PATTERNS AND DETERMINANTS OF THE INTRADAY BID-ASK SPREAD AND DEPTH OF CBOE EQUITY OPTIONS

A Thesis Submitted to the College of

Graduate and Postdoctoral Studies

In Partial Fulfillment of the Requirements

For the Degree of Master of Science in Finance

In the Department of Finance & Management Science

University of Saskatchewan

Saskatoon

By

Junye Chen

© Copyright Junye Chen, December, 2017. All rights reserved.

Permission to Use

In presenting this thesis/dissertation in partial fulfillment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis/dissertation in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis/dissertation work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis/dissertation or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any scholarly use which may be made of any material in my thesis/dissertation.

Disclaimer

The thesis was exclusively created to meet the thesis and/or exhibition requirements for the degree of Master of Science in Finance at the University of Saskatchewan. Reference in this thesis/dissertation to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement, recommendation, or favoring by the University of Saskatchewan. The views and opinions of the author expressed herein do not state or reflect those of the University of Saskatchewan, and shall not be used for advertising or product endorsement purposes.

Requests for permission to copy or to make other uses of materials in this thesis/dissertation in whole or part should be addressed to:

Head of the Department of Finance & Management Science
25 Campus Drive
University of Saskatchewan
Saskatoon, Saskatchewan, S7N 5A7, Canada

OR

Dean
College of Graduate and Postdoctoral Studies
University of Saskatchewan
116 Thorvaldson Building, 110 Science Place
Saskatoon, Saskatchewan, S7N 5C9, Canada

Abstract

This paper analyzes the intraday variation of option bid-ask spreads. We find an L-shaped spread pattern for options confirming the findings of Chan et al. (1995), a reverse U-shaped pattern for option depth, and a reverse S-shaped pattern for the underlying stock spread. In addition, we use regression analysis to analyze the determinants of the intraday spread of options. Our regression models are based on the findings of Cho and Engle (1999), De Fontnouvelle et al. (2003), Pinter (2003), Wei and Zheng (2010), and Verousis and Gwilym (2013). We extend this literature by considering the time-of-the-day effect. We divide each trading day into thirteen 30-minute intervals and use dummy variables to represent the various intervals of the day. In addition, we consider how the spread varies depending on whether the option is out-of-the-money, near-the-money, or deep in-of-the-money.

This study uses intraday quote-level data obtained from the Option Pricing Reporting Authority (OPRA) for equity options listed on the Chicago Board Options Exchange (CBOE) during January, February and March of 2010. Consistent with the propositions of previous studies, for example Wei and Zheng (2010) and Verousis and Gwilym (2013), we find that option bid-ask spreads and percentage option spreads are significantly related to the spreads of the underlying stocks, option depth, time to expiration, moneyness, the number of quote revisions, volatility of underlying stocks, and market volatility. In addition, this study is the first to incorporate the underlying stock price as a determinant of the option spread. We propose that the underlying stock price is a proxy for the hedging costs incurred by option writers. We also discover that option depth is driven by many of the same factors that affect option spread, but the effects are mostly opposite in direction and the collective explanatory power of them for option depth is not as strong as the explanatory power for option spread. As most of the previous studies were conducted with end-of-day data, we confirm their results at the intraday level. In addition, we find that the underlying stock prices have positive effect on option spreads in general. We attribute this relationship to the hedging activities of the suppliers of options. Another unique contribution of this study is finding that the CBOE SPX Volatility Index (VIX) has significant and

positive impact on option dollar spread, but it is insignificant with respect to percentage option spread. Also, it has a significant negative impact on put and call option depth.

Although other factors may be important, we believe that information asymmetry theory can satisfactorily explain the intraday behaviors of option spreads in most cases. As market makers attempt to fulfil their responsibilities by providing liquidity to the market, they provide quotations based on their perception of risks, most critical of which is information asymmetry risk. To manage such risk, they use wide option spread as a cushion to compensate for taking the risk of trading with informed traders due to information disadvantage, and use low depth to lower the exposure to such risk.

Regardless of the causes, we propose that option spreads are significant whether measured in dollar terms or as percentage of premiums, which suggests high transaction costs and high degree of inefficiency in the options market. The market is therefore most suitable for informed investors. Our L-shaped intraday pattern also suggests that timing of trades may be useful in this market, as during a typical trading day option spreads start relatively high in the morning and then drop to a more stable level after the first 90 minutes of trading. Moreover, we find that option spread and option depth are complementary in a sense that they both serve as tools for market makers to manage their inventories and risk exposure to limit potential loss. The spread and the depth are mostly negatively related. A notable exception is near the end of the day when market makers seem to maintain option spread but reduce the depth level, an action consistent with an attempt to avoid potential loss to informed traders.

Acknowledgements

The completion of this paper owes immensely to the intellectual inputs and consistent support from the author's supervisor, Dr. George Tannous, Professor at University of Saskatchewan. His insights, guidance, patience and tolerance are what make this thesis possible. Much appreciation has to be given to Dr. Jason Z. Wei, Professor at University of Toronto, Dr. Craig Wilson, Associate Professor at University of Saskatchewan, and Dr. Fan Yang, Associate Professor at University of Saskatchewan, for their review and feedbacks, which significantly improved the quality and depth of this research. Besides, great thanks are due to all other staff and faculty members of MSc. Finance program at Edwards School of Business, including but not limited to, Dr. Abdullah Mamun and Dr. Marie Racine for their administrative arrangements and constructive comments. The author would also like to express sincere gratitude to all fellow students and colleagues in the program for their meaningful suggestions, to all staff in IT service office at Edwards School of Business for their prompt and efficient technical support, and finally to University of Saskatchewan for offering such a perfect platform for student researchers like myself.

Table of Contents

List of Tables

List of Figures

Figure Number **page number**

Chapter 1: Introduction

Studies on intraday options spreads are very sparse compared to studies on intraday stock spreads. Previous studies, for example Mishra and Daigler (2014), attribute this phenomenon to several option characteristics. First, there are call options (calls) and put options (puts). Second, for each underlying stock there are many different classes of options attributed to different strike prices and different expiration dates. Third, all options expire and at the expiration date, option positions need to be closed. Therefore, unlike the underlying stock, it is not practical to retrieve a long time-series of data for each option series.

We managed to identify only four intraday studies on stock option spreads: Chan, Chung, and Johnson (1995), Cho and Engle (1999), Kodippili (2004), and Mishra and Daigler (2014). Among the four, only Cho and Engle (1999) developed models for regression analysis, while the other three performed graphical analysis and made several proposals without testing them in a comprehensive model that controls for various interactions. Cho and Engle (1999) regressed option spreads on the spread of the underlying stock, option price, moneyness, time to expiry, and other control variables. One big difference between our study and their study is that we control for time-of-the-day effect by using interval dummy variables for thirteen 30-minute intervals of a trading day and we analyze the effect of moneyness closely by introducing interaction terms. A comparison between this study and Chan, Chung, and Johnson (1995), Kodippili (2004), and Mishra and Daigler (2014) is presented in Table 1-1 and discussed in greater detail in Section 2.4.

Table 1-1: Previous Studies of Intraday Option Spreads

	Chan et al. (1995)	**Kodippili (2004)**	**Mishra and Daigler (2014)**	**This Study**
Intraday Interval Length	15 min	5 min	15 min	30 minutes
Number of Underlyings	32 stocks	1 index and 2 stocks	2 indices	20 stocks
Option Selection	Most active call option and put option for each stock	All series from 10% in-the-money to 10% out-of-the-money	All series from 10% in-the-money to 10% out-of-the-money	All series from 30% in-the-money to 30% out-of-the-money
Sample Period	January to March of 1986	Late May to mid-August of 2003	October to December in both 2007 and 2008	January to March of 2010

Option Spread Shape - Intraday	L-shape	Inconsistent results	Inconsistent results	L-shape
Regression Model	No	No	No	Yes

Also, many intraday studies on stocks have reported that stock spreads demonstrate U-shaped, reverse J-shaped, reverse S-shaped, or L-shaped patterns over the course of a trading day. However, we found only one paper, Chan et al. (1995), which did similar analysis and reported an L-shaped pattern for option spreads. Our comparisons indicate that the depth and scope of intraday option spread studies are still primitive relative to those on stocks, and call for more research. Furthermore, we are not aware of any studies that consider the intraday pattern or determinants of the depth. The only relevant study that we have identified is Verousis and Gwilym (2013), an end-of-day study, that discovered determinants of option spread and option depth affect these two liquidity measures oppositely.

Despite the scarcity of related research, the use of options for speculation or hedging is becoming more popular especially around the period of financial crisis, as equity option total volume increased by 19.8% per annum from 2004 to a peak in 2009, according to data on CBOE website. This calls for better understanding of intraday behavior of options, because bid-ask spread in dollar value (dollar spread) and bid-ask spread as a percentage of option value (percentage spread[1]) for options are both substantial, compared to those for stocks. The higher spreads contribute to higher trading costs of options. An illustration of the magnitude of option spreads relative to the spreads of the underlying securities is provided in Appendix. Summary statistics conducted as part of this study show that options have a mean percentage spread of around 11.5%, while the percentage spread for stocks has a mean of only 0.052%. This implies that on average option traders require an 11.5% change in the option premium to recover the spread. The 11.5% average spread may also be interpreted as the average percentage loss option traders start with at the onset of the trade. Although options are leveraged and 11.5% premium change demands a smaller percentage change in the underlying security price, it still indicates significant market inefficiency. Thus, the options market does not seem to be a suitable

[1] Percentage spread, also known as proportional spread in literature, is calculated as the bid-ask spread scaled by the average of best bid price and best ask price.

marketplace for uninformed investors, because they have no superior information of market directions and are charged a high spread. We believe that an improved understanding of option bid-ask spread is important for traders to better their trading performance, as the spread is significant in magnitude and constitutes a significant barrier for trading.

This study aims to provide additional knowledge of intraday behaviors of options and educate traders on trade timing and other certain characteristics in the options market. We analyze the intraday behavior of options' bid-ask spreads because we are interested in finding out the determinants of the spread, which is associated with liquidity in the options market. In addition, we analyze the intraday pattern of the option depth[2] as another dimension of liquidity in the market. Furthermore, we analyze spreads in dollar value and spreads as a percentage of premium to examine the consistency of our findings.

This study makes several contributions to the literature on intraday option spreads. First, we extend the work of Cho and Engle (1999) who developed a regression model to examine the determinants and pattern of the S&P 100 American call options spread at the intraday level. In comparison, our study examines spreads of options related to 20 different stocks and uses a regression model that extends their model by controlling for intraday effect, option depth, frequency of quote revisions (in substitution of option volume), underlying stock price, implied market volatility, moneyness and interaction of moneyness with other control variables. The construction of our models is also based on the findings of option studies that use end-of-day data. These studies and the variables used in their models are listed in Table 1-2.

Table 1-2: Main Variables in Option Spread Studies that Use End-of-Day Data

	De Fontnouvelle et al. (2003)	**Pinter (2003)**	**Wei and Zheng (2010)**	**Verousis and Gwilym (2013)**
Underlying spread	✓		✓	✓
Time to expiry		✓	✓	✓
Moneyness			✓	✓
Underlying volatility	✓		✓	✓
Option volatility			✓	✓

[2] Depth measures the ability of the current market quotation of an exchange-traded security to absorb buy and/or sell trades. A frequently used proxy is the average of best bid size (amount of this security the market offers to buy at best bid price) and best ask price (amount of this security the market offers to sell at best ask price).

Option price	√	√	√	√
Option volume	√		√	
Option Greeks	√	√		

Second, this study provides a comprehensive model of the determinants of the intraday spread by integrating the findings of previous studies, many of which were obtained by simple descriptive statistics, and controlling for the intraday variations in options trading. Moreover, the models developed by some previous studies are vastly different and sometimes ignore some important control variables. For example, some models do not include the spread of the underlying stocks as a determinant of option spreads, while we believe that this factor is a very important factor. Lee, Mucklow and Ready (1993), Dupont (2000) and Tannous, Wang and Wilson (2013) all suggest that information asymmetry is a significant contributor to the spread in equity markets. We believe the information asymmetry is also a positive contributor to the spreads in the options market because information in the stock market is delivered to and absorbed by the option market. Thus, spread of underlying stocks should be included in the analysis.

Third, this study proposes that the underlying stock price can be regarded as a measurement of the cost of hedging for options, and it positively correlates with option spreads and negatively correlates with option depth.

Fourth, we propose that shifts in the overall market sentiment affects the spread and the depth of put and call options. We use the VIX as a proxy for the market sentiment and we find that it has a negative impact on the depth but its effects on spreads differs depending on whether the options are near-the-money, at-the-money, or out-of-the-money.

Fifth, we find that a complementary relationship between option spread and option depth exists. They are two measures market makers use to lower their potential loss from market making for informed traders, but these two measures do not hold the same relationship consistently, as market makers seem to employ different risk management strategies with respect to the use of spread and depth in different scenarios.

Overall, this study summarize previous research on the intraday behavior of option spreads, extends the existing intraday spread framework, and develops a more general intraday option spread model. In this regard, we extend the intraday study of Cho and Engle (1999) on option spreads. We have found that the inclusion of moneyness interaction terms is very meaningful, evidenced by increased model fitness. In addition, we examine some of the propositions that were developed and tested by previous studies using end-of-day data (De Fontnouvelle, Fishe and Harris, 2003; Pinter, 2003; Wei and Zheng, 2010; Verousis and Gwilym, 2013). This research has theoretical implications as it complements the existing theoretical frameworks and improves our understanding of the factors that drive option spreads. In addition, it has practical implications for the industry to develop strategies to manage the spread which is considerable in option trading. We provide insights to option traders about how to time the market and place their option trades at a desirable time to avoid the relatively large trading costs associated with the wide bid-ask spreads.

Chapter 2: Literature Review

2.1 Explanatory Factors for Intraday Behaviors of Option Spreads

Based on existing literature, several factors could possibly explain the intraday behavior of option spread, including option depth, underlying stock spread, time to expiration (also known as time to maturity), moneyness, volatility of underlying securities, option delta, intensity of market activities and other factors, such as market making structure.

2.1.1 Option Depth

Lee et al. (1993), Chung and Van Ness (2001) and Li, Van Ness and Van Ness (2005) all observe a U-shaped spread daily pattern for stocks and a reverse U-shaped depth pattern. They all offered similar explanations for the relationships. Those studies were about stocks, but their explanations apply to options. For example, spread and depth are price dimension and quantity dimension of liquidity respectively (Lee et al., 1993), where high liquidity coincides with low spread and high depth, and low liquidity coincides with high spread and low depth. When planning to provide more/less liquidity, market makers can increase/decrease quoted depth or narrow/widen quoted spread or apply both collectively, which depends on their expectations and market conditions. The same logic can be applied to option spread and option depth as well. Verousis and Gwilym (2013) used intraday option dataset and found out a negative correlation between option spread and option depth.

However, spread and depth (for both stocks and options) are not negatively correlated at all time. For stocks, Tannous et al. (2013) argued that spreads declined in the morning session while the depth held flat, but remained steady in the afternoon session while depth rose sharply. Tannous et al. (2013) attributed the inconsistent correlation between spread and depth to the dynamic strategy adopted by market makers to adjust liquidity at the open and at the close. They argue that market makers adjust liquidity using the spread in the morning, but using depth in the afternoon. Verousis and Gwilym (2013) recorded strong and negative correlation between option spread and option depth on different exchanges as -0.47 for Amsterdam, -0.25 for London and -0.37 for Paris. After all, depth should still be one of the most influential explanatory variables for spread. In this study, the option depth should be incorporated to account for intraday variation of option spread.

2.1.2 Underlying Stock Spread

As suggested by the "Derivative Hedge Theory" in Cho and Engle (1999), market makers set spread in order to transfer away the inventory risks and information risks of their positions in the underlying market. They argued that option spread is inversely related to the ability of option market makers to hedge in underlying stock market. Thus, high stock spreads lead to low liquidity in the stock market and weaken market makers' ability to hedge in underlying market, which ultimately leads to high option spreads. Cho and Engle (1999) concluded that option spread and underlying stock spread are positively correlated. More recent studies, for example De Fontnouvelle et al. (2003) and Wei and Zheng (2010), also confirmed the positive relationship between the underlying spread and option spread. Verousis and Gwilym (2013) reinforced this proposition in their intraday study and reported that "underlying market liquidity is a strong determinant of option spread" and underlying spread is significantly positively related to option spread. Both studies referred to the Derivative Hedge Theory in explaining the positive relationship.

As explained theoretically by Sheikh and Ronn (1994) and Chan et al. (1995), information about a company affects its stocks and options simultaneously, therefore, underlying stock spreads can capture the firm-specific information and risks that drive the option spread. This can be another justification for positive relationship between underlying stock spreads and option spreads, in addition to Derivative Hedge Theory.

2.1.3 Time to Expiration

Kodippili (2004) found option bid-ask spread to be positively correlated with time to expiration (or as he called it "term-to-maturity"), because market makers are inclined to set larger spread for options that expire in a relatively long time, given that longer-term options are more likely to end up in the money at expiration and longer-term options cost more to hedge against. Pinter (2003) indicated that this positive correlation may result from a negative relationship between time to expiration and the level of trading, along with a negative relationship between option dollar spread and the level of trading in the same option. The double negatives may lead to a positive relationship between option dollar spread and time to expiration.

2.1.4 Moneyness

A positive relationship between moneyness and the spread was proposed by Kodippili (2004) and Verousis and Gwilym (2013), which suggests in-the-money options have higher dollar spread than near-the-money options and near-the-money options have higher spread than out-of-the-money options[3]. The reasoning is that market makers require a higher bid-ask spread to compensate for the greater risks embedded in the in-the-money options. Their arguments are built on the basis that the greatest amount an option trader can lose is the premium and in-the-money options have high premiums hence a larger amount to lose.

However, in-the-money options do not behave in the exact opposite way as out-of-the-money options. In particular, the price of deep in-the-money options is approximately linear with respect to the price of underlying securities, while the price of deep out-of-the-money options is close 0. The option spread should not be simply a linear function of moneyness. In this study, we introduce two dummy variables to represent in-the-money options and out-of-the-money options respectively to capture the asymmetry.

2.1.5 Volatility of Underlying Stock and Option

Hait (1999) contended that the short-term volatility of the underlying stock price is an important determinant for option spread. The author uses the annualized ten-day trailing standard deviation of stock price returns as a proxy for short-term volatility. Mayhew, Sarin and Shastri (1999) also contended that options would be more liquid if the underlying stocks were more volatile, because high volatility of stock returns imply greater interests in hedging instruments like options and thus higher liquidity of options. Wei and Zheng (2010) observe that option spread decreased with stock volatility and interpret this observation on the basis that high stock volatility usually led to high volume and thus low spread. However, they observe that the explanatory power of stock volatility is not as significant as other variables. Their result seems to be consistent with the findings of De Fontnouvelle et al. (2003), who concluded that the underlying volatility has a very minor and insignificant impact on option spread, and inconsistent

[3] Among call options, in-the-money option is an option whose underlying spot price is higher than the strike price, and out-of-the-money option is an option whose underlying spot price is lower than the strike price. Among put options, in-the-money option is an option whose underlying spot price is lower than the strike price, and out-of-the-money option is an option whose underlying spot price is higher than the strike price.

with the findings of Cho and Engle (1999) and Verousis and Gwilym (2013) who report that option spreads are strongly and significantly increasing with stock volatility. These seemingly inconsistent observations call for additional analysis of option spreads.

As for option volatility, both Wei and Zheng (2010) and Verousis and Gwilym (2013) found a positive association between option volatility and option spread. Both papers attributed the positive relationship to the greater amount of inventory risks faced by the market makers. The two papers seem to agree that the volatility of the underlying asset is significant determinant of the spread. Wei and Zheng (2010) find that option volatility, defined as the volatility of the underlying asset multiplied by the hedge ratio, is the strongest determinant of option liquidity and spread while Verousis and Gwilym (2013) observe that their direct measure of option volatility is not as decisive as other factors, such as the volatility of the underlying stocks.

2.1.6 Option Price

Previous studies, for example De Fontnouvelle et al. (2003), propose that the bid-ask spreads of options are positively related to the prices of options. Mayhew (2002) observed that dollar bid-ask spreads tend to increase with the price of the option while percentage spreads tend to decrease with the price of the option. The changes seem to diminish as the option price increases. Thus, there is no linear relationship between dollar spread and option price or between percentage spread and option price.

2.1.7 Intensity of Market Activities

Traditionally, trading volume has been used to gauge the level of market activities. Lee et al. (1993) reported that for stocks increased volume could drive down quoted depth and widen the spread. Similar findings are available for options as well. Mayhew (2002) and Pinter (2003) advocated that the spread should be negatively related to trading volume. Mayhew (2002) further observed that option bid-ask spreads are sensitive to total trading volume of all options with the same underlying stock and that the bid-ask spread appears to be a decreasing convex function of volume. In contrast, Cho and Engle (1999) and Wei and Zheng (2010) provide evidence suggesting that option market volume does not have a dominant impact on option spread. This study aims to provide some further empirical evidence about the impact of market activities on option spread, but we select the frequency of quote revision as the proxy.

2.1.8 Option Delta

Option delta, also known as the hedge ratio, is believed to be another factor that contribute to option spread. De Fontnouvelle et al. (2003) and Pinter (2003) both found positive relationship between delta and option spread. Cho and Engle (1999) also used option delta to calculate the hedging costs for options, which suggests that option delta also influence option spread, since hedging cost is a major component of option spread. More recently, Wei and Zheng (2010) used the hedge ratio to determine the option volatility as the product of the hedge ratio and the volatility of the underlying security. In their model, the impact of the hedge ratio is mixed with the impact of the volatility of the underlying asset.

2.1.9 Others

Vijh (1990) and Chan et al. (1995) proposed that the market structure plays an important role in determining option spreads. More specifically, the multi-dealer structure of CBOE may lead to a different intraday spread pattern than the spread patterns observed on the NYSE which operates under a specialist market structure. In a single specialist market, only one market maker can see the order book in the market while in a multiple dealer market no single dealer has access to the total order book. The multiple dealer market gives rise to the differences in the decision-making processes of dealers and leads to differences in the spread behavior. De Fontnouvelle et al. (2003) suggested that cross-listing is another characteristic that may affect the spread as competitive listing on multiple exchanges leads to greater liquidity and lower spread. Besides option delta, other option Greeks, such as Vega and Gamma, have been used in De Fontnouvelle et al. (2003).

2.2 Theoretical Arguments for Microstructure

2.2.1 Microstructure of Options

We have discussed the major factors that contribute to the magnitude of option spreads or to the depth of options. In this section, we discuss the reasons why the intraday behaviors may exist.

Hait (1999) explained the four factors that made up option spread: the cost of hedging, fixed costs of trading, inventory risk, and asymmetric information. The cost of hedging usually entails the transaction costs and the bid-ask spread in underlying stock market in order to hedge the risks of options. Fixed costs are costs that market makers or dealers face when doing their business, which include clearing and processing fees, and amortized cost of exchange membership. They can pass those costs down to option traders through setting up the spread. Inventory risk is the risk market makers take when holding inventories, because they carry long or short balances of inventories in order to provide liquidity, and the value of their holdings may move in the undesirable direction. By setting a spread, the dealer can obtain a cushion against inventory price fluctuation. In this sense, the spreads should be dependent on the degree to which the dealer is risk-averse and whether the dealer is a monopolistic specialist or a competing market maker. Lastly, asymmetric information occurs when market makers, whose responsibility is to provide liquidity, are required to make trades with all traders. Some of the traders may possess superior information than market makers, so the trades those traders initiate put market makers in a disadvantageous situation and incur a loss for market makers. A bid-ask spread compensates the market makers and reduces their potential loss. In support of the theory, Engle and Cho (1999) also found that microstructure of options could be attributed to multiple factors in different scenarios, i.e. high option spreads result from large amount of new asymmetric information in a fast-moving market, while high option spreads result from high inventory risk in a slow-moving market. Overall, Hait (1999) and Cho and Engle (1999) laid out theoretical framework for the microstructure of options.

2.2.2 Microstructure of Stocks

In existing literature, there are greater abundance of theoretical arguments made about microstructure of stocks, compared to relevant arguments for options. Although arguments for stock microstructure are not very closely relevant the studies on option spread, they enable us to better understand our topic, because options and their underlying stocks are matching securities. Information in either of the two markets can flow to the other, so that some theories for stocks can be used to extend our understanding of options.

Sheikh and Ronn (1994) and Chan et al. (1995) argue that daily information flow feed into stocks and options at the same time, thus the patterns for stocks and options should be similar, and there is no leading or lagging relationship between these two. Therefore, there are reasons to believe that the factors that determine intraday patterns for stocks can also influence the intraday patterns for options, and that microstructure of options and microstructure of stocks are interrelated. This allows us to use studies on microstructure of stocks as a reference for our studies to gain insights and theoretical support, especially when there have been few studies on microstructure of options.

