009) document that this spread has predictive power for future stock returns, which diminishes over time. They relate this predictive power to informed trading-induced price pressure in different degrees. I extend the analysis of Cremers and Weinbaum (2010) to the sample period 2002-2013. In order to investigate the extent to which the predictive power of the implied volatility spread for future stock return is due to private information flowing into option markets prior to the equity market, I conduct the analysis using different sets of untraded options. I select the options with zero trading volume or zero open interest so that I can rule out price pressure. The results are comparable to the over-all sample. I also conduct the analysis using the more constrained sub-samples in which the possible price pressure contagion is further limited. The predictive power of the IV spread for future stock returns still holds. I compare the predictive content in the IV spread derived from options with positive volume or with positive open interest to the information contained in the IV spread calculated from untraded options. The analysis suggests that options with positive volume or positive open interest do not necessarily contain more information than the options whose prices are the least likely to be affected by trading induced price pressure. These results suggest that the hypothesis that the predictive content in the IV spread reflects the presence of informed trading in option markets is incomplete.

I further the analysis by examining the association of the IV spread with the option liquidity and the risk-neutral profile of the stocks in each portfolio characterized by the IV spread. I find that the deviation from put-call parity, as measured by the absolute value of the IV spread, is associated with larger bid-ask spread and less option trading activity after controlling for other features of the option. I also find a larger IV spread is associated with smaller risk-neutral variance and more negative risk-neutral skewness. The association is primarily driven by the systematic components in the risk-neutral higher moments. These findings suggest that the IV spread can reflect the difference in the shapes of the underlying stocks' distributions in the equivalent martingale measure. This interpretation is in line with Conrad, Dittmar and Ghysels (2013).

I conduct a calibration study to explore the channel through which the underlying risk-neutral distribution impacts the magnitude of the IV spread. The analysis of the calibration suggests that the risk-neutral return distribution of the underlying stock can be associated with the magnitude of the IV spread through EEP in the way consistent with my empirical findings.

Overall, I find that the predictive content in the implied volatility spread is, at best, partially driven by the trading activities in option markets. A very important piece of information regarding the underlying return distribution (and in turn, the associated risk), the non-normality, gets to impact the magnitude of the implied volatility spread through American options' early exercise premium; this information would eventually get materialized in the future stock returns.

Table 1. Number of Put-Call Pairs

Table 1 presents the numbers of put-call pairs (Panel A) and unique underlying symbols (Panels B, C, and D) by time-to-maturity (TTM) and trading activity in the weekly analysis. The first column presents the number of option pairs/unique underlying symbols in the full sample. The second column presents the number of option pairs/unique underlying symbols that have zero trading volume. The third column presents the number of option pairs/unique underlying symbols that have zero open interest. Panel B presents the full sample period, and Panels C and D present the years of 2002 and 2013, respectively.

TTM\Trading Activities	Full Sample	Zero Volume	Zero Open Interest
Panel A: Number of Option Pairs			
< 1 month	2,440,725	1,143,623	279,747
1 - 3 months	6,495,730	3,538,440	1,118,249
3 - 6 months	5,870,208	3,503,806	389,942
6 - 12 months	3,171,415	2,196,206	656,615
Panel B: Number of Unique Underlying Symbols			
< 1 month	4,337	4,312	4,158
1 - 3 months	4,364	4,356	4,332
3 - 6 months	4,366	4,357	4,202
6 - 12 months	4,254	4,249	4,215
Panel C: Number of Unique Underlying Symbols(2002)			
< 1 month	1,974	1,895	1,563
1 - 3 months	1,994	1,967	1,875
3 - 6 months	1,999	1,976	1,603
6 - 12 months	1,980	1,970	1,835
Panel D: Number of Unique Underlying Symbols(2013)			
< 1 month	2,665	2,655	2,467
1 - 3 months	2,695	2,694	2,676
3 - 6 months	2,684	2,681	2,370
6 - 12 months	1,711	1,709	1,668

Table 2. Summary Statistics of IV Spread

Table 2 presents the summary statistics of the IV spreads calculated from different sets of options in the weekly analysis. On each Wednesday, the IV spread is calculated by equally weighting all the spreads in implied volatilities between pairs of call and put options on the same underlying stock. Full Sample is the full option sample. Zero Volume 1 is the sample in which there is zero trading volume in the options. Zero Volume 2 is the sample in which there is zero trading volume in the options across strikes given a maturity. Zero Volume 3 is the sample in which there is zero trading volume in the options across strikes and times-to-maturity. Zero Open interest 1 is the sample in which options have zero open interest. Zero Open interest 2 is the sample in which options have zero open interest across strikes given a maturity. Zero Volume 3 is the sample in which options have zero open interest across strikes and times-to-maturity.

Sample \Statistics	Mean	Median	Std. Dev.	N
Full Sample	-0.38%	-0.25%	7.44%	1,266,070
Zero Volume 1	-0.36%	-0.32%	7.91%	1,209,156
Zero Volume 2	-0.13%	-0.25%	8.89%	777,838
Zero Volume 3	0.63%	0.11%	10.94%	277,419
Zero Open Interest 1	0.02%	-0.31%	10.21%	780,755
Zero Open Interest 2	0.77%	-0.03%	12.82%	229,543
Zero Open Interest 3	4.21%	2.15%	21.81%	11,376

Table 3. Transition Frequency

Table 3 presents the transition frequency for stocks in each portfolio characterized by the magnitude of the IV spread. Each row is the percent of the stocks in each portfolio that remain in or migrate into each of the five portfolios. Panels B, C, D, and E report these transitions at 4-week, 12-week, 26-week, and 52-week frequencies, respectively.

	Transition Port No.				
	1	2	3	4	5
Panel A:	1 week				
Port No.					
1	44.49	17.49	11.64	11.23	15.14
2	17.25	27.5	23.89	19.19	12.16
3	11.29	23.9	28.22	24.05	12.54
4	10.97	18.98	23.88	27.2	18.97
5	15.47	12.42	12.74	18.72	40.65
Panel B:	4 weeks				
Port No.					
1	40.64	17.7	12.36	12.29	17.01
2	17.15	25.52	23.59	20.01	13.74
3	11.95	23.3	26.92	23.84	13.99
4	11.96	19.84	23.45	25.46	19.29
5	17.28	14.18	14.37	19.05	35.11
Panel C:	12 weeks				
Port No.					
1	36.57	18.24	13.42	13.53	18.24
2	17.38	24.45	23.59	20.27	14.32
3	12.89	23.23	26.33	23.29	14.25
4	12.98	20.01	23.29	24.8	18.91
5	18.16	14.96	14.68	19.35	32.85
Panel D:	26 weeks				
Port No.					
1	33.13	18.67	14.47	14.73	19
2	17.16	23.77	23.29	20.73	15.05
3	13.46	22.77	25.94	23.13	14.69
4	13.66	20.29	23.26	24.21	18.59
5	18.92	15.69	15.49	19.4	30.5
Panel E:	52 weeks				
Port No.					
1	29.73	19.56	16.08	15.76	18.87
2	17.19	23.54	23.55	20.76	14.97
3	13.74	22.62	25.7	23.26	14.69
4	13.88	20.21	23.09	24.25	18.57
5	18.69	15.85	15.8	19.91	29.74

Table 4. Relation between IV Spread and Portfolio Return: Zero Trading Volume

Table 4 presents the median of the IV spread in each quintile portfolio and the equal-weighted average return of the portfolio following the formation period during 2002-2013. Panels A, B, and C present the results from options with zero volume, zero volumes across strikes given a certain maturity, and zero volumes across strikes and maturities, respectively. The portfolio is sorted by the IV spread calculated from options with no trading volume. The reported IV spread is the median spread between implied volatilities from call and put options in each portfolio. Return is the equal-weighted average weekly return following the formation of the portfolio. CAPM α, 3F α, 4F α and 5F α are the risk-adjusted returns from the CAPM, Fama-French 3-factor model, Fama-French-Carhart 4-factor model, and Fama-French-Carhart-Harvey-Siddique 5-factor model. β is the average beta of the stocks in the portfolio.

Quintile	IV Spread	Return	CAPM α	3F α	4F α	5F α	β
Panel A:							
1	-0.0554	0.0001	-0.0016	-0.0021	-0.0019	-0.0019	1.4640
2	-0.0183	0.0019	0.0004	-0.0001	0.0001	0.0000	1.3330
3	-0.0023	0.0018	0.0004	0.0000	0.0002	0.0001	1.2949
4	0.0135	0.0026	0.0012	0.0010	0.0012	0.0011	1.2690
5	0.0485	0.0037	0.0023	0.0018	0.0020	0.0019	1.3166
5 - 1	0.1039	0.0036	0.0039	0.0038	0.0038	0.0038	-0.1474
t-value	51.3425	11.4923	12.7603	13.7564	13.9224	13.2686	-24.4149
Panel B:							
1	-0.0598	0.0003	-0.0015	-0.0020	-0.0018	-0.0018	1.4950
2	-0.0186	0.0018	0.0005	-0.0002	0.0000	-0.0001	1.3430
3	-0.0016	0.0022	0.0008	0.0003	0.0004	0.0004	1.2831
4	0.0155	0.0027	0.0014	0.0009	0.0011	0.0010	1.2623
5	0.0566	0.0037	0.0023	0.0017	0.0019	0.0019	1.3823
5 - 1	0.1164	0.0034	0.0038	0.0037	0.0037	0.0037	-0.1127
t-value	49.1967	10.3078	11.5753	11.8040	11.7212	11.4993	-17.1114
Panel C:							
1	-0.0687	-0.0003	-0.0019	-0.0023	-0.0021	-0.0021	1.4857
2	-0.0194	0.0019	0.0006	0.0002	0.0002	0.0001	1.2992
3	0.0015	0.0022	0.0009	0.0004	0.0005	0.0005	1.2276
4	0.0235	0.0026	0.0013	0.0007	0.0009	0.0009	1.2347
5	0.0777	0.0043	0.0028	0.0022	0.0024	0.0023	1.4199
5 - 1	0.1464	0.0046	0.0047	0.0045	0.0044	0.0045	-0.0657
t-value	48.9047	9.0471	8.8946	8.4817	8.4131	8.4871	-7.7866

Table 5. Relation between IV spread and Portfolio Return: Zero Open Interest

Table 5 presents the median of the IV spread of each quintile portfolio and the equal-weighted average return of the portfolio following the formation period during 2002-2013. Panels A, B, and C present the results from options with zero open interest, zero open interests across strikes given a certain maturity, and zero open interests across strikes and maturities, respectively. The portfolio is sorted by the IV spread calculated from options with zero open interest. The reported IV spread is the median spread between implied volatilities from call and put options in each portfolio. Return is the equal-weighted average weekly return following the formation of the portfolio. CAPM α, 3F α, 4F α and 5F α are the risk-adjusted returns from the CAPM, Fama-French 3-factor model, Fama-French-Carhart 4-factor model, and Fama-French-Carhart-Harvey-Siddique 5-factor model. β is the average beta of the stocks in the portfolio.

Quintile	IV Spread	Return	CAPM α	3F α	4F α	5F α	β
Panel A:							
1	-0.0732	0.0009	-0.0006	-0.0011	-0.0009	-0.0009	1.3167
2	-0.0239	0.0017	0.0004	-0.0001	0.0000	0.0000	1.2719
3	-0.0024	0.0018	0.0004	-0.0001	0.0001	0.0000	1.2574
4	0.0191	0.0026	0.0013	0.0008	0.0009	0.0009	1.2321
5	0.0716	0.0033	0.0020	0.0014	0.0015	0.0014	1.2510
5 - 1	0.1448	0.0023	0.0026	0.0025	0.0024	0.0024	-0.0657
t-value	54.2183	7.8333	8.4645	8.3515	8.2801	7.8520	-12.2349
Panel B:							
1	-0.0872	0.0007	-0.0008	-0.0014	-0.0011	-0.0012	1.4612
2	-0.0233	0.0016	0.0002	-0.0004	-0.0003	-0.0004	1.3378
3	0.0013	0.0022	0.0008	0.0002	0.0003	0.0003	1.2773
4	0.0287	0.0026	0.0014	0.0009	0.0009	0.0010	1.2792
5	0.1039	0.0039	0.0027	0.0020	0.0023	0.0021	1.4053
5 - 1	0.1911	0.0032	0.0035	0.0034	0.0034	0.0033	-0.0560
t-value	48.1314	5.3180	5.5086	5.2302	5.1235	4.9014	-5.8593
Panel C:							
1	-0.1398	0.0026	0.0007	0.0001	0.0007	0.0003	1.4636
2	-0.0252	-0.0001	-0.0001	-0.0004	0.0004	-0.0008	1.4099
3	0.0294	0.0001	-0.0034	-0.0037	-0.0035	-0.0042	1.3691
4	0.0964	0.0036	0.0016	0.0004	0.0002	0.0009	1.3909
5	0.2527	0.0042	0.0028	0.0018	0.0023	0.0016	1.4847
5 - 1	0.3925	0.0016	0.0021	0.0017	0.0016	0.0013	0.0211
t-stat	41.7939	0.7342	0.6254	0.1658	0.1946	0.2065	0.6462