There are several explanations for the microstructure of stocks, including behaviors of market makers (or specialist), behaviors of institutional investors, intensity of trading activities and supply-demand imbalance.

Market makers' behaviors have been one of the most acknowledged factors that lead to stock microstructure, because they are the party who determines and sets market quotes. Basically, the spreads that we can observe in the market are actually quoted spread decided by market makers, who are obliged to provide liquidity to other market participants. According to the definition on the CBOE website, "market makers are exchange members who provide liquidity in the marketplace by risking their own capital in making bids and offers for their own accounts in the absence of public buy or sell orders". Hence, it makes sense that decisions of market makers have widely acknowledged impact on intraday behaviors of options. Madhavan (1992) and Levin and Wright (1999) found out that the spread falls in the opening hour because the inflow of private information that has accumulated overnight (after the closing of markets at the end of the previous trading day) reduces the degree of information asymmetry, which refers to the phenomenon where material information is known to some, but not known to all market participants (including market makers). In order to avoid huge loss due to lack of superior information, market makers widen the spread at the open. Harris and Panchapagesan (2005) pointed out that market makers enjoy information advantage and can therefore selectively participate in trades, which explains the pattern of spread in the last interval. Brock and Kleidon (1992) attributed the wide spread in opening and closing hours to the monopolistic power of market makers and inelastic demand during those hours. The market makers exploit the opportunities by setting a wide spread. Similarly, Chung and Van Ness (2001) observed more limit orders outstanding at midday and fewer at the open and the close, which makes it easier for market makers to manipulate the spread.

Microstructure of stocks can also be ascribed to behaviors of institutional investors. Breen, Hodrick, and Korajczyk (2002) argued that some institutional investors, for example mutual funds, actively participate in intraday transactions. Their trades can have a huge price impact. Additionally, institutional investors usually make the majority of their trades at some particular time of the day and follow some algorithm that results in a relatively stable trading pattern (Heston, Korajczyk, Sadka, and Thorson, 2011). For example, mutual funds usually adjust their holdings near the close of the market. For high-frequency institutional traders, a large portion of a sample of institutional orders are completed the same day that trading is initiated. All those facts support the notion that institutional investors act as one influential factor that results in intraday patterns.

Intensity of trading activities also greatly affect the intraday variation of stock spreads. As concluded by McInish and Wood (1992), the spread is inversely related to trading activities, including the number of trades and the number of shares per trades, because trades can squeeze the spread to be narrow. With more evidence, Lee et al. (1993) reported the opposite arguing that increased volume can widen spread. Beyond that, Foster and Viswanathan (1993) suggests that trading volume is inversely related to information asymmetry, as high volume leads to low level of information asymmetry, which means narrow spread and large depth. The information asymmetry argument is backed up by Madhavan (1992) and Levin and Wright (1999), where they discovered that the high volume in the opening hour is accompanied by a drop of information asymmetry. The pattern of trading volume leads to varying levels of information asymmetry throughout the day.

Another belief is that the demand for stock trading is associated with the market microstructure and that an inelastic demand for trades often coincides with wide spread. Brock and Kleidon (1992) and Harris and Panchapagesan (2005) argued that supply-demand imbalance as a key driver of daily intraday patterns. Further, Brock and Kleidon (1992) and Heston, Korajczyk and Sadka (2010) explain the wide spread at the open and close by the huge demand with the imbalance between supply and demand. The imbalance is often characterized by inelastic demand to make trades. Chung and Van Ness (2001) found that the competition between security suppliers and demanders are highest during the midday, which narrows the spread. Also, as quoted by Heston et al. (2010), “investors have a predictable demand for immediacy at certain times of the day". In all, the supply-demand dynamic follows a certain daily pattern, which probably gives rise to a certain pattern for spread and the depth.

2.3 Observed Patterns for Spreads

Previous studies suggest that option and stock spreads follow special patterns during regular trading hours. For option spread, we find Chan et al. (1995). For stock spread, there are Brock and Kleidon (1992), Chan et al. (1995), Lee et al. (1993), Heston et al. (2010) and Tannous et al. (2013). For stock depth, there are Lee et al. (1993), Dupont (2000) and Tannous et al. (2013). Other metrics include market execution speed by Garvey and Wu (2009) and trading volume by McInish and Wood (1992), Foster and Viswanathan (1993) and Hora (2006). Those intraday studies unanimously argue for the existence of microstructure. However, in this section, we limit the scope to only the patterns for spread, due to the focus of this research. Although our research concentrates on option spread, we believe options and stocks are closely related. Information can flow simultaneously into those two markets, so that option spread and stock spread should have a close relationship. Therefore, we intend to demonstrate, compare, and analyze stock spread patterns and option spread patterns altogether.

As in the previous literature, the mainstream method to analyze different metrics of options or stocks on intraday basis is to divide a typical trading day into multiple equal-length intervals. The interval can be as long as 1 hour, 30 minutes, 15 minutes or even 1 minute. Among these choices, the most popularly used interval length is 30-minutes. Each trading day (9:30 a.m. to 4:30 p.m. EST) is broken down into 13 consecutive 30-minute intervals, as in McInish and Wood (1992), Li et al. (2005), Heflin, Shaw and Wild (2007), Heston et al. (2010), and Tannous et al. (2013). As detailed in Section 4-5, the spread for each 30-minute interval is calculated as a time-weighted spread.

For option spread, Chan et al. (1995) is the only study that presents microstructure visually with graphs. They reported that option spread, on an average day, drops sharply after the open then levels off, resembling an L-shaped pattern. Chan et al. (1995) discovered an **L-shaped option spread** for CBOE options. Additionally, they found a U-shaped intraday spread pattern for NYSE stocks. They contended that the difference is due to different market making structure. CBOE, the option market, has a more competitive market making structure than NYSE. Specifically, there are multiple market makers on CBOE and they do not see the order book, so that each of them has little monopolistic power and the demand imbalance in the market can be corrected quickly due to the competition. The difference in market making structure leads to differences in the spreads.

While only one study reported about the pattern for option spreads, significantly more studies present patterns for stock spreads.

One frequently proposed pattern of stock spreads within a trading day is the U-shaped pattern. **U-shaped stock spread** was presented in many studies, such as Brock and Kleidon (1992) and Lee et al. (1993). To the author's knowledge, there has been no study proposing a U-shaped pattern for option spreads. The only remotely relevant work is Sheikh and Ronn (1994), who suggested a U-shaped pattern for option return variance. In Figure 2-1, Brock and Kleidon (1992) showed the U-shaped stock spread pattern and attributed the spike at the open and close of the day to the increased demand. They suggested demand appears to be high at the open because investors seek optimal portfolio proportions at the open, and at the close because of behaviors to transfer away or reduce overnight risk.

Figure 2-1 has been removed due to copyright restrictions. It was a figure of U-shaped stock spread graphed against 390 minutes of a trading day. Original source: Brock, W. A., & Kleidon, A. W. (1992). Periodic market closure and trading volume: A model of intraday bids and asks. Journal of Economic Dynamics and Control, 16(3), 451-489.

Figure 2-1: U-shaped spread, Brock and Kleidon (1992)

As in Figure 2-2, the research of Lee et al. (1993) also yielded similar U-shaped spread. Their main explanation for the pattern is that market makers adjust the spread up and depth down when they are not confident about the accuracy of their information, which typically happens at the open and the close.

Figure 2-2 has been removed due to copyright restrictions. It was a figure of stock spread, depth and volume graphed against 13 half-hour intervals of a trading day. Original source: Lee, C. M., Mucklow, B., & Ready, M. J. (1993). Spreads, depths, and the impact of earnings information: An intraday analysis. Review of Financial Studies, 6(2), 345-374.

Figure 2-2: U-shaped spread and reverse U-shaped depth, Lee et al. (1993)

Several other papers revealed different patterns for stock spreads. McInish and Wood (1992) discovered a **reverse J-shaped stock spread** as in Figure 2-3. They observed that even though high-priced stocks have a different pattern from low-priced stocks, the pattern still resembles a reverse J shape on average. The insight they provided is that the spread is correlated to the amount of new information that come into the market and that the reverse J-shaped pattern may reflect the time-of-day preference of trading for an average investor.

Figure 2-3 has been removed due to copyright restrictions. It was a figure of percentage stock spread graphed against 390 minutes of a trading day, displaying reverse J shape. Original source: McInish, T. H., & Wood, R. A. (1992). An analysis of intraday patterns in bid/ask spreads for NYSE stocks. The Journal of Finance, 47(2), 753-764.

Figure 2-3: Reverse J-shaped spread, McInish and Wood (1992)

Reverse S-shaped stock spread was proposed by Chung and Van Ness (2001) as in Figure 2-4. They suggested that the decline in spread from the beginning to midday is primarily because the traders and market makers have increasingly greater interests in trading and provide more competitive prices throughout the morning session, which boosts competition and drives down the spread. There is a decline in spread near the close of the day, which differentiates itself from reverse L-shaped pattern. They attributed this decline to inventory control of market makers near market close. Specifically, in order to readjust the inventory level to target inventory level, they offer more appealing pricing to replenish securities that they are running short of and sell off excess inventories that they have accumulated during the day.

Figure 2-4 has been removed due to copyright restrictions. It was a figure of reverse S-shaped (standardized) percentage stock spread graphed against 13 half-hour intervals of a trading day, displaying reverse J shape. All three time periods demonstrate such intraday pattern. Original source: Chung, K. H., & Van Ness, R. A. (2001). Order handling rules, tick size, and the intraday pattern of bid–ask spreads for NASDAQ stocks. Journal of Financial Markets, 4(2), 143-161.

Figure 2-4: Reverse S-shaped spread, Chung and Van Ness (2001)

An **L-shaped stock spread** pattern was found by Tannous et al. (2013) for stocks. As per

Figure 2-5, the spread starts to fall since opening and continues to decline at a decreasing rate until 1:30 PM after which the spread widens slightly during the 1:30-2:00 interval and then it resumes the declining pattern. They observe that the slight increase in the spread is corresponding to a significant increase in information asymmetry between 12:00 noon and 2:00 PM. Tannous et al. (2013) argue that the difference between the intraday pattern of information asymmetry and the intraday pattern of spreads is observed because market makers are applying a dynamic strategy of adjusting the spread, the depth, or both to manage their risk. Close to the end of the day when the information asymmetry arises, market makers offer lower liquidity by lowering depth, instead of widening the spread.

Figure 2-5 has been removed due to copyright restrictions. It was a figure of L-shaped stock spread graphed against 13 half-hour intervals of a trading day. Upper bound, mean and lower bound all demonstrate such intraday pattern. Original source: Tannous, G., Wang, J., & Wilson, C. (2013). The intraday pattern of information asymmetry, spread, and depth: Evidence from the NYSE. International Review of Finance, 13(2), 215-240.

Figure 2-5: L-shaped spread, Tannous et al. (2013)

2.4 Summary of Relevant Studies

Compared to studies on stocks, there have been limited number of studies on option spreads, many of which used daily data and few of which used intraday data (also known as quote-level data or tick-level data). Moreover, among studies that used intraday option data, there are studies, like De Fontnouvelle et al. (2003), Kaul, Nimalendran and Zhang (2004) and Verousis and Gwilym (2013), who did not perform analysis at intraday level. They constructed daily variables, aggregated quote-level data into daily data by simple averaging or weighted averaging, and then performed daily analysis, whereas in this study we control for the intraday variances in the spread and its determinants by dividing a trading day into 13 intervals.

Based on our search, Cho and Engle (1999) is the only paper on intraday option spreads that incorporated regression models. They proposed Derivative Hedge Theory and examined the impact of the underlying market on option liquidity and spread. They ran regression on percentage option spread, controlling for option price, moneyness, time to expiry, volatility of underlying security, option delta, volume and the percentage spread of underlying security. Our research is similar because we are also using intraday data and we control for many of the factors they use in their models. However, our research is different from Cho and Engle (1999) for the following reasons:

[1] We collected a sample of equity options of 20 stocks in first three month of 2010, while they collected a sample of index option of S&P 100 American call options from May 1993. Our focus is entirely on the microstructure of equity options, which could be significantly different from that of index options. We also intend to compare call options and put options, instead of just call options. In addition, our sample is more recent which could lead to different results due to evolvement of the options market.

[2] Cho and Engle (1999) did not control for time-of-the-day effect, while we believe it is important, since options exhibit patterns in their intraday variations, as evidenced by Chan et al. (1995). We incorporate interval variables similar to those employed by many intraday studies on stocks. Intraday studies on option spreads also divided each trading day into intervals and presented descriptive statistics or graphs but they did not run regressions. See following paragraphs in the current section for more details on those intraday option spread studies.

[3] Our research provides a more comprehensive analysis of the impact of moneyness. We introduce dummy variables to identify deep in the money options and far out of the money options. Then, we interact these dummy variables with other key variables. The rationale is that the effect of the underlying spread, for example, on option spread for out-of-the-money options is likely to be different from the same effect for in-the-money options. This justifies introduction of interactions terms.

[4] Cho and Engle (1999) devoted most of their efforts to analyze percentage option spreads. We analyze both dollar spreads and percentage spreads as well as the depth.

In addition to Cho and Engle (1999), there are three (3) intraday studies on option spreads. These are Chan et al. (1995), Kodippili (2004) and Mishra and Daigler (2014), although none of these papers developed a model. Table 1-1 has summarized some details about those three papers as well as this paper.

Chan et al. (1995) focused on the options of 32 stocks. The selected the most active call option and the most active put option for each of their 32 stocks and collected their data during the first 61 trading days in 1986 (January, February, and March 1986). They divided each trading day into 15-minute intervals. They found that, on average, option spread had an L-shape intraday pattern.

Kodipilli (2004) had a sample period around 3 months in 2003 and selected all series from 10% in-the-money to 10% out-of-the-money. They divided each trading day into 5-minute intervals and gathered option data for one index and two stocks. They did not find systematic or consistent pattern for option spreads among the index and the two stocks. They found out that option spreads increase with time to maturity and are higher for in-the-money options.

Mishra and Daigler (2014) used a sample of 6 months altogether in 2007 and 2008 and also selected all series from 10% in-the-money to 10% out-of-the-money. They chose SPX and SPY options both with S&P 500 index as underlying security. Each trading day was divided into 15-minute intervals. They found U-shaped option spread pattern for SPY options, but not for SPX options.

We consider the literature inadequate, given that there are limited number of intraday studies on option spreads, compared to the abundance of intraday studies on stock spreads. In terms of the pattern of option spreads on intraday basis, only Chan et al. (1995) found a consistent intraday option spread pattern, which was L-shaped, while there have been so many different studies proposing intraday patterns in stock intraday study literature. Furthermore, according to our investigation, only one intraday study, Cho and Engle (1999) used regression models and the sample was drawn from a long time ago (in May of 1993), although many daily studies on option spreads developed models and drew sample from recent years. It will be the contribution of this paper to use a more recent sample to analyze the pattern for intraday option spreads, and finetune the models for intraday studies based on daily option spread studies, as well as briefly investigate the determinants of option depth. The major variables used in those models have been covered in Section 2.1. We will use some similar data cleaning and preparation techniques, but there will be some variations from those models, since many studies used daily data instead of intraday data, so some techniques do not apply to our data.

Table 1-2 has already provided a quick summary of the regression models used in those daily option spread studies, as a quick reference for the models to be introduced in this paper.

The regression models in our paper will include some variables from the intraday study, which is Cho and Engle (1999), and daily studies, including but not limited to the papers in Table 1-2, but our models include some but not all of their variables, and include some new variables, due to our limited scope and capacity, different methodologies we are to employ and the fact that we are analyzing intraday behaviors of option spreads. Among those studies (either intraday or daily), De Fontnouvelle et al. (2003) and Pinter (2003) chose option dollar spread as dependent variable, while Cho and Engle (1999), Wei and Zheng (2010) and Verousis and Gwilym (2013) chose option percentage spread as dependent variable. In our paper, we will run separate regressions using dollar spread and percentage spread as dependent variable to test how spread interacts with other factors both in dollar term and in percentage term. Apart from all these, in addition to existing literature, we will run regression with our control variables on option depth, so that we can improve our understanding about how option spread and option depth affect and complement each other. See the details of our models in Chapter 6.

Chapter 3: Theoretical Arguments and Hypotheses

Previous studies propose several theories to explain the magnitude and pattern of the bid-ask spread in the stock market. Spread variation in stock markets has been attributed to market information asymmetry, fixed cost of trading, and inventory holding cost (Lee et al., 1993; Dupont, 2000; Tannous et al. 2013). Information asymmetry theory argues that market makers are faced with adverse selection, because some traders have superior information over them, but market makers are obliged to provide liquidity to the market. Fixed cost of trading refers to the costs borne by market makers to carry their market making duties, such as order processing cost. Inventory holding cost is the potential capital loss resulting from holding securities, the cost to adjust inventory level, and the capital cost needed to hold the inventory.

Previous studies that examine the spreads of options extend the asymmetric information, transaction cost, and the inventory holding cost theories to explain the intraday pattern of option spreads (Chan et al. 1995; Cho and Engle, 1999; Hait, 1999). In addition, previous studies propose the cost of hedging as an additional determinant of the spread in the options market (Hait, 1999). In this chapter, we summarize the propositions made by previous authors and explain their implications for option spreads. Beyond that, we make two unique propositions. The objective is to develop a comprehensive set of propositions regarding the determinants of the option bid-ask spread and to test these propositions jointly using intraday data of option quotations.

3.1 Contributions by previous studies

Information asymmetry theory suggests that market makers modify the bid-ask spread in response to the degree of information asymmetry in the options market (Chan et al. 1995; Cho and Engle, 1999; Hait, 1999). This theory is borrowed from the stock market studies which argue that market makers face significant risks from trading with informed traders (Lee et al., 1993; Dupont, 2000; De Fontnouvelle et al., 2003; Tannous et al. 2013). They manage this risk by widening the spread when they expect high level of informed trading and lower the spread when this risk subsides.

Many previous studies of stock spreads use the asymmetric information theory to explain their observations of a U-shaped or L-shaped intraday pattern of stock spreads or option spreads

(Lee et al., 1993; Tannous et al., 2013). The common explanation is that information asymmetry is highest at the open because the amount of important private information accumulates overnight, resulting in high level of information asymmetry at market open. This situation leads market makers to increase the stock spread to be the highest at market open. Then, as information is transmitted to the market during the early minutes of trading the degree of information asymmetry drops and the spread is reduced accordingly. Furthermore, the level of information asymmetry reaches a low level and stays relatively stable for the remainder of the day leading to a relatively stable spread. Hence, some previous studies observe an L-shaped or U-shaped patterns for stock spreads.

Previous studies of option spreads use the theory of information asymmetry to argue that option spreads should be directly related to the underlying stock spreads (Cho and Engle, 1999; De Fontnouvelle et al., 2003; Verousis and Gwilym, 2013). This argument is supported by Sheikh and Ronn (1994) and Chan et al. (1995) who propose that since options are securities that derive their values from the values of the underlying assets, information asymmetry should feed into both stock and option markets at the same time. Therefore, information about the recent developments and the long-term prospects of a company affect both markets, resulting in the similarity of intraday variation of information asymmetry between stocks and options. Furthermore, the positive relationship between stock spreads and option spreads is also supported by the derivatives hedge theory proposed by Cho and Engle (1999). They argue that derivatives, such as options, are hedging tools used to transfer away risks associated with the underlying stocks. Therefore, illiquidity of the options markets is positively related to the illiquidity of the underlying market.

Previous studies on option spreads argue that the volatility of the underlying stock should be negatively correlated with option spread (Wei and Zheng, 2010) and positively correlated with option liquidity (Mayhew et al., 1999). They argue that high volatility of the underlying suggests high trading volume or greater trading interest which means higher liquidity in the options market. However, Cho and Engle (1999) and Verousis and Gwilym (2013) argued that higher volatility of the underlying stock comes with greater asymmetric information, leads to greater variation in the option price, and brings about higher risks, which ultimately lead to wider spread. Nevertheless, the significance of this factor has been discredited as minor De Fontnouvelle et al. (2003).

Mayhew (2002) and Pinter (2003) propose that the option market activities (either quote revisions or executed trades) convey information to all market participants and mitigate risks associated with information asymmetry. Thus, market activities should ease the concerns of market makers. Therefore, quote revisions and trading volume should be negatively correlated with option spread. However, some empirical results of previous studies do not confirm this notion. For example, Cho and Engle (1999) and Wei and Zheng (2010) find the effect to be insignificant and minor.

Unlike stocks, options are limited-life instruments while stocks are securities that have unlimited life. Previous studies, for example Pinter (2003) and Kodippili (2004), argue that option spread should be positively correlated with time to expiration of the specific contract. They explain that longer-term options involve more uncertainty, higher chance of occurrence of material private information, hence greater risks. The risk-averse nature of market makers pushes them to increase the spread to compensate for the risks.

Kodippili (2004) and Verousis and Gwilym (2013) suggest that the degree by which an option is out-of-the-money or in-the money should affect the spread. They argue that in-the-money options carry greater uncertainty and have higher spread than out-of-the-money options, because they have higher premiums to allow for greater losses.

3.2 Contributions of this study

This research will examine the arguments proposed by previous studies. Our contributions in this regard is to examine these propositions jointly in a single regression model that controls for all factors proposed by previous studies. In addition, our analysis uses intraday data and controls for time-of-the-day variations. Therefore, confirmation of the conclusions of previous end-of-day studies is a worthy contribution. In addition, we make three new contributions to the literature.

First, we propose that the asymmetric information theory also implies that an option bid-ask spread should be inversely related to the average number of contracts offered at the bid and ask prices, known as the option depth. This conclusion follows from the arguments that the spread and depth are two dimensions of liquidity that may be used interchangeably to manage stock market maker's risk (Lee et al., 1993). Tannous et al (2013) confirm this conclusion for intraday stock bid-ask spreads and argue that market makers are using a dynamic strategy of reducing the spread or increasing the depth or both in response to a drop in information asymmetry. In contrast, when information asymmetry increases market makers can reduce the liquidity provided by raising the spread or reducing the depth or both. This study proposes that the option depth can be used by option market makers in the same way it may be used by stock market makers. Verousis and Gwilym (2013) study the determinants of the end-of-day option depth. Their results suggest that the determinants of the depth also affect the spread but in opposite directions. For example, the underlying proportional bid-ask spread affects the end-of-day spread positively and the end-of-day depth negatively. One objective of this study is to examine the relationship between the bid-ask spread and the depth in the options market hoping to confirm that an increase in the depth is associated with a decrease in the spread or vice versa and confirm the findings of previous studies. Therefore, our first hypothesis may be stated as:

Hypothesis 1: The bid-ask spread of an option is negatively related to the option's depth.

Second, we propose that the price of the underlying security has a significant positive effect on the spreads of the related options and this relation is the result of the costs of hedging that option writer are likely taking to supply options. We propose that option writers may be divided into three groups. First, there are traders who might write call options when they forecast a drop in the underlying stock or write puts when they forecast a rise in the underlying stock. We call this group "speculators". We propose that the trades of speculators are short term in nature, conducted without hedging, and have little impact on the supply of options. Second, there are underwriters who enter the market to make profits from underwriting insurance contracts on the underlying stocks. As underwriters, this group are likely to hedge their positions by keeping an inventory of underlying assets. Third, some option writers may enter the market to hedge their inventories of stocks over a short period of time. For example, they may sell calls when they hold the underlying stock and they expect the stock price to drop or be stable until the expiry of the contract. Similar to underwriters, option writing by this group is done primarily in combination with a hedging portfolio of underlying securities held by the option writers. We call the combination of the second and third groups as "hedged writers". We propose that the majority of option writers belong to this category. Further, we propose that the inventory holding costs of options are directly related to the value of the hedging portfolio. This proposition follows if we assume that a high stock price implies high hedging cost as it requires a larger amount of capital to complete the hedge. Therefore, the inventory holding costs of options with high underlying stock price are higher than the inventory holding costs of options with low underlying stock price. The implication of this proposition is that the underlying stock price should positively affect the bid-ask spread of options because the higher stock price implies higher hedging costs for suppliers. Previous studies, for example Hait (1999), argue that hedging activities help in transmitting information asymmetry from the stock market to the option market so that information asymmetry affects option spreads in the same way it affects the spread of the underlying security. Our proposition suggests in addition that hedging activities increase the costs of writing options hence the spreads of options of high-priced stocks are higher than the spreads of options of low-priced stocks. Therefore, our second hypothesis may be stated as follows.

Hypothesis 2: The price of the underlying stock positively affects the bid-ask spread of the corresponding options.