Table 6. Comparison of Predictive Power of IV Spread: Actively Traded vs. Untraded

Table 6 presents the difference in returns between the long-short portfolio formed based on the IV spread derived from actively traded options and the long-short portfolio formed based on the IV spread derived from inactively traded or untraded options. Zero Volume 1 is the sample in which there is zero trading volume in the options. Zero Volume 2 is the sample in which there is zero trading volume in the options across strikes given a maturity. Zero Volume 3 is the sample in which there is zero trading volume in the options across strikes and times-to-maturity. Zero Open interest 1 is the sample in which options have zero open interest. Zero Open interest 2 is the sample in which options have zero open interest across strikes given a maturity. Zero Volume 3 is the sample in which options have zero open interest across strikes and times-to-maturity. Return is the equal-weighted weekly return following the formation of the portfolio, CAPM α, 3F α, 4F α and 5F α are the risk-adjusted returns adjusted by CAPM, 3-factor model, 4-factor model, and 4-factor plus the Harvey and Suddique (2000) co-skewness factor.

	IV Spread	Return	CAPM α	3F α	4F α	5F α
Zero Volume 1	-0.0432	0.0007	0.0006	0.0008	0.0009	0.0009
t-value	(-28.0771)	(2.0088)	(1.8042)	(2.2274)	(2.4007)	(2.5560)
Zero Volume 2	-0.0557	0.0009	0.0008	0.0009	0.0010	0.0011
t-value	(-30.2494)	(2.2288)	(1.9049)	(2.1988)	(2.4127)	(2.4984)
Zero Volume 3	-0.0857	-0.0003	-0.0001	0.0002	0.0003	0.0003
t-value	(-34.9227)	(-0.5380)	(-0.2139)	(0.2484)	(0.4444)	(0.4600)
Zero Open interest 1	-0.0560	0.0016	0.0016	0.0018	0.0018	0.0019
t-value	(-37.2823)	(5.2666)	(5.2085)	(6.0404)	(6.2237)	(6.2264)
Zero Open interest 2	-0.1023	0.0007	0.0006	0.0008	0.0009	0.0010
t-value	(-36.1330)	(1.1702)	(0.9570)	(1.3245)	(1.3574)	(1.4223)
Zero Open interest 3	-0.3138	0.0015	0.0024	0.0041	0.0040	0.0043
t-value	(-33.7776)	(0.3613)	(0.5544)	(0.9257)	(0.8793)	(0.9409)

Table 7. IV Spread and Bid-ask Spread

Table 7 presents the association between the IV spread and the bid-ask spread. Bid-ask Spread is the average bid-ask spread of each pair of call and put. Moneyness is (Spot*e^{rT})/Strike, where r is risk-free rate and T is time-to-maturity. TTM is time-to-maturity. Call Volume is the trading volume of the call scaled by 1,000,000. Put Volume is the trading volume of the put scaled by 1,000,000. Trading Volume is the average of Call Volume and Put Volume. Options are categorized according to their moneyness to construct the Moneyness Fixed Effect (0.7 - 0.85; 0.85 - 0.95; 0.95 - 1.05; 1.05 - 1.15; 1.15 - 1.3). Options are categorized according to their TTM to construct the TTM Fixed Effect (<45 days; 45 - 105 days; 106 - 195 days; 196 - 365 days).

	(1)	(2)	(3)	(4)	(5)	(6)
Bid-ask Spread	0.0324	0.0324	0.0324	0.0324	0.0368	0.0385
t-value	(659.2)	(659.1)	(659.2)	(659.1)	(1026)	(1137)
Moneyness					0.0121	0.0133
t-value					(179.9)	(176.3)
TTM					-0.0361	-0.0376
t-value					(-696.3)	(-648.1)
Trading Volume		-0.0725				-0.5477
t-value		(-9.150)				(-55.32)
Call Volume				-0.0760		
t-value				(-11.78)		
Put Volume			-0.0145			
t-value			(-2.640)			
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Moneyness Fixed Effect	Yes	Yes	Yes	Yes	No	No
TTM Fixed Effect	Yes	Yes	Yes	Yes	No	No

Table 8. Relation between IV Spread and Risk-neutral Moments Estimated from 1-Month Options

Table 8 presents the risk-neutral profile of each quintile portfolio sorted by the IV spread calculated from options with no trading volume (Panel A), no open interest (Panel B), positive trading volume (Panel C), or positive open interest (Panel D). The selected options have maturities closest to 1 month given the strikes. The reported IV spread is the median of the spread between the implied volatilities from the call options and from the put options in each portfolio. Var, $Skew$, $Kurt$, $Co - Var$, $Co - Skew$, and $Co - Kurt$ are the risk-neutral variances, skewness, kurtosis, covariance, co-skewness, and co-kurtosis as in Conrad, Dittmar, and Ghysels (2013) averaged over a week starting from each Thursday and ending with the next Wednesday.