Third, we propose that option spreads are affected by market sentiment. Quoted spreads are provided by a group of market makers on CBOE, who are aware of the possibility that they may be facing information disadvantage compared to their trading counterparties. Despite this risk, market makers are obliged to maintain liquidity either by matching buy trade(s) and sell trade(s) or by filling trades from their own inventories. In contrast, informed market participants make trades only in situations when the quotes are lucrative to them. In a volatile and fast-moving market, characterized by high degree of information asymmetry, such behavior becomes more prominent. Consistent with the asymmetric information theory argument, we expect market makers to set wider spreads in the face of greater risks arising from overall market information asymmetry to compensate themselves for providing liquidity during a high-risk environment. Furthermore, we propose that the overall market information asymmetry is separate from and magnifies the degree of information asymmetry originating from company specific factors. For example, assume that on Day t, a market maker is market-making for the options of Stock X with average level of information asymmetry and during Day t the level of information asymmetry in the market is also normal. Further assume that under this environment, the market maker will be satisfied with 8% spread. Now assume that on Day t+1, the information environment of Stock X is the same as it was during Day t but now the market environment has changed and the market information asymmetry is now higher. We propose that during Day t+1 the market maker will require a spread higher than 8%. Therefore, we propose that the component of the spread attributable to information asymmetry should be split into two independent components, one attributable to the underlying asset's information environment and the other attributable to the overall market's information asymmetry. Market information asymmetry measures the dispersion of investor's opinions and uncertainty regarding overall market indicators such as policy changes, central bank actions, political risks, employment, and corporate earnings. Higher uncertainty about these market indicators implies higher expectations of market volatility and a sentiment of incoming risk. Therefore, we propose that the Chicago Board Options Exchange (CBOE) SPX Volatility Index, known as VIX underwritten on S&P 500 component stocks, is a proper proxy of the overall market's information asymmetry. According to the CBOE website, VIX "is a key measure of market expectations of near-term volatility" and may be regarded as "the world's premier barometer of investor sentiment and market volatility." [4] Therefore, our second hypothesis may be stated as follows: quotations

Hypothesis 3: CBOE SPX Volatility Index (VIX) is positively related to the bid-ask spread of options or negatively related to the depth.

[4] The quotations in this sentence are copied from the Chicago Board Options Exchange (CBOE) webpage: http://www.cboe.com/products/vix-index-volatility/vix-options-and-futures/vix-index

Chapter 4: Data

4.1 Sample Period

The sample used in this study covers January, February and March of 2010. In the sample period, data were collected on 61 trading days, with 19 days in January, 19 days in February and 23 days in March.

4.2 Data Source

The intraday data for options are Trade-and-Quote (TAQ) data. They were purchased from Options Price Reporting Authority (OPRA), a security information processor and distributor in the US that provide quotation information along with other services. The option quotation data we purchased from OPRA originated from Chicago Board Options Exchange (CBOE). In the raw data, we have every quote of every monthly option that traded on CBOE in January, February and March of 2010. For stock data, the quoted minimum tick size for stocks is $0.01 cents. For option data, quoted minimum tick size is $0.05 for options trading below $3, and $0.10 for all other series.

Besides option quotation data, daily average stock prices for the underlying stocks were obtained from the database of the Center for Research in Security Prices (CRSP).

Additionally, we captured daily stock market volatility using CBOE SPX volatility VIX index, which is calculated using out-of-the-money call options and put options for S&P 500 component stocks and, by the definition of CBOE, measures the near-term market expectation of volatility of S&P 500. The VIX index data were downloaded from Datastream portal.

4.3 Raw Data and Sample Construction

The majority of raw data are the TAQ option data for the period of January, February and March of 2010, originated from CBOE and purchased from OPRA. A series of data trimming actions were conducted to remove all the erroneous quotes as well as those quotes that do not fit into this research. Figure 4-1 and 4-2 show a screengrab of raw data chosen at random. Figure 4-2 is just the continuation of Figure 4-1 due to the length of each record.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1		**Date**	**Time**	**Milisec**						**expiry**	**call/put**	**strike price**	**option bid**	**option bid size**	**option ask**	**option ask size**			
2	Q	20100301	83014	186	450108	N	R	K	C	20100320	C	35	16.8	1	17.6	1	N	O	
3	Q	20100301	83014	188	450158	A	R	K	C	20100320	C	35	16.9	1	17.6	11	N	O	
4	Q	20100301	83014	196	450306	N	R	K	C	20100320	C	35	16.8	21	17.5	1	N	O	
5	Q	20100301	83014	198	450393	A	R	K	C	20100320	C	35	16.8	21	17.5	1	N	O	
6	Q	20100301	83014	206	450500	N	R	K	C	20100320	C	35	16.8	22	17.6	22	N	O	
7	Q	20100301	83014	209	450571	A	R	K	C	20100320	C	35	16.8	22	17.6	22	N	O	
8	Q	20100301	83014	218	450900	A	R	K	C	20100320	C	35	16.8	22	17.6	11	N	O	
9	Q	20100301	83014	296	452406	N	A	K	C	20100320	C	35	16.8	22	17.6	22	N	O	
10	Q	20100301	83014	326	453371	N	A	K	C	20100320	C	35	16.8	22	17.6	22	N	O	
11	Q	20100301	83014	335	453748	N	A	K	C	20100320	C	35	16.8	22	17.6	11	N	O	
12	Q	20100301	83014	369	455091	A	A	K	C	20100320	C	35	16.8	22	17.6	11	N	O	
13	Q	20100301	83014	548	459950	A	A	K	C	20100320	C	35	16.8	22	17.6	22	N	O	
14	Q	20100301	83014	615	461515	N	A	K	C	20100320	C	35	16.9	10	17.6	11	N	O	
15	Q	20100301	83014	681	463464	X		K	C	20100320	C	35	16.8	42	17.6	42	N	O	
16	Q	20100301	83014	685	463608	X		K	C	20100320	C	35	16.8	31	17.6	31	N	O	
17	Q	20100301	83014	688	463697	X		K	C	20100320	C	35	16.8	21	17.6	21	N	O	

Figure 4-1: Sample data, part 1

S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
		stock bid	**stock bid price**	**stock ask**	**stock ask size**									**underlying symbol**
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K
		52	4	52.31	10	1-Mar-10	F	0			3	2010	9	K

Figure 4-2: Sample data, part 2

This sample data consists of quote data for options written on the common stocks of Kellogg's (whose underlying ticker symbol is K). The headings for all relevant columns are bolded in row 1. From left to right in order, there are date, time of day, millisecond, expiration date, call/put indicator, strike price, bid price and size for the option, ask price and size for the option, bid price[5] and size for the underlying stock (which is Kellogg's in this case), ask price and size for the underlying stock and the ticker symbol of the same stock. The total size of the raw TAQ option data files is astronomical, well over 40 Terabytes, and a small portion of the data are corrupted, which makes data trimming imperative.

First off, the raw data files contain options underwritten on over 3400 equities and indices. Provided that this study focuses on equity options because the behavior of index options is

[5] Bid price and ask price referred to in this paper are the best quoted bid and best quoted ask.

trickier to interpret, all the quotes on index options can be deleted.

Further, after removing index options, there are still equity options on thousands of equities. The options on ADRs are also removed from our master data, because an ADR is the depository receipt of a foreign company whose primary stock exchange is outside of the US, whereas our option data originate from CBOE inside the US. Due to the complex structure of ADR, we decide the options on ADRs should be removed, despite some of which are very actively traded in 2010 when the data were recorded, e.g. options on Baidu Inc. (ADR) and Petroleo Brasileiro SA Petrobras (ADR).

The remainder are all non-ADR equity options traded on CBOE. Then we are to delete all options underwritten on the stocks with a ticker that starts with “A”, due to file corruption of some files containing quotes of options, whose underlying tickers start with “A”. All other files are intact from the same type of corruption. Deleting options on A-stocks is not ideal, especially for those with highest level of liquidity in option market, such as Apple (AAPL), Amazon (AMZN) and Barrick Gold Corp (ABX). It makes us lose important samples, however, in the case of corruption, deleting them is necessary. Moreover, there is no reason to believe that deleting them will lead to biased results, since options should not be expected to behave differently simply for whether their underlying stocks’ ticker start with “A” or not.

Now, we are left with non-ADR equity options whose underlying stock tickers start with any letter but “A”. The amount of data is still beyond our and our devices’ capability to process. To shortlist the options, we added up the total number of market quotations for each underlying stock (company) within the three-month period: January 2010 to March 2010, then applied a sorting based on the total quote counts. As shown in Table 4-1, at the top of the list are those stocks with most number of option market quotes, which comes along with highest liquidity, but of course, those exclude ADRs and stocks whose ticker start with “A”, due to the prior filters, as well as companies whose ticker symbols in 2010 were no longer identifiable by early 2017, the time this research was conducted.

Table 4-1: Selected Companies

Number	Ticker Symbol	Quote Counts	Company Name
1	GOOG	1582051194	ALPHABET INC.

2	X	1306446428	UNITED STATES STEEL CP
3	GS	1131494489	GOLDMAN SACHS GROUP INC
4	POT	1013679817	POTASH CORP SASKATCHEWAN
5	GG	938175262	GOLDCORP INC.
6	FSLR	928011817	FIRST SOLAR INC.
7	NEM	889579883	NEWMONT MINING CORP
8	JPM	848740853	JPMORGAN CHASE & CO COM STK
9	FCX	802610212	FREEPORT-MCMORAN INC.
10	IBM	652295187	INTL BUSINESS MACHINES CORP
11	QCOM	633819852	QUALCOMM INC
12	COF	624174620	CAPITAL ONE FINANCIAL CORP
13	WFC	565269172	WELLS FARGO & CO
14	ISRG	540810252	INTUITIVE SURGICAL INC
15	CAT	540073409	CATERPILLAR INC
16	DOW	539493507	DOW CHEMICAL CO
17	CME	533958972	CME GROUP INC.
18	NUE	528491043	NUCOR CORP
19	SLB	518688203	SCHLUMBERGER LTD
20	PCLN	509813355	PRICELINE GROUP INC/THE

Only options written on those 20 companies are selected to construct the sample, because those companies had the most liquid option chains in the three-month sample period. By doing so, we can collect a sample to conduct a study that provides most insights for practitioners, because the options in our sample represent the most liquid and the most frequently traded ones. Next, some further data trimming will be carried out to clean this sample.

4.4 Data Cleaning

The remaining data are option Trade-and-Quote data on the selected 20 companies. We leave out trade data, and keep only quote data, because trade data do not reflect the spread in the market. Then, within the current dataset, there are only market quotes for all options of those 20 companies on CBOE for January, February and March 2010. Some quotes are still erroneous or not suitable to the purpose of this study, which calls for more data trimming.

Quotes with zero bid price or zero ask price for either the option or the underlying stock are removed. Quotes with non-positive bid-ask stock spread or non-positive bid-ask option spread are removed.

Using the time stamp of each quote (consisting of date, time of the day and millisecond), we can obtain the exact moment that each quotation was quoted. All quotes with a time stamp before 8:30 a.m. CST or after 3:00 p.m. CST are removed, since those quotes were quoted before the market open or after the market close. Then the time elapsed between two consecutive quotes, which is equivalent to how long the former quote stayed active in the market, can be calculated using their time stamps. Those quotes that stayed active for longer than 30 minutes are deemed to be stale and inactive, and are left out of our sample.

4.5 Data Preparation

After removing those illiquid, inactive or erroneous data, in this section, we will tailor the data to better suit the needs of this research.

Moneyness Filter: Previous studies focused mostly on liquid, active, near-the-money options. Chan et al. (1995) chose the most active option series for each day for a given stock in their matching sample. Kodippili (2004) only kept market quotes that range from 10% in-the-money to 10% out-of-the-money. Verousis and Gwilym (2013) set the cut-off points at 5% in-the-money and 5% out-of-the-money. In this study, 30% is used as the cut-offs to obtain a broader sample and better take advantage of the availability of our data, because we believe that there is large amount of applicable data between 10% - 30% in the money or out of the money. As shown in Table A.1, although volume clusters around at-the-money options for Apple on that specific date, we can observe decent amount of liquidity outside 10% cut-offs. Thus, we only exclude option quotes that are more than 30% in-the-money or more than 30% out-of-the-money, which means we keep options, if and only if they satisfy $0.7 < \frac{S}{K} < 1.3$, where K stands for strike price and S stands for spot price[6] for a specific option. Further, if an option series had a single quote on one day outside the acceptance range, we delete all quotes of that option series on that entire day. This means that all the quotes of an option series on one day should be selected into the sample if the mid-point of stock bid and ask of that option series on that day always remained no lower than 70% of and no higher than 130% of the strike price, otherwise all the quotes of that option series on that day should be discarded.

[6] Spot price, in this paper, refers to the current market price of the underlying stock.

Time-to-Expiration Filter: Both De Fontnouvelle et al. (2003) and Verousis and Gwilym (2013) selected options that mature within 90 calendar days, but not within 7 calendar days. The explanation they provided is that short-term options are faced with expiration effects caused by rollover activities, while longer-term options are “thinly traded, making inference difficult”. This study will follow the same criteria to keep quotes of those option series that expire in more than 7 calendar days, but less than 90 calendar days.

Construct 12 Interval Dummies: The quote-level data in our sample are collected starting 8:30 and ending at 15:00 CST. The 6.5-hour trading session per day can be divided equally into thirteen 30-minute intervals. Then, we convert quote-level data into interval-level data using a time-weighting technique. Although dividing a continuous trading day into intervals will average out some information in quote-level data, it will also get reduce the fuzziness, messiness, and outliers of all the quote-level data. At the same time, interval-level data can still satisfactorily reveal the microstructure and the daily variation, which is not viable with daily data. This technique is frequently used in intraday studies for stocks and options. Among intraday studies for option spreads, Chan et al. (1995) selected intervals of 15 minutes, while Kodippili (2004) and Mishra and Daigler (2014) chose intervals of 5 minutes. Chan et al. (1995) argued against the use of short intervals, because that will make estimates for less actively traded options difficult to interpret and provide fuzzy results. Most of intraday studies on stock spreads used 30-minute intervals. Therefore, this study will choose longer intervals following the example of Lee et al. (1993), Chung and Van Ness (2001) and Tannous et al. (2013) to divide each day into thirteen intervals of 30 minutes. Given 13 intervals, a dummy variable is assigned to each of the intervals, except the first interval 8:30 to 9:00, so that we can compare all other intervals with the first 30-minute interval within a typical trading day. Previous studies on option spreads or stock spreads agree that the first trading period of the day has significantly lower liquidity and higher spread than the rest of the day.

Construct 2 Moneyness Dummies: A common theme in previous literature is that they usually split selected options into three categories: in-the-money, at-the-money and out-of-the-money (Pinter, 2003; Kodippili, 2004; Mishra and Daigler, 2014). For a brief example, Kodippili (2004) only selected options that are between 10% in-the-money and 10% out-of-the-money, which means an option has to satisfy the condition: $0.9 < \frac{S}{K} < 1.1$, where K stands for strike price and S stands for spot price. Using two cut-offs at 3% in-the-money and 3% out-of-the-money, he further categorized quotes into three categories, in-the-money (ITM), at-the-money (ATM)[7] and out-of-the-money (OTM). In this study, we keep a broader spectrum of options as we include all options between 30% in-the-money and 30% out-of-the-money. Therefore, we use two broader cut-off values to group options between out-of-the-money, near-the-money, and in-the-money. Options that are more than 10% in-the-money are classified as in-the-money-group, options that are more than 10% out of the money are classified as out-of-the-money group, and options that satisfy the condition $0.9 < \frac{S}{K} < 1.1$, where K stands for strike price and S stands for spot price, are classified as near-the-money group. We calculate spot price as the average of best bid price and best ask price ($\frac{\text{bid+ask}}{2}$).

Formally, for call options, ITM, ATM and OTM should satisfy equations 4.1, 4.2 and 4.3 respectively. For put options, ITM, ATM and OTM options should satisfy equation 4.3, 4.2 and 4.1 respectively.

$$1.1 \leq \frac{\text{bid} + \text{ask}}{2\text{K}} < 1.3 \quad \text{(equation 4.1)}$$

$$0.9 < \frac{\text{bid} + \text{ask}}{2\text{K}} < 1.1 \quad \text{(equation 4.2)}$$

$$0.7 < \frac{\text{bid} + \text{ask}}{2\text{K}} \leq 0.9 \quad \text{(equation 4.3)}$$

This is in an attempt to follow the method of Kodippili (2004) and to divide the range equally. We assign two dummies ITM and OTM, so that we can label each quote as in-the-money, at-the-money or out-of-the-money. We construct dummy variables for ITM and OTM, so that we can compare ITM and OTM option quotes against ATM options quotes.

Define Option Quote Group: This study is interested in understanding the intraday relationship between option spread and moneyness. To the best of our knowledge, Kodippili (2004) is the only one paper that studies this relationship on an intraday basis. However, Kodippili

[7] By strict definition, the middle category should be near-the-money options, but we will follow the definition of Kodippili to name them at-the-money (ATM) options.

(2004) divided the data into three groups ITM, ATM and OTM using 3% cut-off without explaining how exactly those three groups are constructed. Some other daily studies, such as Wei and Zheng (2010) and Verousis and Gwilym (2013), did not divide options into moneyness categories, instead they directly ran regression using moneyness variable, defined by exercise price over stock price. In this study, we divide options into three categories based on moneyness, which we believe is meaningful, because such method allows us to construct dummy variable and then construct interaction terms between moneyness dummies and other key variables. The construction process, however, has to be carefully done to avoid couple possible pitfalls. First, it is problematic to sort an entire day of quotes from an option series into moneyness categories because there is the possibility that an option series may straddle over the border of the cut-offs. For instance, a particular call option series may fall into the category of OTM in the first half of the trading day, and then move into the category of ATM or ITM, as the price of the underlying stock changes. Also, it is problematic to divide an entire 30-minute interval of quotes from an option series between ITM, ATM or OTM categories, because technically, during an interval an option series can belong to two categories. A reasonable solution to this problem is examining which range the spot price stays in for the longest time. Fortunately, our investigation suggests all option series in our sample did not cross over moneyness categories in any given interval, which eases the concern. Therefore, we divide the data into option quote groups to avoid the potential problems mentioned above. An "option quote group" is made up of quotes related to the same underlying security, the same expiration date, and the same moneyness criterion. There is no constraint over strike price, as long as the same moneyness criterion is met. More specifically, two option series with the same underlying security, the same expiration date, but different strike price may have quotes that belong to the same option quote group, because each of the three intervals (ITM, ATM and OTM) is wide enough to cover several strike prices. Also, the underlying security price may change, so an option with certain strike price may be determined as in-the-money during this interval, but becomes at-the-money in the next 30-minute interval. Once we grouped quote data into different option quote groups we then obtain the time-weighted average within each group and within each 30-minute interval.

Apply Time Weight to Quotes: This method applies a time weight to quotes within the same option quote group, using the length of time the quote stays on the market as the weight. With the time stamp of each quote, we can calculate the amount of time that each quote stayed on the market, which can sometimes be several seconds and sometimes as short as several milliseconds. Then, we use the time-weighting technique to summarize data of all quotes within each interval on one specific day for each option quote group into one sample point. Equation 4.4, which is adapted McInish and Wood (1992) for stock studies, provides a formula to calculate the time-weighted option spread:

$$WAIS_{ABC,T,i} = \sum_{q=1}^{Q}(AskPrice_{ABC,T,i,q} - BidPrice_{ABC,T,i,q}) \times {time_{ABC,T,i,q}}/{30minutes} \quad 4.4)$$

Where "$WAIS_{ABC,T,i}$" is the weighted-average interval spread for "stock ABC" on "day T" for "interval I", the term in the bracket calculates the bid-ask spread for the "quote q", the term "$time_{ABC,T,i,q}$" represents the length of time in minutes that this "quote q" stayed active on the market.

Once the time-weighted average spreads for a particular stock are calculated for all trading days and all intervals, the interval spreads for the same 30-minute intervals can be averaged across different days to obtain the weighted-average interval spread for "interval I" for "stock ABC" but for the entire sample period, rather than for "day T" itself. Similarly, the time-weighted average depth for a given interval and a particular stock are determined using the same technique.

There have been some studies that used this method for intraday studies of stocks, including McInish and Wood (1992), Li et al. (2005), Heflin et al. (2007), Heston et al. (2010), and Tannous et al. (2013). Within the limited number of intraday studies on options, Chan et al. (1995) also used this technique. As shown in Figure 4-1 and Figure 4-2, within the 14^{th} second in the minute starting at 8:30 on March 1, 2010, there were so many quote changes for the call option on Kellogg with a strike price of 35 dollars and an expiration date of March 20, 2010. The time-weighted technique groups thousands of (or even tens of thousands of) quotes into one interval-level sample point. When a variable, such as option spread and option depth, varies from one quote to the next quote, this interval-level sample point takes the value of weighted average of this variable within the interval, using the weight of how long each quote stayed on the market. On the other side, when the variable, such as the number of days to expiration, does not vary from one quote to the next quote (since the former and latter quotes are both for the same option quote group and recorded on the same date), the unvarying value can be assigned to the interval-level sample point. By doing so, we create some new variables at interval level: time-weighted option spread, time-weighted option depth, time-weighted underlying stock spread, time-weighted percentage option spread and time-weighted percentage underlying stock spread[8], which reduces the sample size to a manageable level and makes analysis possible.

Trim Extreme Values: The processed data demonstrate some extreme values for option spread and quote count[9]. In two extreme cases, option spread for one option quote group of Nucor Corporation reached over 282 dollars at a time when the stock was trading at around 42 dollars and the quote count for the option quote group in a 30-minute session was only 1. After investigation, we found that the former was due to erroneous option ask prices in some quotes that are unrealistically high, which drives up the time-weighted option spread for that interval, while the latter was due to the inactivity and illiquidity of some deep in-the-money or out-of-the-money options that have only 1 or 2 quote changes in 30 minutes. We used data trimming to mitigate the problems caused by erroneous data or by the illiquidity of option quote group. Given that the total sample size for the interval level data is large, approximately 200,000 observations per interval, we can delete extreme values to lower the possibility of contaminating the sample with invalid data. Therefore, we delete all entries whose option spread or quote count falls within the highest or lowest 1%, which leads to 2% drop in the sample size of calls and a similar drop in the sample size of puts.

4.6 Summary Statistics Related to the Key Variables

A description of the key variables and how they are calculated is presented in Table 4-2. As the table shows, for each quote, the option depth is calculated as the average of the option's bid size of best bid price and ask size of best ask price. Percentage stock spread is calculated as the difference between stock ask price and bid price divided by the average of stock ask price and bid price. Similarly, percentage option spread is calculated as the difference between option ask price

[8] For simplicity, those time-weighted variables will be referred to by original variable names directly, when interval-level data are involved. For example, time-weighted option spread will be referred to as option spread.

[9] Quote count represents the number of quotations that are summarized into each interval-level sample point. It reflects the frequency of quote changes within that 30-minute interval for the option quote group.

and bid price divided by the average of option ask price and bid price. *Quote Count* variable has been scaled by 100,000. All time-weighted variables are the weighted averages using the weight of the time the quote stayed on the market. The entire dataset are panel data, where different option quote groups are the cross-sectional dimension and the 13 intervals are the time dimension.

Table 4-2: Variable Description

Dependent Variable Name	**Dependent Variable Explanation**
option_spread	time-weighted option dollar spread within the interval for the option quote group
%_option_spread	time-weighted percentage option spread within the interval for the option quote group
Independent Variable Name	**Independent Variable Explanation**
option_depth	time-weighted option depth within the interval for the option quote group
stock_spread	time-weighted stock dollar spread within the interval for the option quote group
%_stock_spread	time-weighted percentage stock spread within the interval for the option quote group
days_to_expiry	number of days left till expiration date for the option quote group
stock_stdev	standard deviation for underlying stock daily returns from Dec 1 2009 to April 30 2010
daily_avg_stkprc	daily average price of the underlying stock of the options
quote_count	frequency of quote revisions within the interval for the option quote group
VIX_daily	daily VIX index to control for near-term market expectation of volatility
D_ITM	in-the-money dummy, which equals 1 if it belongs to in-the-money option class group, otherwise equals 0
D_OTM	out-of-the-money dummy, which equals 1 if it belongs to out-of-the-money option class group, otherwise equals 0
D2	equals 1 if it is interval 9:00-9:30 CST, otherwise equals 0
D3	equals 1 if it is interval 9:30-10:00 CST, otherwise equals 0
D4	equals 1 if it is interval 10:00-10:30 CST, otherwise equals 0
D5	equals 1 if it is interval 10:30-11:00 CST, otherwise equals 0
D6	equals 1 if it is interval 11:00-11:30 CST, otherwise equals 0
D7	equals 1 if it is interval 11:30-12:00 CST, otherwise equals 0
D8	equals 1 if it is interval 12:00-12:30 CST, otherwise equals 0
D9	equals 1 if it is interval 12:30-13:00 CST, otherwise equals 0
D10	equals 1 if it is interval 13:00-13:30 CST, otherwise equals 0

D11	equals 1 if it is interval 13:30-14:00 CST, otherwise equals 0
D12	equals 1 if it is interval 14:00-14:30 CST, otherwise equals 0
D13	equals 1 if it is interval 14:30-15:00 CST, otherwise equals 0

Summary statistics for both call options and put options are presented in Table 4-3. Several observations must be emphasized. First, days-to-expiry has a minimum of 8 and a maximum of 89, because we only keep the quotes of option series on specific days where they expire in more than 7 days but less than 90 days. Daily average stock price has a high of over 600 due to the inclusion of Alphabet Inc. in our sample. Top and bottom 1% of extreme values of option spread and quote count have been trimmed as explained in the previous section. Lastly, the maximum of percentage option spread is around 161.7%, similar to the cut-off value of 150% adopted by Wei and Zheng (2010) and Verousis and Gwilym (2013) for sample selection.

Table 4-3: Summary Statistics of Key Variables for Both Call Options and Put Options

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
option_spread	186725	0.302144	0.5291079	0.0183279	3.0038629	0.1057297
%_option_spread	186725	0.115436	0.1885289	0.0057033	1.6169696	0.0342005
option_depth	186725	218.3737667	297.9948668	7.2575758	7568.62	129.7559326
stock_spread	186725	0.0845553	0.1289948	0.01	1.8269631	0.021908
%_stock_spread	186725	0.000518132	0.000364572	0.0000938	0.0051078	0.00039412
days_to_expiry	186725	40.4366314	21.0801598	8	89	39
stock_stdev	186725	0.0221659	0.0052241	0.010399	0.032237	0.021531
daily_avg_stkprc	186725	124.7782071	132.349548	26.18	626.75	63.07
quote_count	186725	0.340965	0.364961	0.00197	2.04538	0.2126
VIX_daily	186725	20.466453	3.0776963	16.35	27.31	19.35

* Quote count has been scaled by 100,000.

Some preliminary observations from summary statistics are as follow. [1] The option spreads are significantly higher than stock spreads, judging from mean, minimum, maximum and median. Options have medium spread of 10.57 cents, almost five times as high as the medium spread for stocks, 2.19 cents. The average spread for options, 30.21 cents, is almost four time as much as the average spread for stocks, 8.46 cents. The difference in magnitude between option dollar spread and percentage spread is also apparent in our graphs in the next chapter, where we have to scale them on different axis due to the big difference. [2] The relationship between mean and median indicates that both stock spread and option spread are right-skewed, with significant extreme values in the right tail, which suggests that trading costs for both stocks and options can be much higher than usual in some rare occasions. [3] Percentage spread for options are higher than the percentage spread for stocks to a greater extent, compared to the relationship between dollar spread[10] of stocks and dollar spread for options. Options' percentage spread has a mean of 11.54%, a median of 3.42% and a maximum of 161.70%, as opposed to 0.052%, 0.039% and 0.511% respectively for stocks' percentage spread. The sharp contrast tells the same story about the trading cost for options and for stocks.

Separate summary statistics for call options alone and put options alone are provided respectively in Table 4-4 and Table 4-5. The number of observations for calls and puts are roughly the same. The numbers are mostly similar to the statistics for calls and puts as a whole in Table 4-3. The means of options spreads are $0.272 for call options and $0.331 for put options, while the respective medians are $0.103 and $0.110. The percentage option spreads are 14.92% for call options and 8.21% for put options, while the medians are 3.64% and 3.28% respectively. It seems that some large outliers caused the means to be much higher than medians.

Table 4-4: Summary Statistics of Key Variables for Call Options

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
option_spread	92821	0.2724466	0.4835786	0.0183335	3.0035942	0.1028676
%_option_spread	92821	0.1491598	0.2212194	0.0068338	1.6169696	0.0363997
option_depth	92821	234.709129	341.953712	7.2575758	7568.62	134.318139
stock_spread	92821	0.0869877	0.1320504	0.01	1.8269631	0.0221403
%_stock_spread	92821	0.00052386	0.0003708	0.0000971	0.0051078	0.00039557
days_to_expiry	92821	40.7294147	21.0059574	8	89	39
stock_stdev	92821	0.0221882	0.0051967	0.010399	0.032237	0.021531
daily_avg_stkprc	92821	126.49008	133.655293	26.18	626.75	63.32
quote_count	92821	0.337645	0.359271	0.00197	2.04538	0.21635
VIX_daily	92821	20.4773895	3.0813827	16.35	27.31	19.35

* Quote count has been scaled by 100,000.

[10] Dollar spreads are used to differentiate from percentage spreads. All option spreads and stock spreads mentioned later are dollar spreads, unless specifically indicated as percentage option spreads or percentage stock spreads.

Table 4-5: Summary Statistics of Key Variables for Put Options

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
option_spread	93904	0.3314989	0.5690342	0.0183279	3.0038629	0.1100944
%_option_spread	93904	0.0821012	0.1416605	0.0057033	1.4541651	0.0327676
option_depth	93904	202.226801	245.907368	11.0487666	4020.64	125.498098
stock_spread	93904	0.0821511	0.1258561	0.01	1.2748603	0.021686
%_stock_spread	93904	0.00051247	0.00035822	0.0000938	0.0039605	0.00039273
days_to_expiry	93904	40.1472248	21.1493794	8	89	39
stock_stdev	93904	0.022144	0.005251	0.010399	0.032237	0.021531
daily_avg_stkprc	93904	123.086077	131.024809	26.18	626.75	62.88
quote_count	93904	0.344247	0.370471	0.00197	2.04508	0.208435
VIX_daily	93904	20.4556426	3.0740262	16.35	27.31	19.26

* Quote count has been scaled by 100,000.

Comparing option spread between call options and put options, we notice that call options have lower mean and median dollar spread, but higher mean and median percentage spread, compared to put options. The comparison demonstrates that in our sample, call options on average have lower premiums compared to put options. Table 4-6 provides some supporting statistics, while Figure 4-3 shows that the relationship holds across the day and it does not simply result from odd occurrences that are specific to peculiar time of the day only.

Table 4-6: Statistics for Premium Comparison between Calls and Puts

Premium	Mean	Median	Maximum	Minimum	Standard Dev.	5th percentile	95th percentile
Calls	8.3729	2.9646	104.6538	0.0197	15.0924	0.0531	39.2836
Puts	11.4106	3.6678	176.8651	0.0198	21.2128	0.1087	51.9021

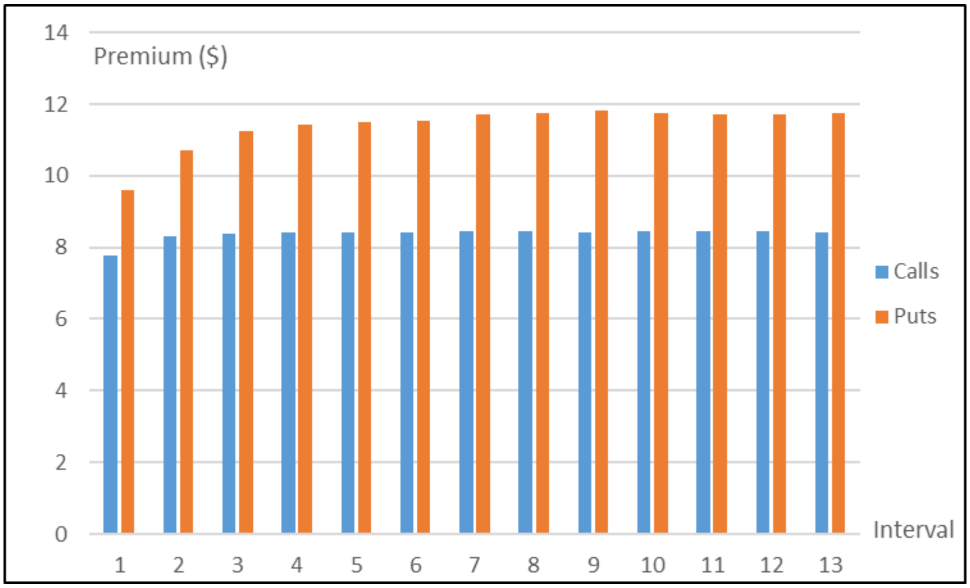

Figure 4-3: Premiums of Calls and Puts across Intervals

Table 4-7 displays the correlation coefficients of different pairs of variables. We used t-statistic ($t_{stat} = \frac{r \times \sqrt{n-2}}{\sqrt{1-r^2}}$, where r is the correlation coefficient between two of the variables) to judge the significance of the correlation coefficient. Given that the number of observation is 186,725, using a two-tailed t-test at 1% significance level, a correlation coefficient has to be greater than 0.00596 or lower than -0.00596 to be significant. In the table, notably, option depth is negatively correlated with option dollar spread and percentage spread, with coefficients of -0.21 and -0.07, conforming to the negative relationship in Verousis and Gwilym (2013). Option dollar (percentage) spread is positively correlated with stock dollar (percentage) spread, with coefficient of 0.60 (0.14), confirming the observations of previous studies. Both quote count and volume of underlying stock, as metrics of market activities, have strong negative correlation with option dollar and percentage spreads, confirming the observations of Mayhew (2002) and Pinter (2003). The magnitude of underlying stock price has strong positive correlation with both option dollar spread and percentage spread, providing evidence of underlying stock price as hedging cost component of option spreads and support for Hypothesis 2.

Coefficient matrices have been produced based on the data for call options alone and put options in Table 4-8 and Table 4-9 respectively. Using t-statistic at 1% significance level, for call option observations, a significant correlation coefficient needs to be greater than 0.00846 or lower than -0.00846, while for put option observations a significant correlation needs to be greater than 0.00841 or lower than -0.00841. The highlighted numbers are the variables of interest that have significant correlations.

Later, when we construct regression models, we will avoid using significantly correlated variables as independent variables at the same time. In this setting, significance refers to economic significance, instead of merely statistical significance.

Table 4-7: Correlation Coefficient Matrix for Both Calls and Puts

	Option spread	*% option spread*	*Option depth*	*Stock spread*	*% stock spread*	*Days to expiry*	*Stock stdev*	*Daily avg stkprc*	*Quote count*	*VIX daily*
Option spread	1									
% option spread	-0.135588	1								
Option depth	**-0.209788**	**-0.075069**	1							
Stock spread	**0.604737**	0.198359	-0.282128	1						
% stock spread	0.428442	**0.137188**	-0.215582	0.829363	1					
Days to expiry	-0.001044	-0.228507	0.063415	-0.001197	-0.014394	1				
Stock stdev	-0.128975	-0.114424	-0.136922	-0.071866	0.266069	-0.019092	1			
Daily avg stkprc	**0.575066**	**0.157957**	-0.324068	0.790364	0.412191	-0.001453	-0.279564	1		
Quote count	**-0.071523**	**-0.3267**	-0.055035	-0.077706	-0.04165	0.009305	0.023365	-0.022363	1	
VIX daily	-0.003546	0.010763	-0.059181	0.044706	0.15573	-0.015798	-0.019963	-0.045755	0.223588	1

Table 4-8: Correlation Coefficient Matrix for Calls

	Option spread	***% option spread***	***Option depth***	***Stock spread***	***% stock spread***	***Days to expiry***	***Stock stdev***	***Daily avg stkprc***	***Quote count***	***VIX daily***
Option spread	1									
% option spread	-0.15077	1								
Option depth	**-0.18471**	**-0.11448**	1							
Stock spread	**0.639291**	0.211656	-0.27663	1						
% stock spread	0.46715	**0.154742**	-0.21713	0.833854	1					
Days to expiry	0.01439	-0.18178	0.042626	-0.00124	-0.0157	1				
Stock stdev	-0.1355	-0.11204	-0.1441	-0.08283	0.252395	-0.02617	1			
Daily avg stkprc	**0.592351**	**0.164357**	-0.31706	0.789145	0.41787	-0.00219	-0.28695	1		
Quote count	**-0.08811**	**-0.3707**	-0.06677	-0.09285	-0.05774	-0.00437	0.02267	-0.03937	1	
VIX daily	0.008837	0.039479	-0.06208	0.043873	0.15341	-0.01845	-0.02105	-0.04529	0.19113	1

Table 4-9: Correlation Coefficient Matrix for Puts

	Option spread	***% option spread***	***Option depth***	***Stock spread***	***% stock spread***	***Days to expiry***	***Stock stdev***	***Daily avg stkprc***	***Quote count***	***VIX daily***
Option spread	1									
% option spread	-0.11144	1								
Option depth	**-0.24747**	**-0.02609**	1							
Stock spread	**0.584549**	0.186186	-0.30035	1						
% stock spread	0.401657	**0.11476**	-0.22185	0.824485	1					
Days to expiry	-0.01251	-0.33053	0.092307	-0.00168	-0.01352	1				
Stock stdev	-0.12417	-0.13209	-0.13278	-0.06087	0.279987	-0.01234	1			
Daily avg stkprc	**0.567785**	**0.157329**	-0.34594	0.791739	0.406049	-0.00107	-0.27242	1		
Quote count	**-0.05941**	**-0.2926**	-0.04047	-0.06228	-0.02546	0.022572	0.024104	-0.00552	1	
VIX daily	-0.01364	-0.03423	-0.0577	0.045478	0.15808	-0.01329	-0.01893	-0.04633	0.254918	1

Chapter 5: Intraday Graphical Analysis

With the existing data, averages of variables within each interval can be calculated to illustrate how these variables change on intraday basis. Figure 5-1 and Figure 5-2 show the intraday trends of option spreads, respectively for call options and put options in our sample, compared to underlying stock spreads. Table 5-1 and Table 5-2 contain the corresponding data. The underlying stock spread data from 5-1 and 5-2 correspond to call option quote data and put option quote data respectively. Once again, the scale of the two axes reveal the significant difference in magnitude between option spreads and stock spreads, regardless of the intraday interval. The blue line with diamond markers represents an L-shaped pattern for option spreads, evidenced by both figures, which confirms the finding of Chan et al. (1995). The spreads of both call options and put options dropped sharply in the first 30-minute interval, by 10.8% and 8.1% respectively, decreased mildly in the following interval, and then remained relatively stable for the rest of the day. On the contrary, the orange line with round markers represents a reverse S-shaped pattern for stock spreads, which is consistent with the results of Chung and Van Ness (2001). Despite using stock data corresponding to call option quotes and put option quotes, stock spreads in Figure 5-1 and Figure 5-2 both decreased sharply by over 20% in the first 30 minutes, declined slowly during the day, and then dropped sharply again in the last 30 minutes by around 20%. The L-shaped pattern of intraday option spread indicates that information asymmetry is the highest at the beginning of the day, then dropped quickly.

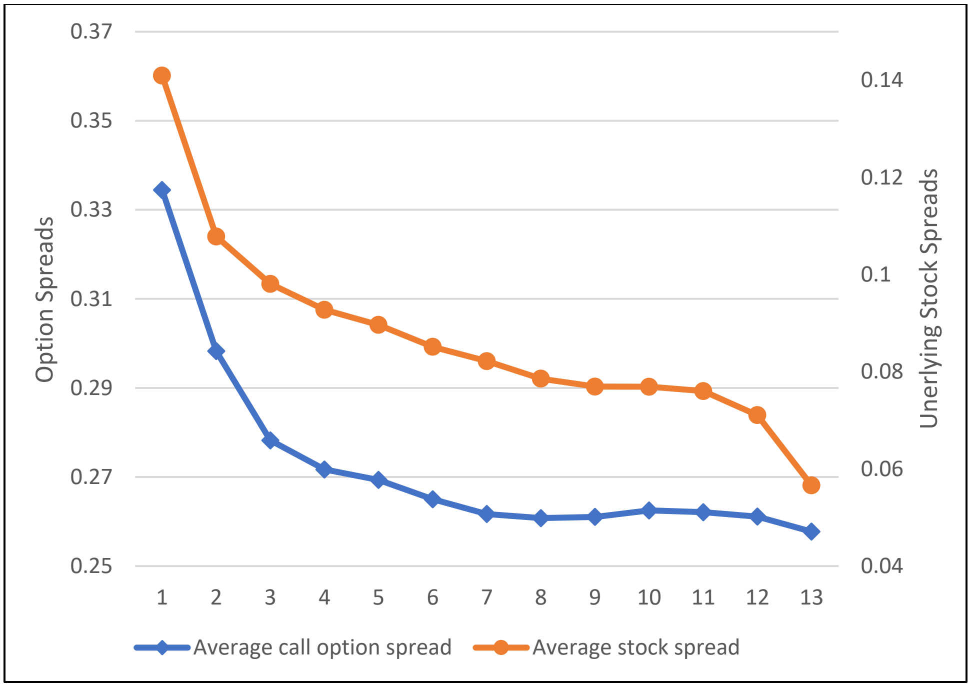

Figure 5-1: Averages of call option spreads in dollars (scaled on left axis) versus underlying stock spreads in dollars (scaled on right axis) across intervals

Table 5-1: Data for Figure 5-1

Interval	Time Period (CST Time)	Call Option Spread (in dollars)	Underlying Stock Spread (in dollars)
1	8:30 - 9:00	0.334465426	0.140947811
2	9:00 - 9:30	0.298268462	0.107835137
3	9:30 - 10:00	0.278238496	0.098093251
4	10:00 - 10:30	0.271696132	0.092748788
5	10:30 - 11:00	0.269344596	0.089640012
6	11:00 - 11:30	0.265005895	0.085135691
7	11:30 - 12:00	0.261688002	0.082183722
8	12:00 - 12:30	0.260765256	0.078582424
9	12:30 - 13:00	0.261039021	0.076946836
10	13:00 - 13:30	0.262502653	0.076915327
11	13:30 - 14:00	0.262100903	0.07602044
12	14:00 - 14:30	0.261106656	0.071061008
13	14:30 - 15:00	0.257739962	0.056624102

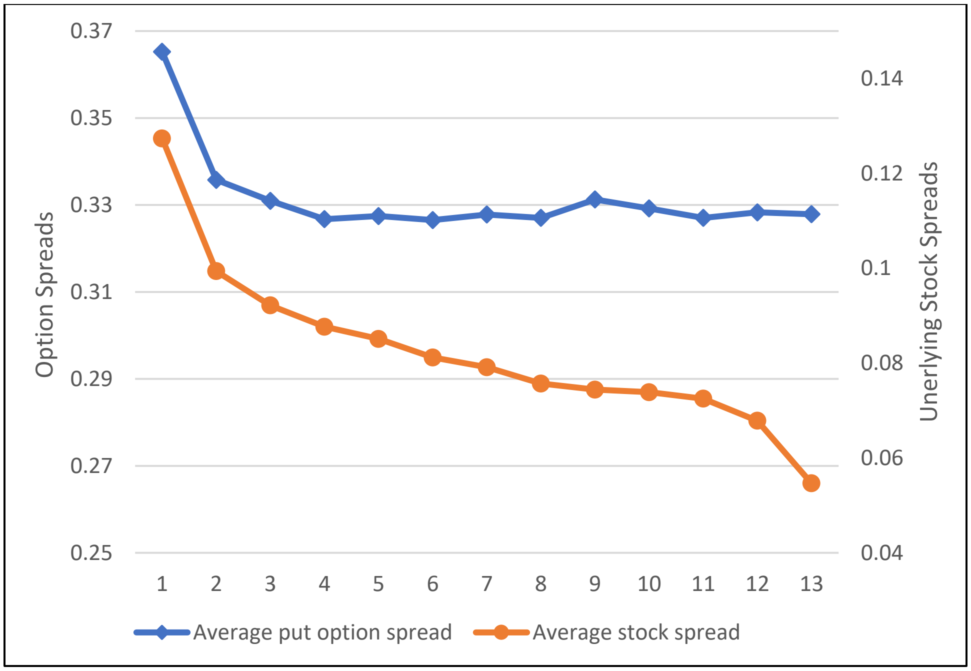

Figure 5-2: Averages of put option spreads in dollars (scaled on left axis) versus underlying stock spreads in dollars (scaled on right axis) across intervals

Table 5-2: Data for Figure 5-2

Interval	**Time Period (CST Time)**	**Put Option Spreads (in dollars)**	**Underlying Stock Spreads (in dollars)**
1	8:30 - 9:00	0.365227184	0.127365251
2	9:00 - 9:30	0.335765602	0.099386539
3	9:30 - 10:00	0.330943432	0.092168986
4	10:00 - 10:30	0.326741745	0.087651053
5	10:30 - 11:00	0.327458613	0.085092518
6	11:00 - 11:30	0.326523556	0.081174968
7	11:30 - 12:00	0.327802179	0.07912921
8	12:00 - 12:30	0.327038969	0.07568097
9	12:30 - 13:00	0.331264947	0.074406615
10	13:00 - 13:30	0.329210937	0.073863295
11	13:30 - 14:00	0.327023229	0.072502809
12	14:00 - 14:30	0.328305569	0.06783705
13	14:30 - 15:00	0.327871241	0.05464935

Despite a similar L-shaped intraday pattern for option spreads, Chan et al. (1995) found a U-shaped pattern for stock spreads, which suggests spreads of stocks should increase near the end of the day. They suspected the difference was due to the difference in market making structures for option market and stock market. However, we found L-shaped intraday pattern for option spreads, but a reverse S-shaped pattern for stock spreads. The same reason could possibly result in this difference.

In order to confirm the intraday dollar spread to be L-shaped, we will use t-test to analyze whether the fluctuations for the afternoon session can be considered to be stable, which is to test whether there is a significant difference in means. In Figure 5-1, there could possibly be a statistically significant drop from interval 10 to interval 13, while in Figure 5-2, there could possibly be a statistically significant rise from interval 8 to interval 9. Call option spread has a mean of 0.2625, a standard deviation of 0.47 and number of observations of 7174 in interval 10, as well as a mean of 0.2577, a standard deviation of 0.46 and number of observations of 7173 in interval 13. The one-tailed test for difference in means has a p-value of 0.27. The drop in call dollar spread is therefore not significant from interval 10 to interval 13. Similarly, the one-tailed test has a p-value of 0.33 for the difference in call dollar spread between interval 8 and interval 9. So the increase is not significant either. Therefore, these tests serve as stronger evidence suggesting the dollar spread has an L-shaped pattern.

Figure 5-3 and Figure 5-4 display the results for percentage spreads for call and put options respectively, compared to underlying stock spreads. Table 5-3 and Table 5-4 contain the corresponding data. The percentage spreads for options in the first 30 minutes of the day averaged to be 19.3% for call options and 10.6% for put options, then dropped and stabilized around 14% and 8% respectively. According to the two figures, percentage spreads remain quite steady, so we decide there is no strong urge to use t-test, as done earlier. For stocks, the percentage spreads started at around 0.08%, declined sharply from the first interval to the second, and then decline slowly and steadily to the last 30-minute interval, where they went through another sharp drop by about 15%. Percentage spread pattern also implies that information asymmetry in option market is the highest at market open.