Quintile	IV Spread	Var	$Skew$	$Kurt$	$Co - Var$	$Co - Skew$	$Co - Kurt$
Panel A:							
1	-0.0337	0.0216	-0.6758	3.5740	0.0277	-0.1650	8.4196
2	-0.0099	0.0186	-0.6348	3.5350	0.0281	-0.1641	9.0813
3	0.0019	0.0176	-0.6424	3.5797	0.0276	-0.1684	9.6081
4	0.0148	0.0167	-0.6448	3.5584	0.0273	-0.1728	9.8084
5	0.0440	0.0156	-0.6977	3.5940	0.0258	-0.1838	10.1256
5 - 1	0.0777	-0.0060	-0.0219	0.0200	-0.0019	-0.0188	1.7060
t-stat	41.9591	-14.5447	-3.1026	0.7423	-7.7792	-6.9023	9.2325
Panel B:							
1	-0.0652	0.0185	-0.6730	3.5987	0.0280	-0.1770	9.3843
2	-0.0221	0.0180	-0.6474	3.6721	0.0284	-0.1720	9.8891
3	-0.0015	0.0177	-0.6262	3.5846	0.0291	-0.1695	10.2642
4	0.0204	0.0172	-0.6389	3.6976	0.0285	-0.1749	10.9406
5	0.0703	0.0158	-0.6664	3.7033	0.0265	-0.1809	10.9314
5 - 1	0.1371	-0.0024	0.0076	0.1208	-0.0019	-0.0025	1.5430
t-stat	41.5616	-4.5713	0.4944	1.4740	-4.2647	-0.4516	3.5358
Panel C:							
1	-0.0139	0.0249	-0.6374	3.5119	0.0280	-0.1511	7.9723
2	-0.0041	0.0183	-0.6411	3.4858	0.0278	-0.1665	8.8575
3	0.0012	0.0172	-0.6603	3.5218	0.0274	-0.1753	9.3526
4	0.0070	0.0164	-0.6646	3.5052	0.0264	-0.1741	9.5604
5	0.0197	0.0174	-0.7036	3.5148	0.0253	-0.1773	9.2424
5 - 1	0.0336	-0.0075	-0.0662	0.0029	-0.0028	-0.0263	1.2701
t-stat	34.3341	-18.2739	-9.5867	0.1071	-11.3586	-10.0398	6.5761
Panel D:							
1	-0.0165	0.0247	-0.6429	3.5626	0.0277	-0.1507	8.1306
2	-0.0044	0.0190	-0.6350	3.4926	0.0282	-0.1645	8.7354
3	0.0022	0.0174	-0.6486	3.5080	0.0274	-0.1715	9.2483
4	0.0095	0.0165	-0.6755	3.5621	0.0267	-0.1792	9.8629
5	0.0247	0.0167	-0.7126	3.5863	0.0253	-0.1821	9.8782
5 - 1	0.0414	-0.0080	-0.0697	0.0237	-0.0024	-0.0314	1.7476
t-stat	39.1139	-18.2035	-9.7776	0.7604	-10.3552	-11.9139	6.8372

Table 9. Relation between IV Spread and Risk-neutral Moments Estimated from 12-Month Options

Table 9 presents the risk-neutral profile of each quintile portfolio sorted by the IV spread calculated from options with no trading volume (Panel A), no open interest (Panel B), positive trading volume (Panel C), or positive open interest (Panel D). The selected options have maturities closest to 12 month given the strikes. The reported IV spread is the median of the spread between the implied volatilities from the call options and from the put options in each portfolio. Var, $Skew$, $Kurt$, $Co-Var$, $Co-Skew$, and $Co-Kurt$ are risk-neutral variances, skewness, kurtosis, covariance, co-skewness, and co-kurtosis as in Conrad, Dittmar, and Ghysels (2013) averaged over a week starting from each Thursday and ending with the next Wednesday.

Quintile	IV Spread	Var	$Skew$	$Kurt$	$Co-Var$	$Co-Skew$	$Co-Kurt$
Panel A:							
1	-0.0337	0.0299	-0.6762	3.6337	0.0306	-0.1607	7.8856
2	-0.0099	0.0262	-0.6379	3.6246	0.0307	-0.1592	8.5648
3	0.0019	0.0244	-0.6487	3.6389	0.0300	-0.1635	9.1411
4	0.0148	0.0230	-0.6487	3.6092	0.0297	-0.1681	9.2716
5	0.0440	0.0216	-0.6941	3.6211	0.0284	-0.1803	9.3975
5 - 1	0.0777	-0.0083	-0.0179	-0.0126	-0.0021	-0.0196	1.5120
t-stat	41.9591	-14.5579	-2.3427	-0.3698	-6.7721	-6.4622	6.4556
Panel B:							
1	-0.0652	0.0246	-0.6730	3.6492	0.0305	-0.1748	8.9800
2	-0.0221	0.0242	-0.6551	3.8458	0.0305	-0.1690	9.9352
3	-0.0015	0.0243	-0.6356	3.6603	0.0314	-0.1684	10.3295
4	0.0204	0.0226	-0.6486	3.7702	0.0307	-0.1723	10.4997
5	0.0703	0.0211	-0.6633	3.6987	0.0285	-0.1765	10.2492
5 - 1	0.1371	-0.0033	0.0092	0.0646	-0.0022	-0.0015	1.2566
t-stat	41.5616	-4.4320	0.6131	1.0102	-4.2403	-0.2687	3.0709
Panel C:							
1	-0.0139	0.0353	-0.6364	3.5717	0.0308	-0.1480	7.7681
2	-0.0041	0.0264	-0.6465	3.5458	0.0307	-0.1601	8.1050
3	0.0012	0.0249	-0.6601	3.5573	0.0304	-0.1698	8.6132
4	0.0070	0.0239	-0.6640	3.5460	0.0294	-0.1666	8.6669
5	0.0197	0.0253	-0.6963	3.5230	0.0286	-0.1730	8.5210
5 - 1	0.0336	-0.0100	-0.0599	-0.0487	-0.0022	-0.0251	0.7529
t-stat	34.3341	-16.3200	-8.2434	-1.6473	-6.6465	-7.8259	2.1508
Panel D:							
1	-0.0165	0.0348	-0.6435	3.6382	0.0306	-0.1479	7.8573
2	-0.0044	0.0272	-0.6400	3.5463	0.0310	-0.1578	7.9980
3	0.0022	0.0251	-0.6499	3.5431	0.0302	-0.1657	8.4187
4	0.0095	0.0235	-0.6750	3.5933	0.0295	-0.1736	9.2298
5	0.0247	0.0238	-0.7051	3.5969	0.0284	-0.1780	9.2647
5 - 1	0.0414	-0.0110	-0.0616	-0.0413	-0.0022	-0.0301	1.4074
t-stat	39.1139	-17.3581	-8.0990	-1.1712	-6.9763	-9.6375	4.1983