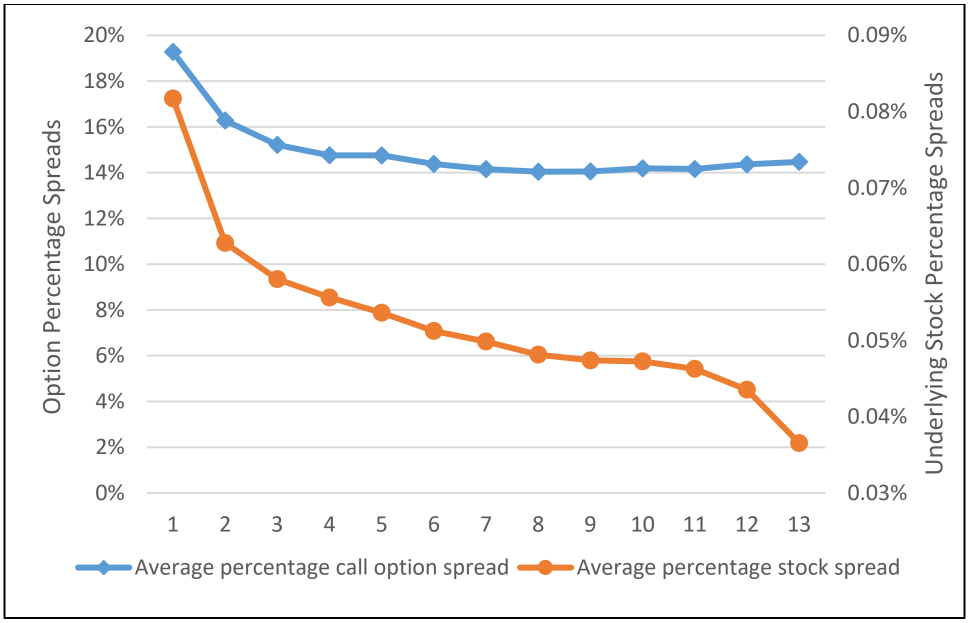

Figure 5-3: Averages of percentage call option spreads (scaled on left axis) versus percentage stock spreads (scaled on right axis) across intervals

Table 5-3: Data for Figure 5-3

Interval	Time period (CST Time)	Percentage Option Spreads	Percentage Underlying Stock Spreads
1	8:30 - 9:00	14.755%	0.082%
2	9:00 - 9:30	12.771%	0.062%
3	9:30 - 10:00	12.303%	0.058%
4	10:00 - 10:30	12.138%	0.055%
5	10:30 - 11:00	12.101%	0.053%
6	11:00 - 11:30	12.040%	0.051%
7	11:30 - 12:00	12.027%	0.050%
8	12:00 - 12:30	11.948%	0.048%
9	12:30 - 13:00	11.977%	0.047%
10	13:00 - 13:30	12.044%	0.047%
11	13:30 - 14:00	12.009%	0.046%
12	14:00 - 14:30	12.125%	0.043%
13	14:30 - 15:00	12.147%	0.037%

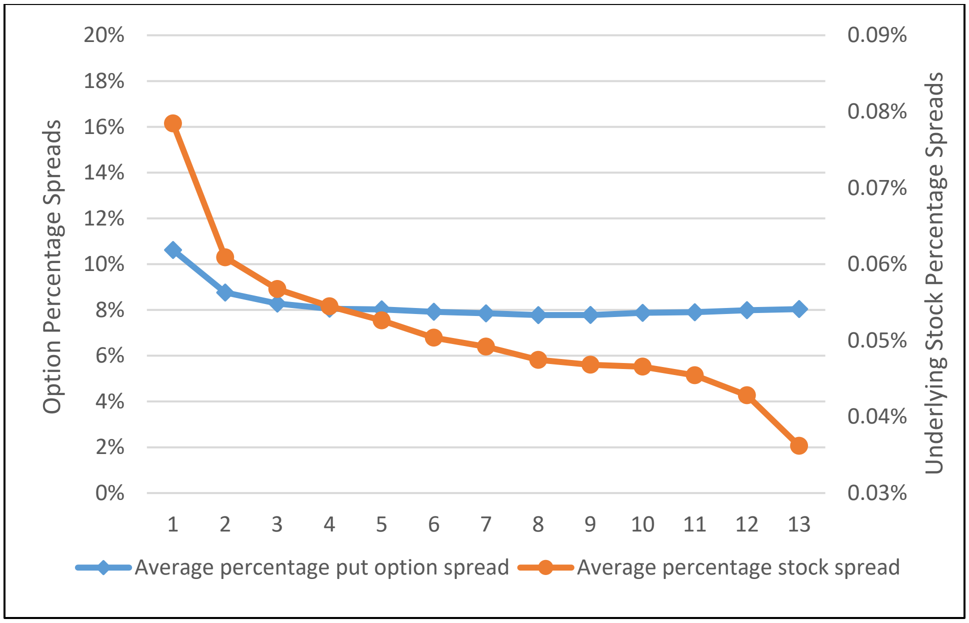

Figure 5-4: Averages of percentage put option spreads (scaled on left axis) versus percentage stock spreads (scaled on right axis) across intervals

Table 5-4: Data for Figure 5-4

Interval	Time period (CST Time)	Percentage Option Spreads	Percentage Underlying Stock Spreads
1	8:30 - 9:00	14.755%	0.082%
2	9:00 - 9:30	12.771%	0.062%
3	9:30 - 10:00	12.303%	0.058%
4	10:00 - 10:30	12.138%	0.055%
5	10:30 - 11:00	12.101%	0.053%
6	11:00 - 11:30	12.040%	0.051%
7	11:30 - 12:00	12.027%	0.050%
8	12:00 - 12:30	11.948%	0.048%
9	12:30 - 13:00	11.977%	0.047%
10	13:00 - 13:30	12.044%	0.047%
11	13:30 - 14:00	12.009%	0.046%
12	14:00 - 14:30	12.125%	0.043%
13	14:30 - 15:00	12.147%	0.037%

For both stocks and options, spreads and percentage spreads resemble similar pattern in Figure 5-1 and Figure 5-2. Shape is L-shaped for options and reverse S-shaped for stocks. The declines at the market open of spreads for stocks and options can be due to various reasons, such as market makers' decision to avoid risks caused by information asymmetry, etc., as mentioned in Section 2.2. The spread declines for stocks, but not for options near the market end. Chung and Van Ness (2001) explained the decline of stock spreads near market close with inventory control by market makers, who offer attractive pricing in order to achieve desired inventory level. The decline in option spreads does not occur near the market close, probably because market makers in option market do not involve themselves in inventory control at the end of the day, or control the risks through hedging in stock market (Cho and Engle, 1999).

Figure 5-5 and Figure 5-6 compare the option spreads and percentage option spreads for call options and put options across intraday intervals. There is a huge drop after the first interval and it stays comparatively flat, regardless of whether it is for calls or puts and whether it is spread or percentage spread. Compared to put options, call options have higher spreads in dollar value, but lower percentage spreads, consistent with summary statistics, where call options have a mean dollar spread of 0.2724 and a mean percentage spread of 14.92%, but put options have a mean dollar spread of 0.3315 and a mean percentage spread of 8.21%. This indicates that call options have higher premiums than put options on average (across different strikes and expiry). It is reasonably expected because most businesses are expected to grow and so are their stock prices. Overall premiums for call options should be of greater value than overall premiums for put options. The premium data in the example in Table A.1 confirm this argument. The average bid price and ask price for all available call options' premium are $26.74 and $ 26.95, while the average bid price and ask price for all available put options' premium are merely $21.14 and $21.31.

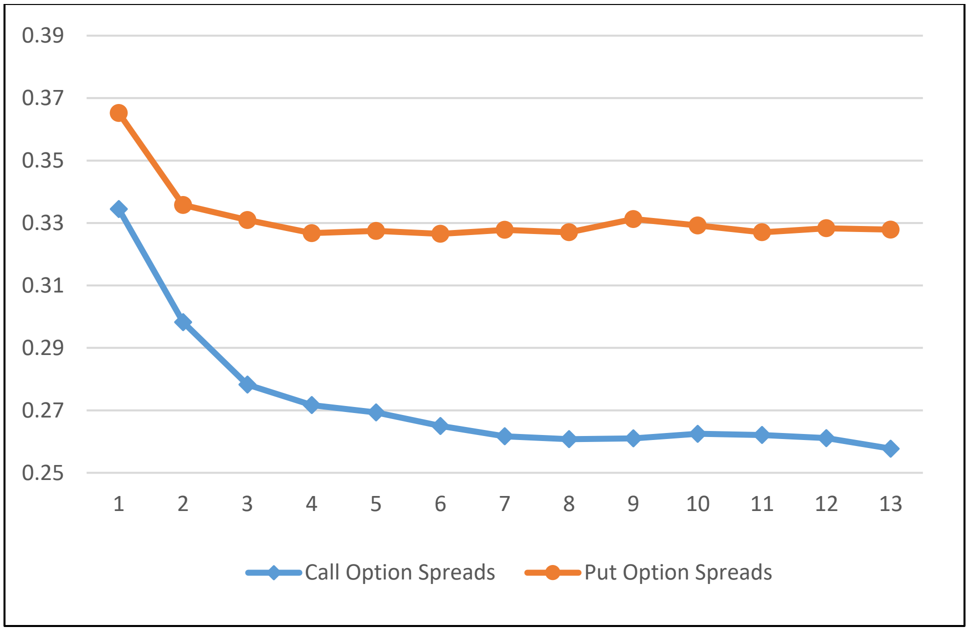

Figure 5-5: Averages of option spreads (in dollars) for calls and puts across intervals

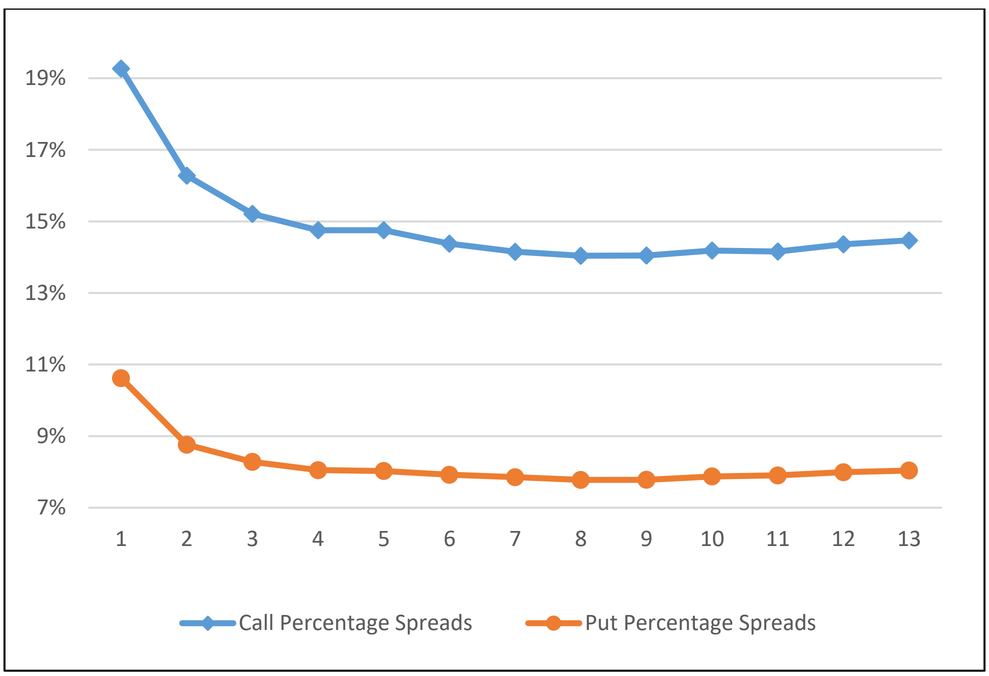

Figure 5-6: Averages of percentage option spreads for calls and puts across intervals

Regardless of the moneyness, Figure 5-7 and Figure 5-8 present L-shaped pattern for dollar spreads for call options and put options while Figure 5-9 and Figure 5-10 present L-shaped pattern for percentage spreads for call options and put options. The two kinds of spreads would typically fall drastically in the first interval and stay relatively flat for the rest of the day, with the only exception being dollar spread for deep in-the-money put options, which does not show a drop in the first interval. However, Figure 5-7 and Figure 5-8 show that, on average, in-the-money options have higher spreads in dollar value than at-the-money options and at-the-money options have higher spread in dollar value than out-of-the-money spreads, consistent with the results of Kodippili (2004). On the contrary, Figure 5-9 and Figure 5-10 show that, in-the-money options have the lowest percentage spreads and out-of-the-money options have the highest percentage spreads, consistent with Cho and Engle (1999) and Kodippili (2004). Mayhew (2002) explains the inverse relationship arguing that option spreads increase with option prices but spreads do not increase as fast as option prices.

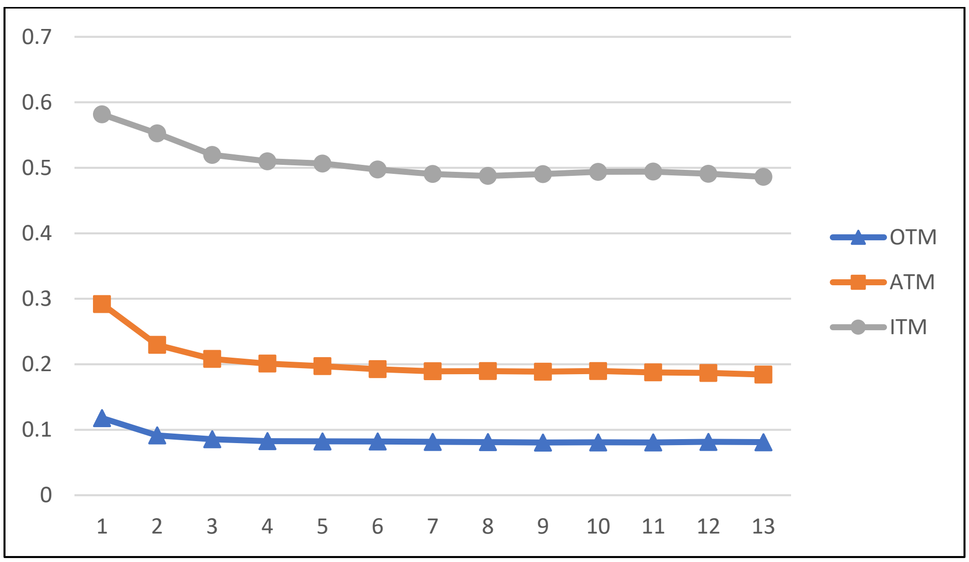

Figure 5-7: Average option dollar spreads for out-of-the-money, at-the-money and in-the-money call options across intervals

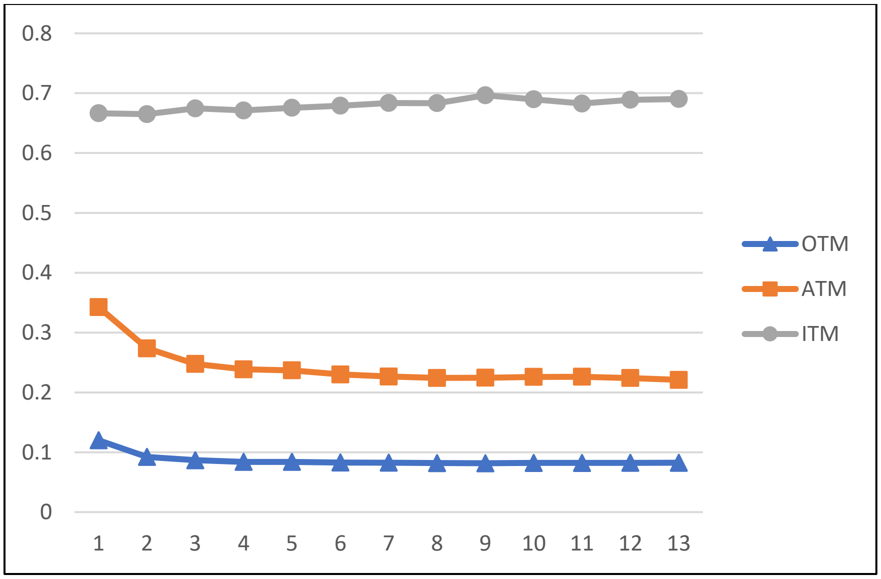

Figure 5-8: Average option dollar spreads for out-of-the-money, at-the-money and in-the-money put options across intervals

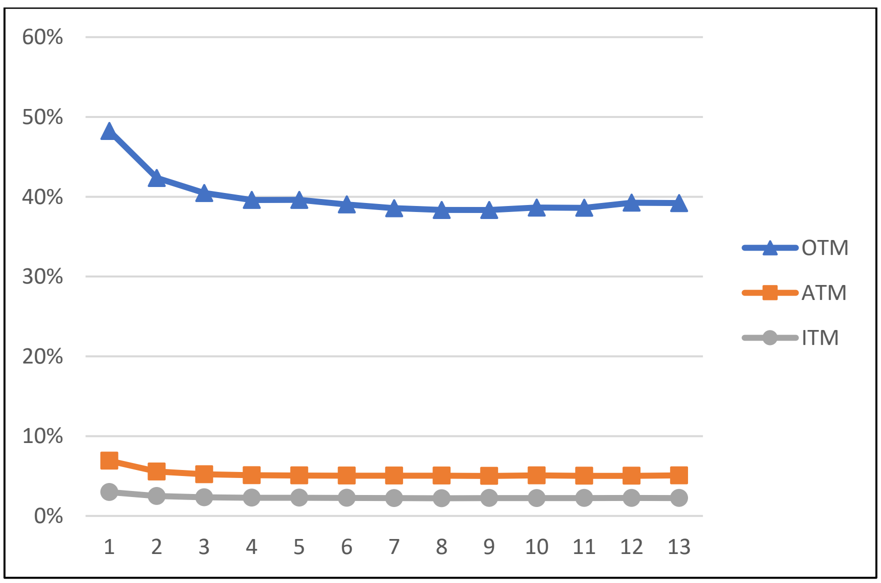

Figure 5-9: Average percentage option spreads for out-of-the-money, at-the-money and in-the-money call options across intervals

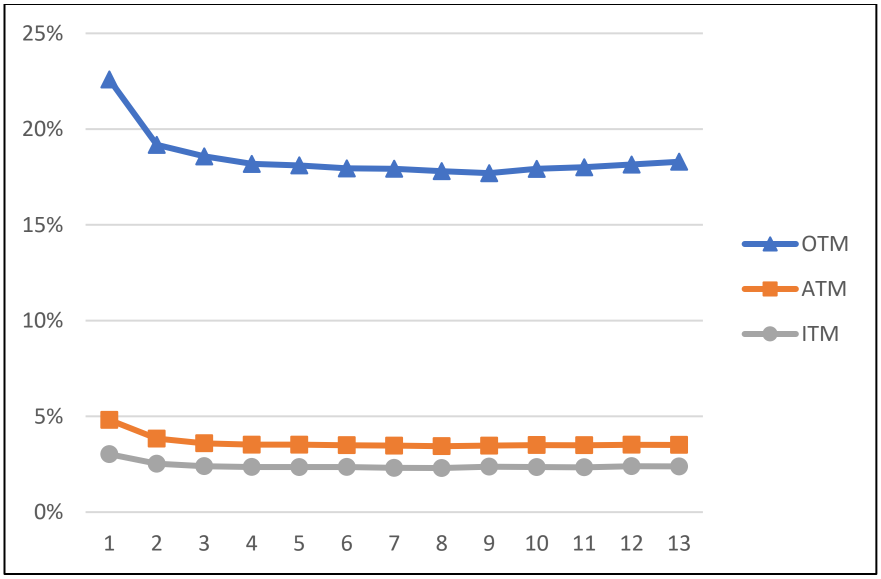

Figure 5-10: Average percentage option spreads for out-of-the-money, at-the-money and in-the-money put options across intervals

Consistent with previous studies, for example Lee et al. (1993), we find paper found the intraday pattern of the option depth is shown in Figure 5-11. For calls and puts, the depth starts off low at the market open, rises in the morning session, and then dips a bit near market close. The drop near the end of the trading day is not as much as the rise at the beginning of the day. If the drop is deemed as significant, this intraday variation would resemble a reverse U-shaped pattern, otherwise a reverse L-shaped pattern. We compare the option depth for intervals 11 and 13, because interval 11 is a local maximum for option depth and interval 13 is the last interval, using a similar t-test at the beginning of this chapter. For call options, average depth in last two intervals are 246.10612 and 235.54063, while for put options the average depths in last two intervals are 212.67386 and 202.88609. The number of observations are 7167 and 7173 for calls, 7285 and 7294 for puts. Standard deviations are 345.61 and 345.69 for calls, 252.20 and 247.95 for puts. Conducting one-tailed t-test to test whether the mean depths are the same between interval 11 and interval 13 for calls and puts respectively, the p-values are 3.362% for calls and 0.908% for puts. The drop is therefore significant for puts at 5% level and for calls at even 1% level. Therefore, we consider the drop significant overall, so the shape should be perceived as reverse U-shaped. Although being U-shaped, the drop near the end of the day is not as much as the jump at the beginning of the day, which can be attributed to many explanations, but the most plausible is that market makers are decreasing the depth to avoid information risks at the start and the end of the trading hours. Similar to previous argument, low depth at market open can be attributed to high level of information asymmetry, while the drop at the end of the day may also suggest the level of information asymmetry increases slightly at market close.

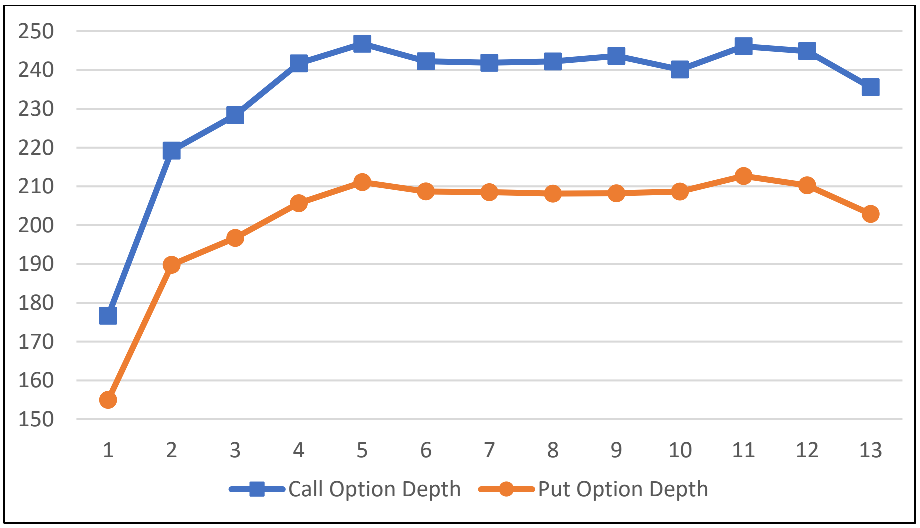

Figure 5-11: Average option depth (in number of contracts) across intervals

Option spreads and percentage option spreads are grouped based on interval dummies and days-to-expiry variable, averaged and plotted against the variables in Figure 5-12 and Figure 5-14 for call options, Figure 5-13 and Figure 5-15 for put options, respectively. Similar to the results reported earlier, interval 1 has the highest dollar spreads regardless of time to expiration, as interval 1 generally has the highest spikes. However, no obvious pattern can be identified from Figure 5-12 or Figure 5-13 for any interval horizontally, which fails to confirm the results of Pinter (2003) and Kodippili (2004) that option dollar spreads are positively related to time to expiry of the options. In contrast, Figure 5-14 and Figure 5-15 collectively suggest that the percentage option spreads decrease with days to expiry, as there is a consistent downward slope from the left to the right for all intervals. This fact is expectedly backed up by the correlation coefficients. As in Table 4-8 for call options, the coefficient between option dollar spread and days to expiry is close to zero, at 0.01439, while the coefficient between percentage option spread and days to expiry is strongly negative, at -0.18178. Similarly for put options, Table 4-9 shows that the coefficient between option dollar spread and days to expiry is close to zero, at -0.01251, while the coefficient between percentage option spread and days to expiry is strongly negative, at -0.33053. The two graphs as well as summary statistics collectively suggest that option spreads are not highly correlated with days to maturity, and that percentage option spreads decrease, when days to expiry increase, as a result from an increase in option prices (premiums).