Table 10. Relation between IV Spread and Idiosyncratic Components in Risk-neutral Moments Estimated from 1-Month Options

Table 10 presents the idiosyncratic components in the risk-neutral moments of each quintile portfolio sorted by the IV spread calculated from options with no trading volume (Panel A), no open interest (Panel B), positive trading volume (Panel C), or positive open interest (Panel D). The selected options have maturities closest to 1 month given the strikes. The reported IV spread is the median of the spread between the implied volatilities from the call options and from the put options in each portfolio. $Idio-Var$, $Idio-Skew$ and $Idio-Kurt$ are the idiosyncratic components in the risk-neutral variances, skewness and kurtosis as in Conrad, Dittmar, and Ghysels (2013) averaged over a week starting from each Thursday and ending with the next Wednesday.

Quintile	IV Spread	$Idio-Var$	$Idio-Skew$	$Idio-Kurt$
Panel A:				
1	-0.0337	0.0116	-0.2690	2.2872
2	-0.0099	0.0094	-0.2381	1.9287
3	0.0019	0.0092	-0.2344	2.3182
4	0.0148	0.0086	-0.2495	2.5192
5	0.0440	0.0090	-0.2932	2.3278
5 - 1	0.0777	-0.0026	-0.0243	0.0406
t-stat	41.9591	-6.1227	-2.3866	1.1614
Panel B:				
1	-0.0652	0.0103	-0.2594	2.0898
2	-0.0221	0.0088	-0.2470	1.8228
3	-0.0015	0.0097	-0.2545	2.2989
4	0.0204	0.0093	-0.2385	2.2158
5	0.0703	0.0077	-0.2224	2.2481
5 - 1	0.1371	-0.0024	0.0371	0.1586
t-stat	41.5616	-2.2121	1.0312	1.0386
Panel C:				
1	-0.0139	0.0131	-0.2392	2.2444
2	-0.0041	0.0093	-0.2493	2.3255
3	0.0012	0.0090	-0.2563	2.5048
4	0.0070	0.0090	-0.2685	2.2959
5	0.0197	0.0108	-0.3105	2.3303
5 - 1	0.0336	-0.0023	-0.0713	0.0859
t-stat	34.3341	-5.6442	-7.5291	1.6603
Panel D:				
1	-0.0165	0.0132	-0.2438	1.9901
2	-0.0044	0.0094	-0.2470	2.2780
3	0.0022	0.0093	-0.2540	2.5482
4	0.0095	0.0092	-0.2695	2.3042
5	0.0247	0.0101	-0.3126	2.3284
5 - 1	0.0414	-0.0031	-0.0688	0.3384
t-stat	39.1139	-7.0568	-7.7196	1.2450

Table 11. Early Exercise Premium and Risk-neutral Distribution

Table 11 presents the association between the early exercise premium (EEP) and the underlying risk-neutral distribution (Variance, Skewness, and Kurtosis). Moneyness is (Spot*e^{rT})/Strike, where r is risk-free rate and T is time-to-maturity. TTM is time-to-maturity. Options are categorized according to their moneyness to construct the Moneyness Fixed Effect (0.7 - 0.85; 0.85 - 0.95; 0.95 - 1.05; 1.05 - 1.15; 1.15 - 1.3). Options are categorized according to their TTMs to construct the TTM Fixed Effect (<45 days; 45 - 105 days; 106 - 195 days; 196 - 365 days).

	(1)	(2)	(3)	(4)	(5)
Variance	-0.0637	-0.0702	-0.0971		
t-value	(-6.42)	(-7.44)	(-15.50)		
Skewness	-0.0084	-0.0094		-0.0115	
t-value	(-5.05)	(-6.06)		(-15.02)	
Kurtosis	0.0003	0.0004			-0.0009
t-value	(1.81)	(2.79)			(-12.83)
Moneyness		0.0167	0.0167	0.0167	0.0167
t-value		(4.91)	(4.83)	(4.81)	(4.71)
TTM		0.0884	0.0891	0.0745	0.0690
t-value		(31.48)	(35.88)	(35.95)	(33.65)
Moneyness Fixed Effect	Yes	No	No	No	No
TTM Fixed Effect	Yes	No	No	No	No

Table 12. IV Spread and Early Exercise Premium

Table 12 presents the association between the IV spread and the early exercise premium. Moneyness is (Spot*e^{rT})/Strike, where r is risk-free rate and T is time-to-maturity. TTM is time-to-maturity. Options are categorized according to their moneyness to construct the Moneyness Fixed Effect (0.7 - 0.85; 0.85 - 0.95; 0.95 - 1.05; 1.05 - 1.15; 1.15 - 1.3). Options are categorized according to their TTMs to construct the TTM Fixed Effect (<45 days; 45 - 105 days; 106 - 195 days; 196 - 365 days). The European option price used to calculate the early exercise premium is the analytical presentation given by Bates (1991) in Column 1, and is given by the Bivariate tree in Hillard and Schwartz (2005) in Column 2.

	IV Spread	IV Spread
Intercept	-0.0348	-0.0344
t-value	(-6.42)	(-7.44)
EEP	1.2223	1.2079
t-value	(13.05)	(12.75)
R^2	0.7362	0.7273

Table 13. Calibrated Calls and Puts

Table 13 presents the second set of calibrated calls and puts to demonstrate how the option prices change in the number of jumps and the average jump size in the jump-diffusion model. Panel A presents the calibration when the spot price is 100 and the strike price is 90. Panel B presents the calibration when the spot price is 100 and the strike price is 110. λ is the number of jumps, and γ is the parameter that sets the average size of the jump.

	r = 0.08, T = 0.25, σ = 0.2, δ = 0.2			
	γ = 0.1		γ = -0.1	
Panel A:	K = 90, S = 100			
λ	Call	Put	Call	Put
1	12.8938	1.1217	13.5237	1.8128
2	13.6252	1.8483	14.6181	2.9260
3	14.4185	2.6362	15.5742	3.8826
4	15.2445	3.4579	16.4243	4.7277
5	16.0770	4.2885	17.1944	5.4940
6	16.8948	5.1064	17.9040	6.2016
Panel B:	K = 110, S = 100			
λ	Call	Put	Call	Put
1	3.0469	11.0743	2.3065	10.6905
2	4.5205	12.4297	3.3105	11.5316
3	5.8040	13.6837	4.3314	12.5029
4	6.9325	14.7935	5.3406	13.5106
5	7.9398	15.7880	6.3168	14.4942
6	8.8540	16.6950	7.2465	15.4219

Table 14. Implied Volatilities and Early Exercise Premium

Table 14 presents the call implied volatility (IVC), put implied volatility (IVP), IV spread (IVS), and early exercise premium (EEP) for the second set of calibrated calls and puts to demonstrate how the these variables change in the number of jumps and the average jump size in the jump-diffusion model. Panel A presents the case in which the spot price is 100 and the strike price is 90. Panel B presents the case in which the spot price is 100 and the strike price is 110. λ is the number of jumps, and γ is the parameter that sets the average size of the jump.

$r = 0.08$, $T = 0.25$, $\sigma = 0.2$, $\delta = 0.2$								
	$\gamma = 0.1$				$\gamma =$ -0.1			
Panel A:	$K = 90$, $S = 100$							
λ	IVC	IVP	IVS	EEP	IVC	IVP	IVS	EEP
1	0.2621	0.2601	0.0020	0.7835	0.3116	0.3134	-0.0018	3.9308
2	0.3190	0.3159	0.0031	0.4242	0.3876	0.3901	-0.0025	3.0762
3	0.3743	0.3708	0.0035	0.2997	0.4491	0.4503	-0.0012	2.3309
4	0.4282	0.4243	0.0039	0.2384	0.5016	0.5016	0.0000	1.8096
5	0.4803	0.4750	0.0054	0.2103	0.5481	0.5478	0.0003	1.4873
6	0.5301	0.5245	0.0057	0.1959	0.5903	0.5903	-0.0000	1.2850
Panel B:	$K = 110$, $S = 100$							
λ	IVC	IVP	IVS	EEP	IVC	IVP	IVS	EEP
1	0.2989	0.2772	0.0217	1.8565	0.2574	0.2508	0.0066	5.2582
2	0.3779	0.3593	0.0186	0.7028	0.3133	0.3057	0.0077	3.4625
3	0.4445	0.4270	0.0175	0.4226	0.3679	0.3636	0.0043	2.7968
4	0.5022	0.4856	0.0167	0.2640	0.4206	0.4178	0.0028	2.5764
5	0.5533	0.5379	0.0154	0.1669	0.4708	0.4698	0.0010	2.4530
6	0.5995	0.5857	0.0138	0.1146	0.5182	0.5186	-0.0004	2.2929

Table 15. Risk-neutral Moments

Table 15 presents the risk-neutral variance (Var), skewness (Skew), and kurtosis (Kurt) for the second set of calibrated calls and puts to demonstrate how these moments change in the number of jumps and the average jump size in the jump-diffusion model. λ is the number of jumps, and γ is the parameter that sets the average size of the jump.

$r = 0.08$, $T = 0.25$, $\sigma = 0.2$, $\delta = 0.2$						
	γ = 0.1			γ = -0.1		
λ	Var	Skew	Kurt	Var	Skew	Kurt
1	0.0266	2.0551	13.9525	0.0217	-0.1517	5.3092
2	0.0430	2.2242	14.4917	0.0300	-0.1049	4.8875
3	0.0596	2.2802	14.8362	0.0445	-0.0092	4.5352
4	0.0765	2.3243	15.3215	0.0561	0.0884	4.3161
5	0.0936	2.3715	15.9446	0.0678	0.1803	4.1629
6	0.1110	2.4241	16.6844	0.0796	0.2656	4.1363

Table 16. Dividend Payment and IV Spread: Positive Open Interest

Table 16 presents the predictive content in the IV spreads constructed from options that the underlying stocks have ex-dividend dates before they expire (Panels A and C) in comparison with those constructed from options that expire before the ex-dividend dates of the underlying stocks (Panel B and D). Options have positive open interest. IV Spread is the median spread between the implied volatilities from a call and from a put in each portfolio. Return is the equal-weighted average weekly return following the formation of the portfolio. CAPM α, 3F α, 4F α and 5F α are the risk-adjusted returns from the CAPM, Fama-French 3-factor model, Fama-French-Carhart 4-factor model, and Fama-French-Carhart-Harvey-Siddique 5-factor model. Panels A and B present the results for the options which will expire in 15 to 45 days, and Panels C and D present the results for the options which will expire in 75 to 105 days.

Quintile	IV Spread	Return	CAPM α	3F α	4F α	5F α
Panel A:	Non-zero dividend payment, 1 month					
1	-0.0308	0.0014	0.0003	-0.0004	-0.0003	-0.0002
2	-0.0022	0.0019	0.0009	0.0004	0.0006	0.0005
3	0.0136	0.0024	0.0012	0.0008	0.0012	0.0012
4	0.0331	0.0031	0.0021	0.0019	0.0019	0.0019
5	0.0766	0.0043	0.0030	0.0028	0.0029	0.0029
5 - 1	0.1074	0.0029	0.0027	0.0032	0.0032	0.0031
t-stat	54.5059	5.7030	5.6183	6.5893	6.4808	6.2134
Panel B:	Zero dividend payment, 1 month					
1	-0.0676	-0.0001	-0.0017	-0.0022	-0.0020	-0.0020
2	-0.0225	0.0012	-0.0002	-0.0006	-0.0005	-0.0005
3	-0.0048	0.0015	0.0001	-0.0002	-0.0001	-0.0001
4	0.0115	0.0024	0.0010	0.0007	0.0009	0.0009
5	0.0482	0.0032	0.0017	0.0012	0.0014	0.0013
5 - 1	0.1158	0.0033	0.0033	0.0034	0.0033	0.0034
t-stat	63.4315	10.5504	10.8591	11.5813	11.4124	10.9375
Panel C:	Non-zero dividend payment, 3 month					
1	-0.0275	0.0017	-0.0001	-0.0008	-0.0007	-0.0006
2	-0.0066	0.0028	0.0013	0.0008	0.0010	0.0009
3	0.0030	0.0027	0.0010	0.0006	0.0008	0.0007
4	0.0136	0.0033	0.0017	0.0012	0.0013	0.0012
5	0.0373	0.0034	0.0020	0.0015	0.0016	0.0017
5 - 1	0.0648	0.0017	0.0021	0.0022	0.0023	0.0022
t-stat	52.5312	7.7491	7.7167	7.8701	8.1032	8.2949
Panel D:	Zero dividend payment, 3 month					
1	-0.0605	0.0001	-0.0025	-0.0031	-0.0028	-0.0029
2	-0.0192	0.0019	-0.0002	-0.0005	-0.0005	-0.0006
3	-0.0051	0.0021	0.0001	-0.0001	0.0002	0.0001
4	0.0071	0.0029	0.0006	0.0003	0.0004	0.0005
5	0.0348	0.0041	0.0017	0.0012	0.0016	0.0016
5 - 1	0.0953	0.0041	0.0042	0.0043	0.0044	0.0046
t-stat	52.5312	7.7491	7.7167	7.8701	8.1032	8.2949