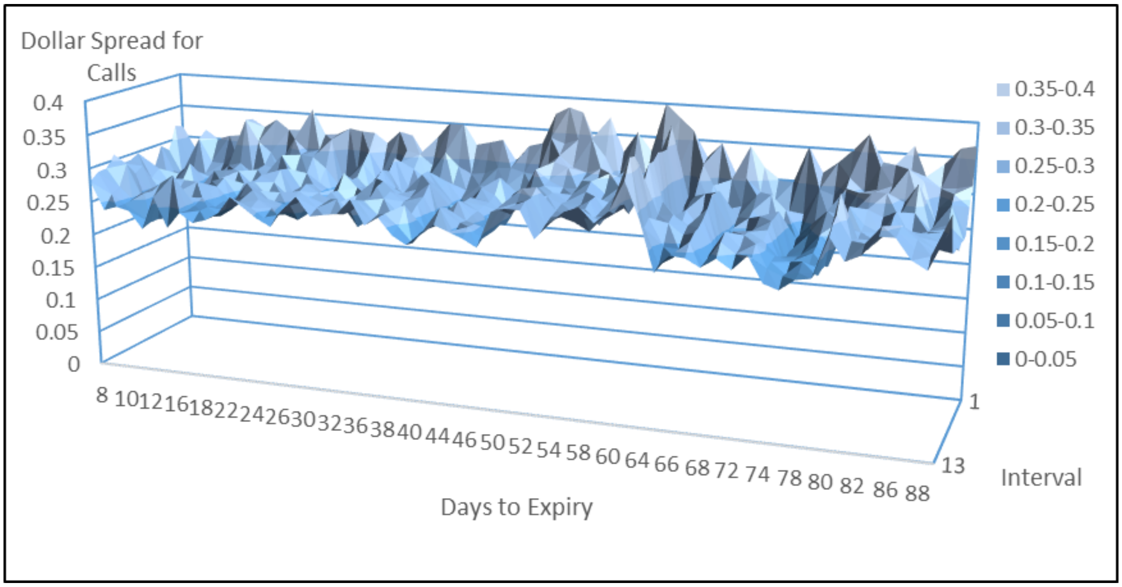

Figure 5-12: Average call option spreads (in dollars) plotted against days to expiry across intervals

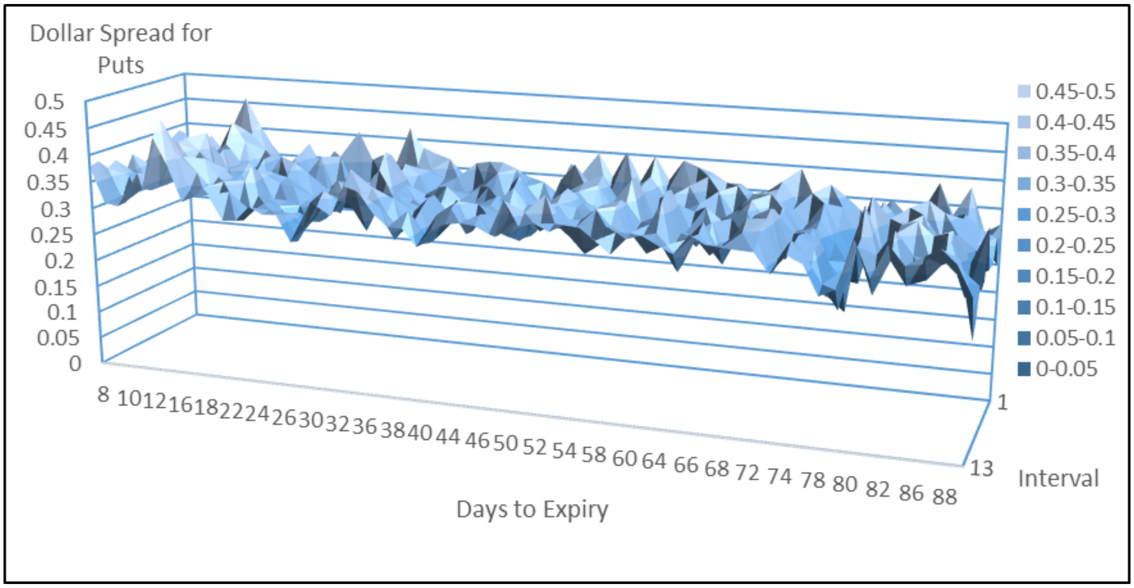

Figure 5-13: Average put option spreads (in dollars) plotted against days to expiry across intervals

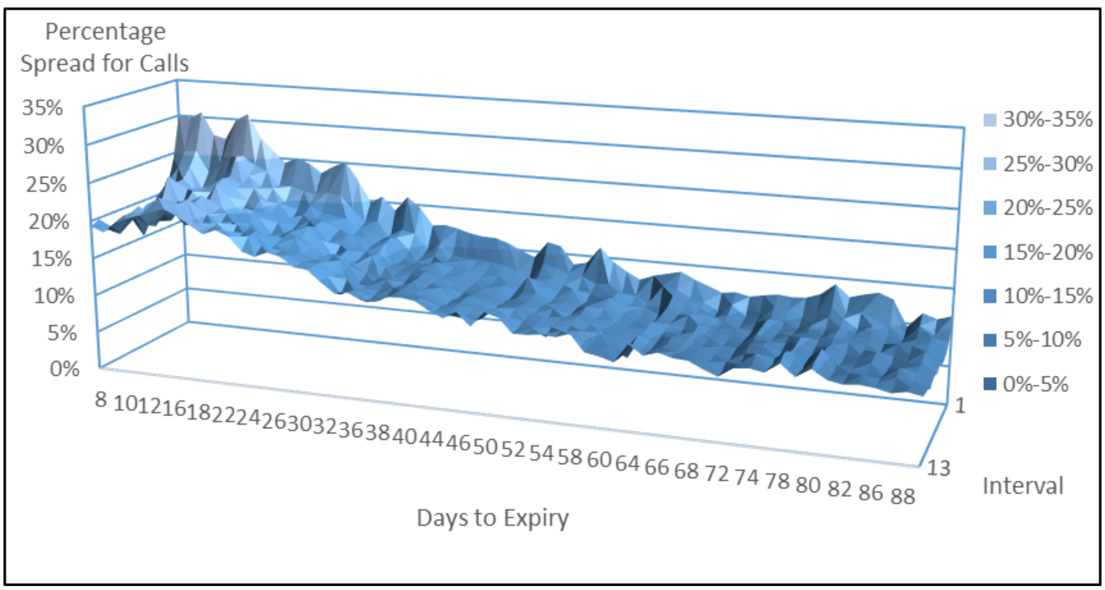

Figure 5-14: Average percentage call option spreads plotted against days to expiry across intervals

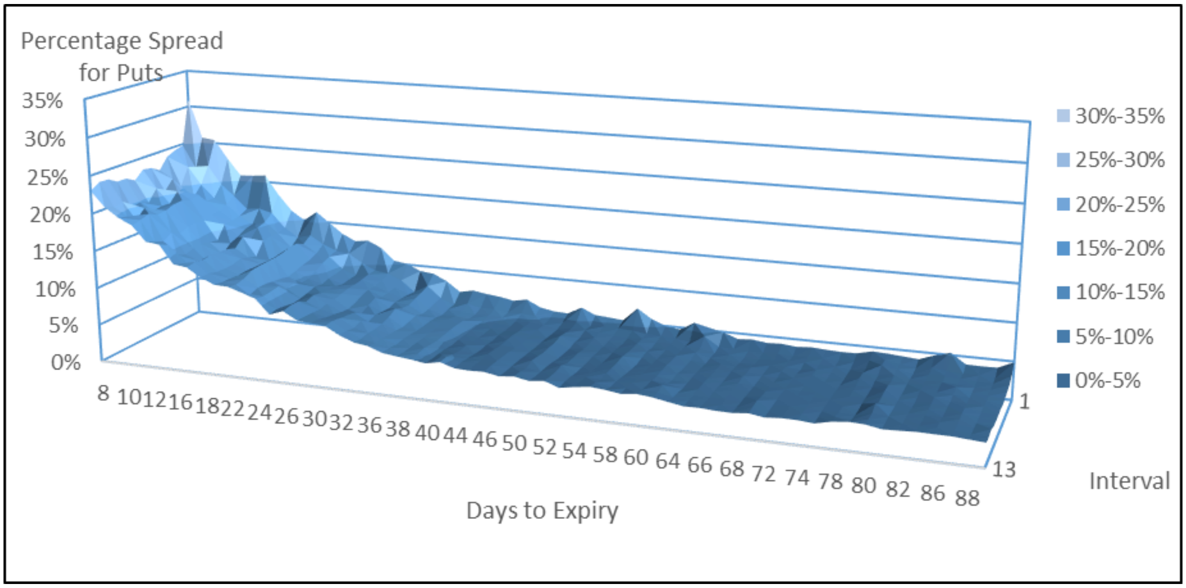

Figure 5-15: Average percentage put option spreads plotted against days to expiry across intervals

Once dollar spreads and percentage spreads are graphed against days to expiry for in-the-money, at-the-money and out-of-the-money options, as in Figure 5-16 and Figure 5-18 for call options, and in Figure 5-17 and Figure 5-19 for put options, a clear pattern cannot be summarized for dollar spreads. However, for percentage spreads, we can observe significant drops, as days to expiry increase for both out-of-the-money options and at-the-money options, but not for in-the-money options. The two results collectively suggest that the price (or the premium) of deep in-the-money options is stable regardless of the days to expiry, because the option is expected to expire in the money and the price should be close to the difference between underlying stock price and its strike price. Also, the two graphs suggest that the option price rises sharply for at-the-money options and out-the-money options, as days to expiry increases, because those options will have greater chance of ending up in the money and greater time value, if there are more days left till expiration date. Therefore, it is indicated that options that expire in a longer period have greater time value, but time value generally has stronger effects on at-the-money and out-of-the-money options as opposed to in-the-money-options.

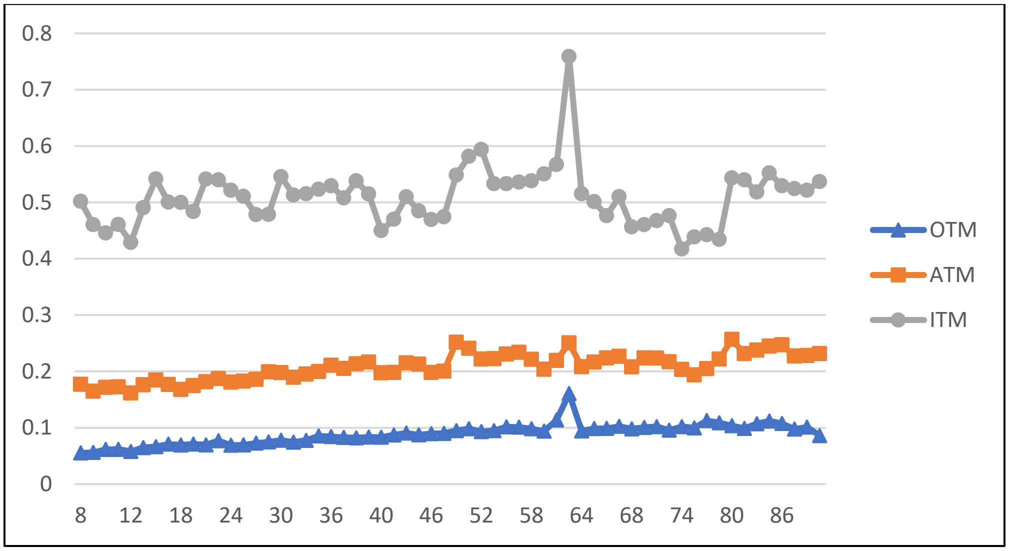

Figure 5-16: Average call option spreads (in dollars) for out-of-the-money, at-the-money and in-the-money options plotted against Days to Expiry

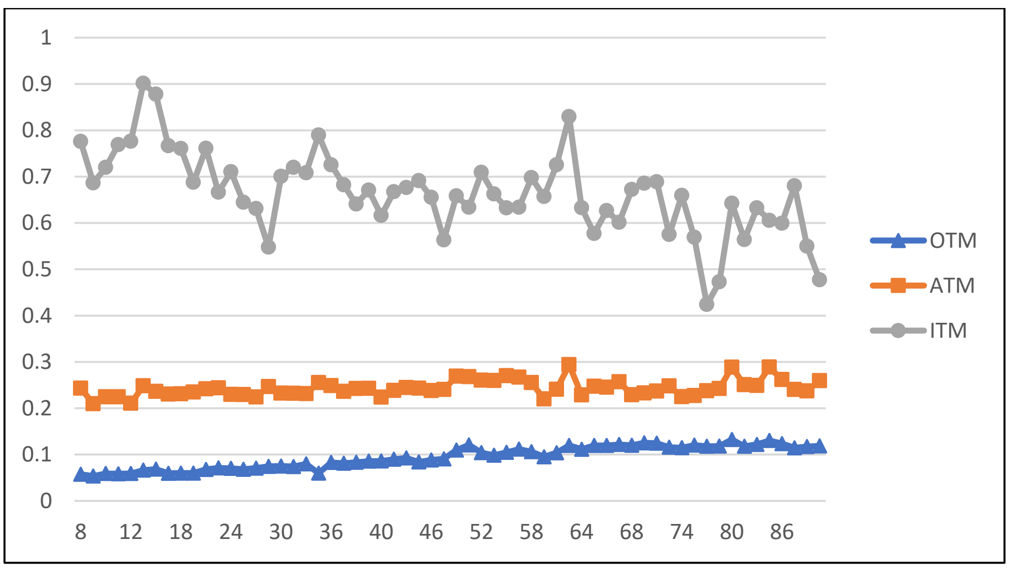

Figure 5-17: Average put option spreads (in dollars) for out-of-the-money, at-the-money and in-the-money options plotted against days to expiry

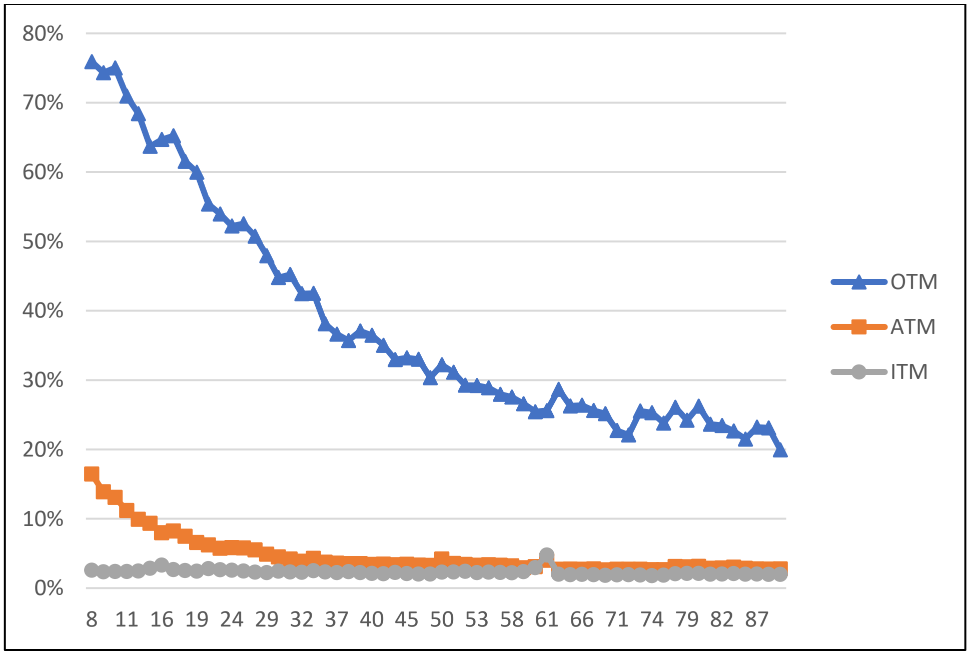

Figure 5-18: Average percentage call option spread for out-of-the-money, at-the-money and in-the-money options plotted against days to expiry

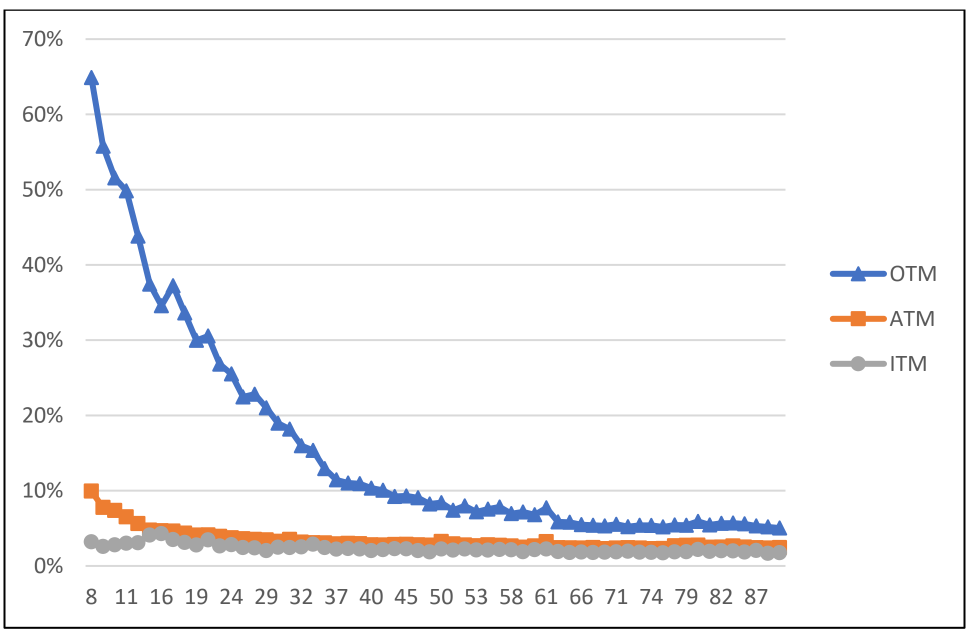

Figure 5-19: Average percentage put option spread for out-of-the-money, at-the-money and in-the-money options plotted against days to expiry

The graphical analysis is mostly based on two or three variables considered jointly. It is straightforward, but may not tell the full story given that some factors interact with each other and that some relationships cannot be recognized visually. Next we use regression analysis to analyze the impact of all variables jointly.

Chapter 6: Regression Analysis Models

This research is based on propositions made and tested by previous studies. We extend the theoretical framework of intraday option spreads, develop models that incorporate more variables, test the results of previous studies, and evaluate the impact of newly included factors. We also seek to examine how these determinants of option spread affect option depth.

In Section 2.1 a list of variables has been discussed. There are findings consistently suggesting that option spread is negatively correlated with option depth (Verousis and Gwilym, 2013), positively correlated with underlying stock spread (Cho and Engle, 1999; De Fontnouvelle et al., 2003; Verousis and Gwilym, 2013), positively correlated with time to expiration (Pinter, 2003; Kodippili, 2004), positively correlated with moneyness[11] (Kodippili, 2004), positively correlated with option price (Mayhew, 2002; De Fontnouvelle et al., 2003), and positively correlated with option delta (De Fontnouvelle et al., 2003; Pinter, 2003). Our model will include these variables except option price, option volatility, and option delta. Wei and Zheng (2010) revealed that option price is highly correlated with moneyness, time to expiry, and the underlying volatility, and they dropped option price variable in most of their regression models because the dependent variable is the percentage option spread. Also, in each option quote group of this study, there are usually multiple strike price, leading to multiple levels of option price, so there is not a good metric for option price for the entire group of quotes. In addition to all those reasons to not include option price as an independent variable, this factor can be taken care of the use of percentage option spread, which places dollar spread on the scale of option price. Moreover, option delta and option volatility for each option quote group (which contain multiple strike prices) are hard to calculate and do not have very meaningful interpretations for intraday data. Previous studies that incorporated option delta were daily studies, instead of intraday studies, and they had much smaller sample size, so there was no need to bundle options series with different strike prices into groups.

There are some mixed results in past literatures. Hait (1999) contended that the volatility of the underlying stock is a key factor for option spread, while Mayhew (2002), De Fontnouvelle et

[11] It means in-the-money options tend to have higher spreads than out-of-the-money options.

al. (2003) and Wei and Zheng (2010) indicate that the volatility is not significant. Mayhew (2002) and Pinter (2003) both argue for the negative relationship between spread and the intensity of market activities (trading volume) of the options, while Cho and Engle (1999) and Wei and Zheng (2010) conclude that the impact is minor.

Overall, all those factors will be included in our models, no matter whether previous studies report results in consensus or in controversy. For those in consensus, we aim to test their significance and validity with our sample; for those in controversy, we aim to provide our own insight in hope to help reinforce one or the other.

As has been done in former research, the spread of the underlying stock, option depth, days to expiry and volatility of underlying stock are included as independent variables for option spread. In addition, we use two dummy variables to control for moneyness effects and 12 interval dummy variables to capture the intraday variations in the spread. Since sample period is January, February and March of 2010, the standard deviation for each underlying stock's daily returns in the period of Dec 1st 2009 to April 30th 2010 are used to calculate the volatility of the underlying stock. Quote count divided by 100,000 for each option quote group for each interval is used to replace option volume as a proxy for intensity of market activities, since the frequency of quote changes symbolizes that the option is active and of interest to traders. Chan, Chung and Fong (2002) suggests that from investors' perspective the option quote revisions are stronger indicators of activeness of options and they contain more information than option volume. They argued the reason is that informed traders much prefer submitting limit orders than placing market orders, therefore many of those activities can be captured by quote revisions, but not necessarily by trading volume. Quote revisions can more effectively convey information and bring down the level of information asymmetry, especially when the option market is characterized by illiquidity and lack of volume. Chung, Chuwonganant and Jiang (2008) also argued that stock liquidity providers are likely to speed up or slow down spread and depth adjustments in response to higher or lower volume of trading. Therefore, frequent quote revisions and high quote counts become associated with high liquidity and fast-moving market, justifying our use of it to represent the level of market activities.

In addition to variables suggested by previous studies, we propose, based on Hypotheses 2 and 3, including the average stock price on each day for each stock and the daily VIX index as explanatory variables of the spread and the depth. Average stock price is introduced as a proxy for the costs of hedging. The daily VIX index is introduced to examine whether the changes in market sentiment and expectations of overall market volatility on one day affects option spread.

Our basic model which is based on previous studies may be presented as follows:

Model 1:

$$\text{Option Dollar Spread} = \beta_0 + \beta_1 \text{Stock Dollar Spread} + \beta_2 \text{Option Depth} + \beta_3 \text{Days to Expiry} + \beta_4 \text{Quote Count} + \beta_5 \text{Volatility of Underlying Stock} + \sum_{i=2}^{13} \alpha_i D_i + \varepsilon_{ij} \quad (6.1)$$

Where ε_{ij} is the random error, *i* denotes the time interval, *j* represents the option quote group. Within interval *i* and for option quote group *j*, *Option Dollar Spread* is the time-weighted option bid-ask spread of all quotes, *Stock Dollar Spread* is the time-weighted stock bid-ask spread, *Option Depth* is the time-weighted option depth of all quotes, *Days to Expiry* is the number of days left till expiration date for the entire option quote group, *Quote Count* is the frequency of quote revisions (scaled by 100,000), *Volatility of Underlying Stoc*k is the standard deviation of daily returns for underlying stock of the entire option quote group from Dec 1st 2009 to April 30th 2010, D_i is the interval dummy that captures the time-of-the-day effect.

In this study, we acknowledge that there are significant differences in the option spread patterns depending on the degree by which an option is in-the-money (ITM) or out-of-the-money (OTM). Therefore, we divide our sample between OTM, ATM, and ITM options and we use two dummy variables to find the impact of moneyness. We also incorporate out-of-the-money and in-the-money interaction terms with other main independent variables in Model 1 to construct Model 2. Model 2 may be stated as follow:

Model 2:

$$\text{Option Dollar Spread} = \beta_0 + \beta_1 \text{Stock Dollar Spread} + \beta_2 \text{Option Depth} + \beta_3 \text{Days to Expiry} + \beta_4 \text{Quote Count} + \beta_5 \text{Volatility of Underlying Stock} + \beta_6 D_{ITM} + \beta_7 D_{OTM} + \beta_8 D_{ITM} \times \text{Stock Dollar Spread} + \beta_9 D_{OTM} \times \text{Stock Dollar Spread} + \beta_{10} D_{ITM} \times \text{Option Depth} + \beta_{11} D_{OTM} \times \text{Option Depth} + \beta_{12} D_{ITM} \times \text{Days to Expiry} + \beta_{13} D_{OTM} \times \text{Days to Expiry} + \beta_{14} D_{ITM} \times \text{Quote Count} + \beta_{15} D_{OTM} \times \text{Quote Count} + \beta_{16} D_{ITM} \times \text{Volatility of} \quad (6.2)$$

$$\text{Underlying Stock} + \beta_{17}D_{OTM} \times \text{Volatility of Underlying Stock} + \sum_{i=2}^{13} \alpha_i D_i + \varepsilon_{ij}$$

D_{ITM} is in-the-money dummy variable that takes 1 if the option quote group is in the money and 0 otherwise, D_{OTM} is out-of-the-money dummy variable that takes 1 if the option quote group is out of the money and 0 otherwise. All other variables and notations are as defined with Equation 7.1.

Model 3 is an extension of Model 2 to incorporate and analyze the effect of the cost of hedging on option spread that we put forward in Hypothesis 2, using average daily stock price as the proxy, as well as its in-the-money and out-of-the-money interaction terms.

Model 3:

$$\begin{aligned}\text{Option Dollar Spread} = {} & \beta_0 + \beta_1\text{Stock Dollar Spread} + \beta_2\text{Option Depth} + \beta_3\text{Days to Expiry} + \beta_4\text{Quote Count} + \beta_5\text{Volatility of Underlying Stock} + \beta_6\text{Average Daily Stock Price} + \beta_7 D_{ITM} \\ & + \beta_8 D_{OTM} + \beta_9 D_{ITM} \times \text{Stock Dollar Spread} + \beta_{10} D_{OTM} \times \text{Stock Dollar Spread} + \\ & \beta_{11} D_{ITM} \times \text{Option Depth} + \beta_{12} D_{OTM} \times \text{Option Depth} + \beta_{13} D_{ITM} \times \text{Days to Expiry} + \\ & \beta_{14} D_{OTM} \times \text{Days to Expiry} + \beta_{15} D_{ITM} \times \text{Quote Count} + \beta_{16} D_{OTM} \times \text{Quote Count} + \\ & \beta_{17} D_{ITM} \times \text{Volatility of Underlying Stock} + \beta_{18} D_{OTM} \times \text{Volatility of Underlying Stock} + \beta_{19} D_{ITM} \times \text{Average Daily Stock Price} + \beta_{20} D_{OTM} \times \text{Average Daily Stock Price} + \sum_{i=2}^{13} \alpha_i D_i + \varepsilon_{ij} \end{aligned} \qquad (6.3)$$

Average Daily Stock Price is the daily average price of the underlying stock. All other variables and notations are as defined with Equation 7.1 and 7.2.

Model 4 further develops Model 3 to include expected market volatility, using VIX index as a proxy, to test its effect on option spread, as mentioned in Hypothesis 3. The in-the-money and out-of-the-money interaction terms of the variable are also added.

Model 4:

$$\begin{aligned}\text{Option Dollar Spread} = {} & \beta_0 + \beta_1\text{Stock Dollar Spread} + \beta_2\text{Option Depth} + \beta_3\text{Days to Expiry} + \beta_4\text{Quote Count} + \beta_5\text{Volatility of Underlying Stock} + \beta_6\text{Average Daily Stock Price} + \beta_7\text{Daily VIX} + \beta_8 D_{ITM} + \beta_9 D_{OTM} + \beta_{10} D_{ITM} \times \text{Stock Dollar Spread} + \beta_{11} D_{OTM} \times \text{Stock Dollar Spread} + \beta_{12} D_{ITM} \times \text{Option Depth} + \beta_{13} D_{OTM} \times \text{Option Depth} + \beta_{14} D_{ITM} \times \text{Days to Expiry} + \\ & \beta_{15} D_{OTM} \times \text{Days to Expiry} + \beta_{16} D_{ITM} \times \text{Quote Count} + \beta_{17} D_{OTM} \times \text{Quote} \end{aligned} \qquad (6.4)$$

$$Count + \beta_{18}D_{ITM} \times Volatility\ of\ Underlying\ Stock + \beta_{19}D_{OTM} \times Volatility\ of\ Underlying\ Stock + \beta_{20}D_{ITM} \times Average\ Daily\ Stock\ Price + \beta_{21}D_{OTM} \times Average\ Daily\ Stock\ Price + \beta_{22}D_{ITM} \times Daily\ VIX + \beta_{23}D_{OTM} \times Daily\ VIX + \sum_{i=2}^{13} \alpha_i D_i + \varepsilon_{ij}$$

Daily VIX is the index level of the CBOE SPX Volatility Index (VIX). All other variables and notations are as defined with Equation 7.1, 7.2 and 7.3.