Table 17. Dividend Payment and IV Spread: Zero Open Interest

Table 17 presents the predictive content in the IV spreads constructed from options that the underlying stocks have ex-dividend dates before they expire (Panels A and C) in comparison with those constructed from options that expire before the the ex-dividend dates of the underlying stocks (Panel B and D). Options have zero open interest. IV Spread is the median spread between the implied volatilities from a call and from a put in each portfolio. Return is the equal-weighted average weekly return following the formation of the portfolio. CAPM α, 3F α, 4F α and 5F α are the risk-adjusted returns from the CAPM, Fama-French 3-factor model, Fama-French-Carhart 4-factor model, and Fama-French-Carhart-Harvey-Siddique 5-factor model. Panels A and B present the results for the options which will expire in 15 to 45 days, and Panels C and D present the results for the options which will expire in 75 to 105 days.

Quintile	IV Spread	Return	CAPM α	3F α	4F α	5F α
Panel A:	Non-zero dividend payment, 1 month					
1	-0.0782	0.0018	0.0008	0.0001	0.0001	0.0003
2	-0.0101	0.0025	0.0013	0.0007	0.0009	0.0008
3	0.0283	0.0024	0.0014	0.0011	0.0012	0.0013
4	0.0733	0.0028	0.0021	0.0019	0.0021	0.0020
5	0.1735	0.0028	0.0021	0.0019	0.0022	0.0023
5 - 1	0.2517	0.0011	0.0013	0.0019	0.0021	0.0020
t-stat	47.8249	1.4830	1.7457	2.4675	2.6851	2.5996
Panel B:	Zero dividend payment, 1 month					
1	-0.1219	0.0011	0.0000	-0.0005	-0.0003	-0.0004
2	-0.0439	0.0017	0.0006	0.0001	0.0002	0.0001
3	-0.0051	0.0017	0.0006	0.0000	0.0002	0.0001
4	0.0324	0.0023	0.0011	0.0005	0.0006	0.0006
5	0.1125	0.0029	0.0016	0.0009	0.0010	0.0009
5 - 1	0.2345	0.0018	0.0016	0.0014	0.0013	0.0013
t-stat	59.9265	5.0661	4.5236	3.9146	3.5585	3.4669
Panel C:	Non-zero dividend payment, 3 month					
1	-0.0709	0.0015	0.0001	-0.0006	-0.0006	-0.0004
2	-0.0187	0.0035	0.0018	0.0013	0.0013	0.0013
3	0.0044	0.0023	0.0011	0.0002	0.0001	0.0002
4	0.0295	0.0031	0.0018	0.0010	0.0012	0.0015
5	0.0984	0.0029	0.0019	0.0014	0.0018	0.0017
5 - 1	0.1693	0.0014	0.0018	0.0020	0.0024	0.0021
t-stat	33.9305	1.3361	1.6232	1.8104	2.1489	1.8817
Panel D:	Zero dividend payment, 3 month					
1	-0.0817	0.0018	0.0000	-0.0005	-0.0004	-0.0005
2	-0.0284	0.0025	0.0004	0.0000	-0.0002	-0.0001
3	-0.0049	0.0013	-0.0006	-0.0013	-0.0011	-0.0012
4	0.0183	0.0045	0.0029	0.0022	0.0023	0.0022
5	0.0773	0.0038	0.0018	0.0010	0.0010	0.0010
5 - 1	0.1590	0.0020	0.0018	0.0015	0.0014	0.0015
t-stat	42.4870	1.8330	1.5086	1.1819	1.1123	1.1762

Table 18. Relation between IV Spread and Monthly Return: Zero Trading Volume

Table 18 presents the median of the IV spread of each decile portfolio and the equal-weighted average return of the portfolio following the formation period. The portfolio is sorted by the IV spread calculated from options with zero trading volume. The reported IV spread is the median of the spread between the implied volatilities from the call options and from the put options in each portfolio. Return is the equal-weighted monthly return following the formation of the portfolio, CAPM α, 3F α, 4F α and 5F α are the risk-adjusted returns adjusted by CAPM, 3-factor model, 4-factor model, and 4-factor plus the Harvey and Suddique (2000) coskewness factor. 3-month return is the cumulative 3-month return following the formation of the portfolio.