This study also develops models with percentage option spread as independent variable. As noted in the literature, option spread and option price are positively correlated. Since we do not have a variable that controls for option price, percentage option spread is analyzed to mitigate this concern. In order to be consistent on both side of the equation, percentage stock spread will substitute stock dollar spread in Equations 7.1, 7.2, 7.3 and 7.4. The resulting Models 5, 6, 7 and 8 may be presented as follows:

Model 5:

$$Percentage\ Option\ Spread = \beta_0 + \beta_1 Percentage\ Stock\ Spread + \beta_2 Option\ Depth + \beta_3 Days\ to\ Expiry + \beta_4 Quote\ Count + \beta_5 Volatility\ of\ Underlying\ Stock + \sum_{i=2}^{13} \alpha_i D_i + \varepsilon_{ij} \quad 6.5$$

Model 6:

$$Percentage\ Option\ Spread = \beta_0 + \beta_1 Percentage\ Stock\ Spread + \beta_2 Option\ Depth + \beta_3 Days\ to\ Expiry + \beta_4 Quote\ Count + \beta_5 Volatility\ of\ Underlying\ Stock + \beta_6 D_{ITM} + \beta_7 D_{OTM} + \beta_8 D_{ITM} \times Percentage\ Stock\ Spread + \beta_9 D_{OTM} \times Percentage\ Stock\ Spread + \beta_{10} D_{ITM} \times Option\ Depth + \beta_{11} D_{OTM} \times Option\ Depth + \beta_{12} D_{ITM} \times Days\ to\ Expiry + \beta_{13} D_{OTM} \times Days\ to\ Expiry + \beta_{14} D_{ITM} \times Quote\ Count + \beta_{15} D_{OTM} \times Quote\ Count + \beta_{16} D_{ITM} \times Volatility\ of\ Underlying\ Stock + \beta_{17} D_{OTM} \times Volatility\ of\ Underlying\ Stock + \sum_{i=2}^{13} \alpha_i D_i + \varepsilon_{ij} \quad 6.6$$

Model 7:

$$Percentage\ Option\ Spread = \beta_0 + \beta_1 Percentage\ Stock\ Spread + \beta_2 Option\ Depth + \beta_3 Days\ to\ Expiry + \beta_4 Quote\ Count + \beta_5 Volatility\ of\ Underlying\ Stock + \beta_6 Average\ Daily\ Stock\ Price + \beta_7 D_{ITM} + \beta_8 D_{OTM} + \beta_9 D_{ITM} \times Percentage\ Stock\ Spread + \beta_{10} D_{OTM} \times Percentage\ Stock\ Spread + \beta_{11} D_{ITM} \times Option\ Depth + \beta_{12} D_{OTM} \times Option\ Depth + \beta_{13} D_{ITM} \times Days\ to\ Expiry + \beta_{14} D_{OTM} \times Days\ to\ Expiry + \beta_{15} D_{ITM} \times \quad 6.7$$

$$Quote\ Count + \beta_{16}D_{OTM} \times Quote\ Count + \beta_{17}D_{ITM} \times Volatility\ of\ Underlying\ Stock + \beta_{18}D_{OTM} \times Volatility\ of\ Underlying\ Stock + \beta_{19}D_{ITM} \times Average\ Daily\ Stock\ Price + \beta_{20}D_{OTM} \times Average\ Daily\ Stock\ Price + \sum_{i=2}^{13} \alpha_i D_i + \varepsilon_{ij}$$

Model 8:

$$Percentage\ Option\ Spread = \beta_0 + \beta_1 Percentage\ Stock\ Spread + \beta_2 Option\ Depth + \beta_3 Days\ to\ Expiry + \beta_4 Quote\ Count + \beta_5 Volatility\ of\ Underlying\ Stock + \beta_6 Average\ Daily\ Stock\ Price + \beta_7 Daily\ VIX + \beta_8 D_{ITM} + \beta_9 D_{OTM} + \beta_{10} D_{ITM} \times Percentage\ Stock\ Spread + \beta_{11} D_{OTM} \times Percentage\ Stock\ Spread + \beta_{12} D_{ITM} \times Option\ Depth + \beta_{13} D_{OTM} \times Option\ Depth + \beta_{14} D_{ITM} \times Days\ to\ Expiry + \beta_{15} D_{OTM} \times Days\ to\ Expiry + \beta_{16} D_{ITM} \times Quote\ Count + \beta_{17} D_{OTM} \times Quote\ Count + \beta_{18} D_{ITM} \times Volatility\ of\ Underlying\ Stock + \beta_{19} D_{OTM} \times Volatility\ of\ Underlying\ Stock + \beta_{20} D_{ITM} \times Average\ Daily\ Stock\ Price + \beta_{21} D_{OTM} \times Average\ Daily\ Stock\ Price + \beta_{22} D_{ITM} \times Daily\ VIX + \beta_{23} D_{OTM} \times Daily\ VIX + \sum_{i=2}^{13} \alpha_i D_i + \varepsilon_{ij} \quad (6.8)$$

Variables in Models 5, 6, 7 and 8 are corresponding to variables in Model 1, 2, 3 and 4, except *Option Dollar Spread* is replaced by *Percentage Option Spread* (the time-weighted percentage option spread) on the left-hand side and *Stock Dollar Spread* is replaced by *Percentage Stock Spread* on the right-hand side (time-weighted percentage stock spread) within interval *i* and for option quote group *j*.

Additionally, it is argued by Lee et al. (1993) that the spread and the depth are respectively the price dimension and the quantity dimension of liquidity. Thus, an interaction, instead of a causal relationship, exists between the two of them, so we develop models to regress option depth on option spread to examine this relationship. In these models, we use the option depth as the dependent variable and option dollar spread as an explanatory variable. We observe that there are strong correlations between the option dollar spread and the percentage option spread, therefore we can only include one of them as an explanatory variable. Further, we noticed that percentage spread has strong correlations with other independent variables in the depth model (days to expiry and quote count) while the dollar spread does not have such strong correlations. Therefore, option dollar spread seems to be a better choice to be used as an explanatory variable, given its relatively low correlations with other independent variables. All other independent variables stay the same for the models of option depth. Model 9 takes similar form as the other two basic models, Model 1 and Model 5; Model 10 takes similar form as the other two models involving moneyness interactions. However, due to strong correlation between option dollar spread and daily average stock price (over 0.5), we cannot regress option depth on these two variables at the same time. Given that there are some arguments suggesting relationship between option spread and option depth (Verousis and Gwilym, 2013) and that we have found no theoretical support for the effect of underlying stock price on option depth, we will only extend models for option depth by including *Daily VIX* variable, but not *Daily Average Stock Price* variable. Thus, in addition to Model 10, Model 11 will include VIX index and its interaction terms.

Model 9:

$$\text{Option Depth} = \beta_0 + \beta_1\text{Option Dollar Spread} + \beta_2\text{Days to Expiry} + \beta_3\text{Quote Count} + \beta_4\text{Volatility of Underlying Stock} + \sum_{i=2}^{13} \alpha_i D_i + \varepsilon_{ij} \quad (6.9)$$

Model 10:

$$\text{Option Depth} = \beta_0 + \beta_1\text{ Option Dollar Spread} + \beta_2\text{Days to Expiry} + \beta_3\text{Quote Count} + \beta_4\text{Volatility of Underlying Stock} + \beta_5 D_{ITM} + \beta_6 D_{OTM} + \beta_7 D_{ITM} \times \text{Option Dollar Spread} + \beta_8 D_{OTM} \times \text{Option Dollar Spread} + \beta_9 D_{ITM} \times \text{Days to Expiry} + \beta_{10} D_{OTM} \times \text{Days to Expiry} + \beta_{11} D_{ITM} \times \text{Quote Count} + \beta_{12} D_{OTM} \times \text{Quote Count} + \beta_{13} D_{ITM} \times \text{Volatility of Underlying Stock} + \beta_{14} D_{OTM} \times \text{Volatility of Underlying Stock} + \sum_{i=2}^{13} \alpha_i D_i + \varepsilon_{ij} \quad (6.10)$$

Model 11:

$$\text{Option Depth} = \beta_0 + \beta_1\text{Option Dollar Spread} + \beta_2\text{Days to Expiry} + \beta_3\text{Quote Count} + \beta_4\text{Volatility of Underlying Stock} + \beta_5\text{Daily VIX} + \beta_6 D_{ITM} + \beta_7 D_{OTM} + \beta_8 D_{ITM} \times \text{Option Dollar Spread} + \beta_9 D_{OTM} \times \text{Option Dollar Spread} + \beta_{10} D_{ITM} \times \text{Days to Expiry} + \beta_{11} D_{OTM} \times \text{Days to Expiry} + \beta_{12} D_{ITM} \times \text{Quote Count} + \beta_{13} D_{OTM} \times \text{Quote Count} + \beta_{14} D_{ITM} \times \text{Volatility of Underlying Stock} + \beta_{15} D_{OTM} \times \text{Volatility of Underlying Stock} + \beta_{16} D_{ITM} \times \text{Daily VIX} + \beta_{17} D_{OTM} \times \text{Daily VIX} + \sum_{i=2}^{13} \alpha_i D_i + \varepsilon_{ij} \quad (6.11)$$

All variables and notations are as defined previously.

Most previous studies acknowledge that call options and put options behave differently. For this reason, previous studies always run two separate regressions for call options and put options. Following this convention, this study will also run two separate regressions for each model, using data of call options in one regression and data of put options in another.

Chapter 7: Empirical Results

We examine three dependent variables: option dollar spreads, option percentage spreads and option depth. We will run models with similar control variables for each of them. For each model, we use call option data and put option data separately to produce two sets of results for calls and puts. Starting from our basic models (Model 1, 5 and 9), we introduce moneyness dummies and in-the-money and out-of-the-money interaction terms as control variables hoping to gain some empirical knowledge regarding the impact of moneyness on option spread and depth. This addition leads to Models 2, 6, and 10. Afterwards, we add to Models 2 and 6 the average daily stock price and its interactions with the moneyness dummy variables as explanatory variables of the dollar and percentage spreads. These additions lead to Models 3 and 7. Finally, we add to Models 3, 7, and 10 the daily VIX index and terms that interact the VIX with the moneyness dummy variables as explanatory variables for dollar spread, percentage spread, and the depth of puts and calls. These additions lead to models 4, 8, and 11. We consider Models 4, 8, and 11 to be superior because they control for moneyness, the interaction terms, and allow us to analyze the effect of underlying stock price and expected market volatility.

The regression results of Models 1, 2, 3, and 4 are displayed in Table 7-1 for call options and in Table 7-2 for put options. For both calls and puts, the adjusted R-squared values jump from lower than 0.45 to around 0.85, after including moneyness dummy variables and the variables representing the interactions between moneyness and other explanatory variables. The change demonstrates the power of moneyness in explaining intraday option dollar spreads. In another word, they suggest that big differences exist among in-the-money (ITM), at-the-money (ATM) and out-of-the-money (OTM) options, as option spreads react very differently to those explanatory factors, given different moneyness. Adding daily stock price shows an effect on improving overall fitness, while adding daily VIX variable doesn't significantly increase adjusted R-squared.

Table 7-1: Main Regression Results for Model 1, Model 2, Model 3 and Model 4, Using Call Option Data, with Option Dollar Spread as Dependent Variable

Column #	(1)	(2)	(3)	(4)

Dependent Variable	Option dollar spread	Option dollar spread	Option dollar spread	Option dollar spread
Calls or Puts	Calls	Calls	Calls	Calls
Model	Model 1	Model 2	Model 3	Model 4
Independent Variables				
stock_spread	2.30933***	1.87182***	1.66942***	1.63066***
	(235.016)	(201.652)	(127.008)	(121.202)
option_depth	-0.00004***	-0.00006***	-0.00002***	-0.00000
	(-9.969)	(-8.770)	(-2.938)	(-0.321)
days_to_expiry	0.00032***	0.00104***	0.00099***	0.00097***
	(5.510)	(20.569)	(20.696)	(20.268)
quote_count	-0.02559***	-0.03779***	-0.05184***	-0.06478***
	(-7.228)	(-13.700)	(-19.778)	(-23.181)
stock_stdev	-8.03621***	-1.05775***	0.57743***	0.94967***
	(-33.883)	(-5.016)	(2.611)	(4.264)
daily_avg_stkprc			0.00026***	0.00030***
			(18.336)	(20.955)
VIX_daily				0.00487***
				(13.321)
D_ITM		0.63440***	0.39393***	0.52135***
		(76.771)	(43.620)	(37.151)
D_OTM		-0.09773***	-0.07212***	-0.00194
		(-10.799)	(-7.271)	(-0.124)
Interaction Terms				
ITM_stock_spread		3.09876***	2.09380***	2.13594***
		(238.824)	(108.082)	(108.233)
OTM_stock_spread		-1.18116***	-1.05306***	-1.02642***
		(-94.442)	(-58.896)	(-56.523)
ITM_option_depth		-0.00003***	-0.00001*	-0.00003***
		(-3.975)	(-1.957)	(-4.408)
OTM_option_depth		0.00007***	0.00004***	0.00002**
		(7.832)	(4.037)	(2.193)
ITM_days_to_expiry		-0.00130***	-0.00133***	-0.00131***
		(-18.299)	(-19.748)	(-19.457)
OTM_days_to_expiry		-0.00023***	-0.00010	-0.00003
		(-2.946)	(-1.338)	(-0.458)
ITM_quote_count		-0.14732***	-0.23259***	-0.21865***
		(-29.050)	(-47.662)	(-43.190)
OTM_quote_count		0.03025***	0.02149***	0.02359***
		(3.892)	(2.914)	(3.030)
ITM_stock_stdev		-20.86744***	-12.73813***	-13.14468***
		(-70.781)	(-41.108)	(-42.185)
OTM_stock_stdev		2.27264***	1.39793***	1.26906***
		(7.189)	(4.229)	(3.780)
ITM_daily_avg_stkprc			0.00124***	0.00119***
			(61.277)	(57.658)
OTM_daily_avg_stkprc			-0.00017***	-0.00020***

			(-8.849)	(-10.113)
ITM_VIX_daily				-0.00594***
				(-11.921)
OTM_VIX_daily				-0.00354***
				(-6.861)
Include Intercept	Yes	Yes	Yes	Yes
Interval Dummies	Yes	Yes	Yes	Yes
Observations	92,821	92,821	92,821	92,821
Adjusted R-squared	0.420	0.846	0.861	0.861

t-statistics in parentheses, ***, ** and * indicate significance at 1%, 5% and 10% significance level respectively.

Quote_count captures the frequency of quote revisions, stock_stdev captures the standard deviation of daily returns of underlying stock, daily_avg_stkprc captures the daily average stock price of underlying stock. The Interaction terms capture either the interaction of in-the-money dummy and corresponding independent variable or the interaction of out-of-the-money dummy and corresponding independent variable.

Table 7-2: Main Regression Results for Model 1, Model 2, Model 3 and Model 4, Using Put Option Data, with Option Dollar Spread as Dependent Variable

Column #	(1)	(2)	(3)	(4)
Dependent Variable	Option dollar spread	Option dollar spread	Option dollar spread	Option dollar spread
Calls or Puts	Puts	Puts	Puts	Puts
Model	Model 1	Model 2	Model 3	Model 4
Independent Variables				
stock_spread	2.51645***	2.35508***	2.13338***	2.11316***
	(199.676)	(195.773)	(126.464)	(122.075)
option_depth	-0.00022***	-0.00006***	-0.00002***	-0.00002**
	(-34.797)	(-7.439)	(-2.899)	(-2.392)
days_to_expiry	-0.00010	0.00051***	0.00044***	0.00042***
	(-1.408)	(7.669)	(6.994)	(6.773)
quote_count	-0.01932***	-0.06944***	-0.08766***	-0.09404***
	(-4.623)	(-19.055)	(-25.744)	(-25.622)
stock_stdev	-11.14664***	-4.95431***	-3.33454***	-3.24544***
	(-38.886)	(-17.941)	(-11.758)	(-11.418)
daily_avg_stkprc			0.00028***	0.00029***
			(15.156)	(15.798)
VIX_daily				0.00136***
				(2.885)

D_ITM		0.94637***	0.53911***	0.40193***
		(87.704)	(46.550)	(21.707)
D_OTM		-0.23069***	-0.20498***	-0.26326***
		(-20.785)	(-17.232)	(-14.232)
Interaction Terms				
ITM_stock_spread		3.47756***	1.57983***	1.51510***
		(192.905)	(58.020)	(54.395)
OTM_stock_spread		-1.55111***	-1.40923***	-1.42365***
		(-94.697)	(-59.846)	(-59.367)
ITM_option_depth		-0.00026***	-0.00017***	-0.00017***
		(-26.858)	(-17.888)	(-18.195)
OTM_option_depth		0.00007***	0.00004***	0.00004***
		(7.098)	(4.068)	(4.207)
ITM_days_to_expiry		-0.00225***	-0.00230***	-0.00226***
		(-23.563)	(-25.847)	(-25.417)
OTM_days_to_expiry		0.00055***	0.00072***	0.00081***
		(5.657)	(7.956)	(8.895)
ITM_quote_count		-0.16525***	-0.26104***	-0.28931***
		(-29.049)	(-48.645)	(-49.087)
OTM_quote_count		0.04333***	0.02390**	0.00598
		(4.197)	(2.480)	(0.599)
ITM_stock_stdev		-24.90149***	-11.40355***	-10.66664***
		(-64.223)	(-28.440)	(-26.381)
OTM_stock_stdev		6.29609***	5.41539***	5.79006***
		(15.933)	(13.381)	(14.204)
ITM_daily_avg_stkprc			0.00216***	0.00223***
			(79.483)	(79.966)
OTM_daily_avg_stkprc			-0.00020***	-0.00018***
			(-7.792)	(-6.983)
ITM_VIX_daily				0.00596***
				(8.834)
OTM_VIX_daily				0.00216***
				(3.348)
Include Intercept	Yes	Yes	Yes	Yes
Interval Dummies	Yes	Yes	Yes	Yes
Observations	93,904	93,904	93,904	93,904
Adjusted R-squared	0.362	0.808	0.833	0.834

t-statistics in parentheses, ***, ** and * indicate significance at 1%, 5% and 10% significance level respectively.

Quote_count captures the frequency of quote revisions, stock_stdev captures the standard deviation of daily returns of underlying stock, daily_avg_stkprc captures the daily average stock price of underlying stock, VIX_daily captures the daily VIX index price. The Interaction terms capture either the interaction of in-the-money dummy and corresponding independent variable or the interaction of out-of-the-money dummy and corresponding independent variable.

Dollar spreads of the underlying stocks are shown to be significantly and positively correlated with option dollar spreads in all columns, consistent with previous studies. It could be attributed to information flow and hedging between stock market and option market.

In the absence of control for market volatility, option depth consistently has a negative relationship between the depth and the option dollar spread for at-the-money calls and puts, which is in line with the findings of previous studies on both stocks and options that depth and spread are two negatively correlated dimensions of liquidity. After we control for market volatility, the impact is non-significant for at-the-money call options, but still significantly negative for at-the-money put options. One possible reason is that the explanatory power of the quoted option depth gets transferred to market volatility variable, so option depth does not appear to be as significant. In another word, option depth may contain a component that is related to market volatility, as market makers lower depth provision in volatile market. This explanation is actually backed up by regression results with option depth as dependent variable, which will be discussed later in this chapter. The interaction terms related to option depth also provide some interesting insights that the effect of option depth on dollar spread is more negative for in-the-money options and more positive for out-of-the-money options, compared to the same effect for at-the-money options. On one hand, spread and depth could be positively correlated in the sense that market makers sometimes take the strategy to quote higher option depth, but set wider spread to offset the risks caused by depth (Verousis et al., 2016). On the other hand, they could be negatively correlated, as market makers incline to adopt an alternative strategy to set wide spread and low depth when faced with high information risk, or to provide low spread and high depth in safe environment. This reveals that market makers may prefer to simultaneously utilize option spread and depth to revise liquidity provided for in-the-money options, but mainly use one of them to change liquidity level, and the other as an offset for out-of-the-money options.

Time to expiry demonstrates an overall positive relationship with dollar spread, confirming the results of Pinter (2003) and Kodippili (2004). The justification may be that longer-term options have greater risks embedded and are therefore riskier. The insignificant result in column 1 for puts is possibly due to lack of control for moneyness and its interactions.

As suggested by Chan et al. (2002), quote count is an informative measure of market activities. Our analysis shows that it is significant and negatively correlated with option dollar spread across the board, confirming the findings of Mayhew (2002) and Pinter (2003) that active options tend to be associated with low information asymmetry and low spreads.

The volatility of the underlying stock, as measured by the standard deviation of the daily stock returns, has significant negative coefficients, except in columns 3 and 4 for calls. This result is different from Mayhew (2002) and De Fontnouvelle et al. (2003), who argued that the effect of volatility is minor. We suspect that the change of signs between calls (positive) and puts (negative) exists because of two forces: on one side, stocks with higher price volatility may attract higher demand from traders leading to a narrower option spread; on the other side, high volatility of underlying stock implies high risks of options, which incentivize market makers to adjust up the spread. When the first force dominates, volatility of underlying stocks should have an overall negative effect on option spread; when the second force dominates, the effect should be positive. In this case, the second force dominates for selected call options and the first force dominates for selected put options. The interaction terms actually provide strong justification for this explanation, as the corresponding out-of-the-money interaction term has positive signs (because they are riskier options and second force dominates) and the corresponding in-the-money interaction term has negative signs (because they are less risky and the second force appears to be less of a concern).

As for the daily average stock price, option dollar spread consistently increases with average daily stock price. This result is contrary to the argument of Mayhew et al. (1999), which suggests options are more liquid for stocks with higher prices. We believe Mayhew et al. (1999) arrived at different results primarily because spread is the measure of liquidity in our study, but they use volume as proxy for liquidity, which can act significantly differently than option spread does. Additionally, they did not control for as many variables. Given the differences, we still believe, based on our results, that options should be less liquid and have higher spread, if the underlying stock prices are higher. The positive price effect can be attributed to hedging costs, a component of option spread proposed by Hait (1999). More specifically, in order to hedge an option contract, market participants need to place an offsetting trade in the stock market, so an option contract with higher underlying stock price will be more expensive to hedge and require greater hedging capital. The related interaction terms suggest that the positive price effect is stronger for in-the-money options but weaker for out-of-the-money options. One possible explanation is that the price of in-the-money options changes in greater magnitude than out-of-the-money options, given the same change in the underlying stock price, so the in-the-money options have higher hedge ratio and require more capital to balance the hedge. Therefore, the effect of underlying stock price, as a proxy of hedging cost, should expect greater effect for in-the-money options, but less for out-of-the-money options.

Our results show that the VIX positively affects option dollar spreads. The impact of the VIX, which represents the implied market volatility, suggests that risk aversion leads market makers to widen the spread when they observe greater unpredictability in the overall market. Judging from interaction terms, the impact of market volatility on dollar spreads seems to be weaker for in-the-money and out-of-the-money call options than for at-the-money call options, while the impact seems to be stronger for in-the-money and out-of-the-money put options than for at-the-money put options.

From the dummy variables ITM and OTM, we discovered that in-the-money options have higher dollar spreads than at-the-money options, and that at-the-money options have higher dollar spreads than out-of-the-money options, validating the conclusion of Kodippili (2004). The same results have been discussed in Figure 5-7 for calls and Figure 5-8 for puts. It could potentially be attributed to the fact that ITM options have higher premiums, therefore higher dollar spreads.

Next, we explore the topic of percentage option spread, which factors the premium level into option dollar spread. The regression results for Models 5, 6, 7 and 8 are displayed in Table 7-3 for call options and in Table 7-4 for put options. The adjusted R-squared values increase by large magnitude from lower than 0.25 to over 0.80 for calls, and from lower than 0.25 to almost 0.65 for puts, suggesting that the inclusion of moneyness dummies and interaction terms improves the explanatory power of the model for percentage option spread as well. It implies that percentage spread for options differs greatly for different moneyness. Adding daily average stock price and daily VIX improves the explanatory power for percentage spread of call options, but not so much for percentage spread of put options.