Decile	IV Spread	Return	CAPM α	3F α	4F α	5F α	3-month Return
Panel A:							
1	-0.0942	0.0004	-0.0047	-0.0036	-0.0028	-0.0029	0.0102
2	-0.0436	0.0062	-0.0004	-0.0005	-0.0003	-0.0006	0.0184
3	-0.0269	0.0069	0.0007	-0.0001	0.0002	0.0001	0.0206
4	-0.0168	0.0061	-0.0001	-0.0004	0.0002	0.0005	0.0201
5	-0.0089	0.0085	0.0022	0.0015	0.0024	0.0021	0.0245
6	-0.0018	0.0087	0.0024	0.0010	0.0015	0.0013	0.0248
7	0.0057	0.0088	0.0027	0.0019	0.0023	0.0022	0.0251
8	0.0150	0.0096	0.0028	0.0023	0.0023	0.0021	0.0275
9	0.0294	0.0094	0.0025	0.0019	0.0031	0.0031	0.0275
10	0.0701	0.0146	0.0067	0.0062	0.0075	0.0083	0.0417
10 - 1	0.1643	0.0141	0.0113	0.0098	0.0103	0.0111	0.0315
t-stat	32.1578	4.8696	4.1018	4.0029	4.2216	4.4717	6.0496
Panel B:							
1	-0.1007	0.0016	-0.0038	-0.0057	-0.0055	-0.0055	0.0171
2	-0.0447	0.0065	0.0011	-0.0012	-0.0009	-0.0007	0.0265
3	-0.0262	0.0080	0.0012	-0.0009	0.0000	-0.0002	0.0277
4	-0.0154	0.0093	0.0030	0.0011	0.0016	0.0010	0.0290
5	-0.0072	0.0089	0.0027	0.0005	0.0009	0.0005	0.0308
6	0.0003	0.0103	0.0031	0.0009	0.0015	0.0013	0.0300
7	0.0084	0.0123	0.0059	0.0038	0.0043	0.0040	0.0350
8	0.0189	0.0113	0.0046	0.0021	0.0030	0.0026	0.0313
9	0.0363	0.0135	0.0066	0.0038	0.0048	0.0050	0.0371
10	0.0866	0.0179	0.0101	0.0079	0.0089	0.0087	0.0402
10 - 1	0.1873	0.0163	0.0140	0.0137	0.0145	0.0142	0.0230
t-stat	30.5366	7.8779	6.6387	7.1275	6.8859	6.6994	7.0033
Panel C:							
1	-0.1210	0.0038	-0.0018	-0.0045	-0.0051	-0.0057	0.0244
2	-0.0528	0.0070	0.0007	-0.0016	-0.0013	-0.0013	0.0265
3	-0.0298	0.0109	0.0041	0.0023	0.0022	0.0017	0.0284
4	-0.0161	0.0091	0.0025	0.0002	0.0013	0.0013	0.0306
5	-0.0056	0.0109	0.0041	0.0020	0.0019	0.0021	0.0342
6	0.0042	0.0143	0.0073	0.0047	0.0053	0.0050	0.0323
7	0.0151	0.0123	0.0060	0.0034	0.0044	0.0041	0.0320
8	0.0295	0.0144	0.0074	0.0040	0.0049	0.0055	0.0351
9	0.0535	0.0145	0.0077	0.0048	0.0057	0.0053	0.0418
10	0.1222	0.0179	0.0099	0.0065	0.0083	0.0084	0.0423
10 - 1	0.2432	0.0141	0.0118	0.0110	0.0134	0.0141	0.0179
t-stat	28.9753	3.7952	3.1893	3.1507	3.3098	3.4878	2.7600

Table 19. Relation between IV Spread and Monthly Return: Zero Open Interest

Table 19 presents the median of the IV spread of each decile portfolio and the equal-weighted average return of the portfolio following the formation period. Panels A and B present the results from options with zero open interest, and zero open interests across strikes given a certain maturity, respectively. The portfolio is sorted by the IV spread calculated from options with zero open interest. The reported IV spread is the median of the spread between the implied volatilities from the call options and from the put options in each portfolio. Return is the equal-weighted monthly return following the formation of the portfolio, CAPM α, 3F α, 4F α and 5F α are the risk-adjusted returns adjusted by CAPM, 3-factor model, 4-factor model, and 4-factor plus the Harvey and Suddique (2000) coskewness factor. 3-month return is the cumulative 3-month return following the formation of the portfolio.

Decile	IV Spread	Return	CAPM α	3F α	4F α	5F α	3-month Return
Panel A:							
1	-0.1102	0.0041	-0.0012	-0.0007	-0.0006	-0.0003	0.0157
2	-0.0549	0.0061	0.0004	-0.0004	-0.0001	-0.0010	0.0147
3	-0.0330	0.0088	0.0026	0.0020	0.0021	0.0022	0.0222
4	-0.0195	0.0067	0.0005	-0.0001	0.0002	-0.0003	0.0214
5	-0.0093	0.0100	0.0032	0.0014	0.0020	0.0014	0.0295
6	-0.0005	0.0077	0.0013	-0.0002	0.0009	0.0003	0.0233
7	0.0091	0.0103	0.0040	0.0023	0.0031	0.0036	0.0265
8	0.0213	0.0115	0.0046	0.0026	0.0032	0.0027	0.0328
9	0.0416	0.0081	0.0025	0.0011	0.0022	0.0022	0.0299
10	0.0969	0.0138	0.0069	0.0044	0.0052	0.0054	0.0359
10 - 1	0.2071	0.0097	0.0081	0.0051	0.0058	0.0057	0.0202
t-stat	35.4102	4.5292	3.6509	2.5821	2.7020	2.7148	4.9517
Panel B:							
1	-0.1396	0.0021	-0.0045	-0.0073	-0.0074	-0.0073	0.0226
2	-0.0585	0.0103	0.0035	0.0016	0.0021	0.0015	0.0280
3	-0.0318	0.0100	0.0031	0.0009	0.0013	0.0014	.0277
4	-0.0168	0.0094	0.0030	0.0007	0.0008	0.0006	0.0323
5	-0.0058	0.0093	0.0031	0.0005	0.0007	-0.0001	0.0277
6	0.0045	0.0121	0.0056	0.0026	0.0026	0.0023	0.0287
7	0.0165	0.0106	0.0045	0.0020	0.0031	0.0034	0.0311
8	0.0328	0.0128	0.0077	0.0050	0.0059	0.0058	0.0316
9	0.0617	0.0104	0.0037	0.0012	0.0019	0.0017	0.0288
10	0.1452	0.0177	0.0118	0.0081	0.0100	0.0103	0.0387
10 - 1	0.2848	0.0156	0.0162	0.0154	0.0174	0.0176	0.0161
t-stat	29.1417	4.5136	4.4828	4.3636	4.3271	4.4679	3.1316

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