Table 7-3: Main Regression Results for Model 5, Model 6, Model 7 and Model 8, Using Call Option Data, with Percentage Option Spread as Dependent Variable

Column #	(1)	(2)	(3)	(4)
Dependent Variable	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread
Calls or Puts	Calls	Calls	Calls	Calls
Model	Model 5	Model 6	Model 7	Model 8
Independent Variables				
%_stock_spread	64.53316***	42.40096***	38.28771***	38.03695***
	(33.922)	(25.519)	(20.701)	(19.708)
option_depth	-0.00008***	0.00001**	0.00001***	0.00001***
	(-42.613)	(2.540)	(3.809)	(3.691)
days_to_expiry	-0.00189***	-0.00119***	-0.00120***	-0.00120***
	(-62.727)	(-46.130)	(-46.427)	(-46.418)
quote_count	-0.24928***	-0.02804***	-0.02875***	-0.02893***
	(-134.318)	(-20.176)	(-20.628)	(-19.396)
stock_stdev	-6.50265***	-3.22152***	-2.97435***	-2.97255***
	(-51.137)	(-29.788)	(-23.647)	(-23.217)
daily_avg_stkprc			0.00002***	0.00002***
			(3.581)	(3.494)
VIX_daily				-0.00009
				(-0.437)
D_ITM		-0.13030***	-0.12691***	-0.13742***
		(-32.455)	(-26.452)	(-18.180)
D_OTM		0.90355***	0.86186***	0.82242***
		(206.295)	(163.104)	(97.596)
Interaction Terms				
ITM_%_stock_spread		-27.63933***	-26.83952***	-28.19753***
		(-11.924)	(-10.218)	(-10.369)
OTM_%_stock_spread		140.60175***	123.68118***	120.56214***
		(63.126)	(49.349)	(46.732)
ITM_option_depth		-0.00001**	-0.00001***	-0.00001***
		(-2.362)	(-3.396)	(-3.255)
OTM_option_depth		-0.00005***	-0.00003***	-0.00002***
		(-10.253)	(-5.235)	(-4.658)
ITM_days_to_expiry		0.00110***	0.00111***	0.00111***
		(30.391)	(30.549)	(30.538)
OTM_days_to_expiry		-0.00498***	-0.00495***	-0.00491***
		(-126.155)	(-125.580)	(-123.448)
ITM_quote_count		0.00496*	0.00327	0.00165
		(1.921)	(1.258)	(0.612)

OTM_quote_count		-0.24944***	-0.24843***	-0.25764***
		(-63.006)	(-62.857)	(-61.976)
ITM_stock_stdev		2.84777***	2.76888***	2.83302***
		(18.560)	(15.611)	(15.737)
OTM_stock_stdev		-17.49740***	-16.08599***	-15.80023***
		(-108.600)	(-86.136)	(-82.522)
ITM_daily_avg_stkprc			-0.00001	-0.00001
			(-1.053)	(-0.639)
OTM_daily_avg_stkprc			0.00011***	0.00012***
			(13.661)	(14.643)
ITM_VIX_daily				0.00047*
				(1.745)
OTM_VIX_daily				0.00156***
				(5.562)
Include Intercept	Yes	Yes	Yes	Yes
Interval Dummies	Yes	Yes	Yes	Yes
Observations	92,821	92,821	92,821	92,821
Adjusted R-squared	0.239	0.808	0.809	0.809

t-statistics in parentheses, ***, ** and * indicate significance at 1%, 5% and 10% significance level respectively.

Quote_count captures the frequency of quote revisions, stock_stdev captures the standard deviation of daily returns of underlying stock, daily_avg_stkprc captures the daily average stock price of underlying stock, VIX_daily captures the daily VIX index price. The Interaction terms capture either the interaction of in-the-money dummy and corresponding independent variable or the interaction of out-of-the-money dummy and corresponding independent variable.

Table 7-4: Main Regression Results for Model 5, Model 6, Model 7 and Model 8, Using Put Option Data, with Percentage Option Spread as Dependent Variable

Column #	(1)	(2)	(3)	(4)
Dependent Variable	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread
Calls or Puts	Puts	Puts	Puts	Puts
Model	Model 5	Model 6	Model 7	Model 8
Independent Variables				
%_stock_spread	50.81208***	36.58721***	28.57297***	29.72334***
	(40.486)	(25.046)	(17.593)	(17.647)
option_depth	0.00000	0.00002***	0.00003***	0.00003***
	(1.183)	(8.041)	(10.856)	(10.965)
days_to_expiry	-0.00217***	-0.00059***	-0.00061***	-0.00060***

	(-113.125)	(-25.541)	(-26.478)	(-26.656)
quote_count	-0.11561***	-0.01515***	-0.01607***	-0.01529***
	(-101.515)	(-12.158)	(-12.987)	(-11.535)
stock_stdev	-4.43484***	-1.35002***	-0.86115***	-0.87690***
	(-54.927)	(-14.030)	(-7.777)	(-7.904)
daily_avg_stkprc			0.00004***	0.00004***
			(8.270)	(8.015)
VIX_daily				0.00030*
				(1.743)
D_ITM		-0.03024***	-0.01590***	-0.01433**
		(-8.449)	(-3.790)	(-2.132)
D_OTM		0.55943***	0.49795***	0.68003***
		(152.515)	(114.886)	(100.462)
Interaction Terms				
ITM_%_stock_spread		-27.44812***	-20.39534***	-20.54756***
		(-12.611)	(-8.406)	(-8.257)
OTM_%_stock_spread		74.11781***	41.58993***	60.80137***
		(37.421)	(18.669)	(26.639)
ITM_option_depth		-0.00002***	-0.00003***	-0.00003***
		(-6.770)	(-9.483)	(-9.681)
OTM_option_depth		-0.00002***	0.00000	-0.00001**
		(-6.470)	(1.179)	(-2.133)
ITM_days_to_expiry		0.00040***	0.00042***	0.00042***
		(12.251)	(12.921)	(13.018)
OTM_days_to_expiry		-0.00516***	-0.00515***	-0.00527***
		(-153.271)	(-154.521)	(-159.138)
ITM_quote_count		-0.00140	-0.00183	-0.00243
		(-0.713)	(-0.936)	(-1.148)
OTM_quote_count		-0.12482***	-0.12400***	-0.08472***
		(-34.982)	(-35.136)	(-23.420)
ITM_stock_stdev		0.78443***	0.29631*	0.28323*
		(5.657)	(1.884)	(1.788)
OTM_stock_stdev		-10.16706***	-7.94844***	-9.12284***
		(-73.307)	(-50.352)	(-57.396)
ITM_daily_avg_stkprc			-0.00004***	-0.00005***
			(-6.418)	(-6.427)
OTM_daily_avg_stkprc			0.00019***	0.00014***
			(27.414)	(20.779)
ITM_VIX_daily				-0.00003
				(-0.106)
OTM_VIX_daily				-0.00770***
				(-32.239)
Include Intercept	Yes	Yes	Yes	Yes
Interval Dummies	Yes	Yes	Yes	Yes
Observations	93,904	93,904	93,904	93,904
Adjusted R-squared	0.236	0.628	0.637	0.645

t-statistics in parentheses, ***, ** and * indicate significance at 1%, 5% and 10% significance level respectively.

Quote_count captures the frequency of quote revisions, stock_stdev captures the standard deviation of daily returns of underlying stock, daily_avg_stkprc captures the daily average stock price of underlying stock. The Interaction terms capture either the interaction of in-the-money dummy and corresponding independent variable or the interaction of out-of-the-money dummy and corresponding independent variable.

The percentage stock spread has positive signs for all columns as expected, because information simultaneously feed into both stock and option markets. Both percentage option spread and percentage stock spread will increase, when there is high degree of uncertainty or information asymmetry in the market.

As for the impact of the option depth, our results almost unanimously show that option depth is positively associated with percentage option spread. Verousis, Gwilym and Chen (2016) discovered the same positive relationship and they argued that higher depth represented an inventory risks to market makers, because more potential trades could possibly deviate their inventory further away from their desired holding level. Therefore, they set up wider spread to compensate the additional risks brought by higher depth.

Time to expiry is negatively correlated with percentage option spread, consistent with the declining trend in Figure 5-14 and Figure 5-15. One possible cause is that longer-term options have only slightly higher dollar spreads compared to near-term options, but due to the higher risks, longer-term options have much higher option premiums than near-term options.

Same as in Mayhew (2002) and Pinter (2003), percentage option spread is negatively related to the intensity of market activities, proxied by quote count variable. It can be explained that higher volume of trades conveys information to the market and reduces information risks.

The volatility of the underlying stock is shown to have a negative impact on percentage option spread for at the money options. For out-of-the-money options, this impact is stronger, but for in-the-money options, it is significantly weaker. The same result applies for both puts and calls. At the same time, we observe earlier that increased volatility of the underlying stock increases dollar spreads for at-the-money options, but this impact is weaker for in-the-money options and stronger for out-of-the-money options. The same result applies to both puts and calls. We propose that the driving force for the negative relationship between percentage spread and the volatility of the underlying is that the higher volatility increases the premiums of put and call options and the increase in premiums is much higher than the increase in the spread for both at-the-money and out-of-the-money options. In contrast, the premium of deep-in-the-money options may increase only slightly with increased volatility because the intrinsic value is the main component of the premium. At the same time, our analysis suggests that the dollar spreads of deep-in-the-money options tend to decrease with an increase in the market volatility. Therefore, the overall impact of volatility on the percentage spread is of in-the-money options is negative. The impact is even more negative for at-the-money and out-of-the-money options.

All columns support a positive underlying stock price impact on the option percentage spread, once again lending support to Hypothesis 2 that high stock price implies a high hedging cost for options. Similar explanation applies that hedging costs for options of expensive stocks are higher proportionate to the premium, holding other factors the same, so the percentage spreads should also be higher. The interaction terms, however, have opposite signs, showing that in-the-money options have lower price effect and lower percentage hedging cost, while out-of-the-money options have higher price effect and higher percentage hedging cost. As argued earlier, in-the-money options are harder to hedge than out-of-the-money options, but due to the higher premium of in-the-money options than out-of-the-money options, the hedging cost proportionate to the premium appears to be lower. Therefore, the in-the-money interaction term has negative sign, while the out-of-the-money interaction term has positive sign.

In regard to implied market volatility, the effect of VIX index on percentage option spreads does not appear to be quite significant after controlling for interactions. Compared with significantly positive coefficients for the dollar spread regression in Table 7-1 and Table 7-2, it leads us to believe that high market volatility results in high option dollar spread, but does not necessary lead to high percentage spread, since it also boosts the premium of options. Looking at the interaction terms, the in-the-money interactions are not very significant for either calls or puts, but the out-of-the-money interactions are positive for calls and negative for puts. The interaction terms demonstrate that impact of market volatility on percentage spread does not differentiate between in-the-money options and at-the-money options, but market volatility does have a much more positive impact for out-of-the-money call options, compared to at-the-money call options, and a much more negative impact for out-of-the-money put options, compared to at-the-money put options. As concluded by previous papers such as Giot (2005), Wee and Yang (2012), Lubnau and Todorova (2015), high implied market volatility (e.g. high VIX) is usually associated with falling market and negative returns in the future. We suspect high market volatility is indicative of an expectation for market downturn, which reduces the value of out-of-the-money call options, but increases the probability for out-of-the-money put options to end up in the money. Therefore, the change in market volatility does not have as much implications on in-the-money or at-the-money options, because volatility does not greatly affect their value. However, increased level in market volatility impairs the value of out-of-the-money call options even further, leading to wider spread, and it largely boosts the value and interest of out-of-the-money options, leading to narrower spread, exactly as we have observed.

With respect to moneyness dummies, contrary to the results for option dollar spreads (in-the-money options have higher option dollar spreads than out-of-the-money options), out-of-money options have higher percentage option spreads than in-the-money options. The same conclusions are drawn from Figure 5-9 for calls and Figure 5-10 for puts. This result is consistent with findings of Cho and Engle (1999) as well. It makes sense in a way that in-the-money options are usually more expensive (premiums are higher) than out-of-money options, so even if the percentage spread is higher for the out-of-money options (since they are riskier), their actual dollar spread is lower. Our results contrast with the statement by Kodipilli (2004) that in-the-money options have higher option spread because they are pricey and hard to hedge against, thus riskier. Our results suggest that the dollar spreads of in-the-money options may be higher but the percentage spreads are lower because their premiums are higher. In contrast, out-of-the-money options have higher percentage spread. As the chance is low for out-of-the-money options to end up in-the-money and their potential returns are more volatile, they may be risker and their premiums are lower so the percentage spread is higher.

The regression results of Models 9, 10, and 11, by which we analyze the determinants of the option depth are reported in Table 7-5 for calls and Table 7-6 for puts. Relative to the regression results in Tables 7-1 to 7-4, the fitness of these models is lower, as the adjusted R-squared values are lower. Therefore, it may be necessary to identify additional explanatory variables for the depth. Another observation to point out is that the inclusion of moneyness dummies and interaction terms boosts the explanatory power of our depth models significantly in comparison to the fitness of the basic model.

Table 7-5: Main Regression Results for Model 9, Model 10 and Model 11, Using Call Option Data, with Option Depth as Dependent Variable

Column #	(1)	(2)	(3)
Dependent Variable	Option depth	Option depth	Option depth
Calls or Puts	Calls	Calls	Calls
Model	Model 9	Model 10	Model 11
Independent Variables			
option_spread	-151.48806***	-292.44713***	-283.42190***
	(-66.738)	(-44.814)	(-42.929)
days_to_expiry	0.66479***	1.14546***	1.14250***
	(12.912)	(13.974)	(13.944)
quote_count	-73.68274***	-59.22863***	-44.21404***
	(-23.477)	(-13.117)	(-9.169)
stock_stdev	-11202.44687***	-7,104.23364***	-7,086.76653***
	(-53.333)	(-21.276)	(-21.232)
VIX_daily			-5.29565***
			(-8.707)
D_ITM		496.57099***	413.85332***
		(39.485)	(20.332)
D_OTM		-88.51954***	-146.02763***
		(-6.601)	(-6.524)
Interaction Terms			
ITM_option_spread		53.97842***	45.17269***
		(7.732)	(6.407)
OTM_option_spread		-195.70313***	-202.58443***
		(-10.994)	(-11.368)
ITM_days_to_expiry		-0.09353	-0.08959
		(-0.809)	(-0.776)
OTM_days_to_expiry		-0.09199	-0.14077
		(-0.731)	(-1.110)
ITM_quote_count		-257.59200***	-268.59302***
		(-31.310)	(-31.588)
OTM_quote_count		-138.19481***	-140.19814***
		(-11.002)	(-10.590)

ITM_stock_stdev		-12045.88283***	-12081.33655***
		(-25.369)	(-25.450)
OTM_stock_stdev		1,035.06075**	858.01834*
		(2.062)	(1.701)
ITM_VIX_daily			4.57144***
			(5.478)
OTM_VIX_daily			3.59746***
			(4.161)
Include Intercept	Yes	Yes	Yes
Interval Dummies	Yes	Yes	Yes
Observations	92,821	92,821	92,821
Adjusted R-squared	0.072	0.181	0.182

t-statistics in parentheses, ***, ** and * indicate significance at 1%, 5% and 10% significance level respectively.

Daily_avg_stkprc is not included in regression on option depth due to lack of theoretical arguments and stock price's strong correlation with option dollar spread. Quote_count captures the frequency of quote revisions, stock_stdev captures the standard deviation of daily returns of underlying stock, VIX_daily captures the daily VIX index price. The Interaction terms capture either the interaction of in-the-money dummy and corresponding independent variable or the interaction of out-of-the-money dummy and corresponding independent variable.

Table 7-6: Main Regression Results for Model 9, Model 10 and Model 11, Using Put Option Data, with Option Depth as Dependent Variable

Column #	(1)	(2)	(3)
Dependent Variable	Option depth	Option depth	Option depth
Calls or Puts	Puts	Puts	Puts
Model	Model 9	Model 10	Model 11
Independent Variables			
option_spread	-116.09788***	-241.02089***	-236.30848***
	(-85.950)	(-64.044)	(-62.411)
days_to_expiry	1.02165***	1.33308***	1.34679***
	(28.380)	(22.316)	(22.576)
quote_count	-30.03856***	-61.71778***	-48.45403***
	(-14.069)	(-18.461)	(-13.522)
stock_stdev	-7,673.56553***	-8,328.15639***	-8,253.65898***
	(-52.524)	(-33.851)	(-33.588)
VIX_daily			-4.63311***
			(-10.428)
D_ITM		22.05999**	-167.11437***

		(2.315)	(-10.747)
D_OTM		-90.87999***	-95.01342***
		(-9.741)	(-6.201)
Interaction Terms			
ITM_option_spread		109.26164***	105.47707***
		(26.630)	(25.572)
OTM_option_spread		-178.73122***	-169.88051***
		(-15.617)	(-14.731)
ITM_days_to_expiry		0.24823***	0.25062***
		(2.902)	(2.934)
OTM_days_to_expiry		-0.51484***	-0.60960***
		(-5.820)	(-6.863)
ITM_quote_count		-93.46398***	-125.70751***
		(-18.188)	(-22.675)
OTM_quote_count		-79.18454***	-70.77775***
		(-8.440)	(-7.278)
ITM_stock_stdev		-20.07836	107.12833
		(-0.057)	(0.305)
OTM_stock_stdev		1,646.26082***	1,368.88975***
		(4.676)	(3.884)
ITM_VIX_daily			9.80680***
			(15.430)
OTM_VIX_daily			0.96691
			(1.571)
Include Intercept	Yes	Yes	Yes
Interval Dummies	Yes	Yes	Yes
Observations	93,904	93,904	93,904
Adjusted R-squared	0.101	0.157	0.160

t-statistics in parentheses, ***, ** and * indicate significance at 1%, 5% and 10% significance level respectively.

Daily_avg_stkprc is not included in regression on option depth due to lack of theoretical arguments and stock price's strong correlation with option dollar spread. Quote_count captures the frequency of quote revisions, stock_stdev captures the standard deviation of daily returns of underlying stock, VIX_daily captures the daily VIX index price. The Interaction terms capture either the interaction of in-the-money dummy and corresponding independent variable or the interaction of out-of-the-money dummy and corresponding independent variable.

As mentioned earlier, option depth varies across the different moneyness ranges. Therefore, we should focus our attention on interpreting the results of Models 8 and 9 where we control for moneyness and introduce terms that interact moneyness with other variables. Option depth is shown to be negatively and significantly associated with option spread. It resonates with previous argument that spread and depth are two negatively correlated measurements of liquidity. Market makers may sometimes set high depth with high spread or low depth with low spread, but this result suggests they still set option spread and depth in opposite directions most of the time.

Days to expiry variable is shown to increase option depth across all columns. It seems that although longer-term options are less liquid and have larger dollar spreads, market makers tend to quote slightly larger quantity of them, compared to near-term options. This effect persists, regardless of whether the option is in-the-money, at-the-money or out-of-the-money and whether the option is a call or a put.

The coefficients of the quote count variable are mostly negative suggesting that market makers typically provide less depth for options that fluctuate more frequently. This is likely to be the time, when they have limited and insufficient time to process market information, so that a low-depth strategy can avoid potential losses from adverse selection in the market. The only insignificant exception in column 3 indicates that the effect may not be stable or existent for at-the-money call options. The negative coefficients for the interaction terms show that market makers will provide even less depth for highly-volatile ITM or OTM options, compared to highly-volatile ATM options. We suspect the reason might be that these options tend to be illiquid and receive less attention from traders.

The depth seems to be negatively and significantly affected by the volatility of the underlying stocks which can be attributed to risk avoidance by market makers.

The coefficients of the VIX index are significantly negative. The results imply that market makers tend to decrease the depth level in anticipation of a volatile market. When depth level is relatively low, market makers can reduce their risk exposure to adverse market movement as fewer orders will get filled at a disadvantageous price for them. Given the low depth, market makers can quickly adjust their quotes to minimize their immediate losses.

The moneyness dummies demonstrate that in-the-money options have significantly higher depth and out-of-the-money options have significantly lower depth relative to at-the-money options. We can think of two reasons. One reason might be that there is greater demand for in-the-money options but less demand for out-of-the-money options and market makers are simply responding to demand conditions. Second, one might argue that in-the-money options are less risky while out-of-the-money options are more risky than at-the-money options. Therefore, market makers limit the depth for out-of-the-money options to reduce risk exposure and are willing to provide higher depth for in-the-money options.

Finally, we graph the coefficients of interval dummies[12] for Model 4, Model 8 and Model 11 from all six tables respectively in Figure 7-1, Figure 7-2 and Figure 7-3, because those three models are more complete and control for the most number of factors. Interval dummies for both option dollar spreads and percentage option spread resemble U-shaped patterns. In the figure for option dollar spread, the change is more significant at the end of the day. In the figure for percentage option spread, the change is more significant at the beginning of the day. The interval dummies for option depth rise significantly at the beginning of the day, then fluctuate in the rest of the day. The changes in coefficients of interval dummies in Model 4, Model 8 and Model 11 throughout the day are significant. This observation suggests that, besides all control factors, the changes in the market environment and trading patterns from one interval to the next also significantly contribute the intraday spread and the depth of options.

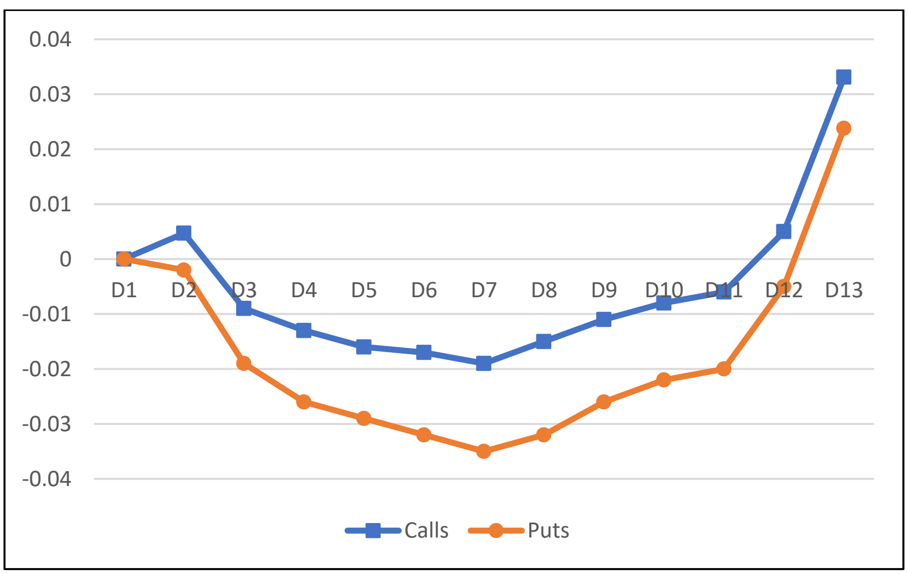

Figure 7-1: Coefficients of interval dummies in model 3 (option dollar spread as dependent variable)

[12] Interval 1 (8:30 to 9:00 CST) is the base interval and it is assigned a value of 0 for graphing purposes.

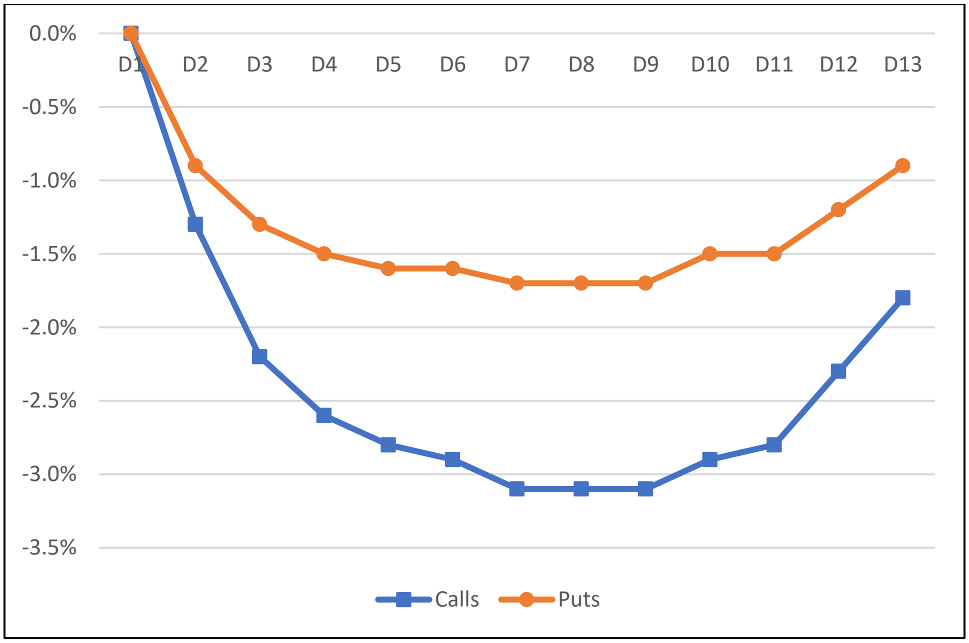

Figure 7-2: Coefficients of interval dummies in model 6 (percentage option spread as dependent variable)

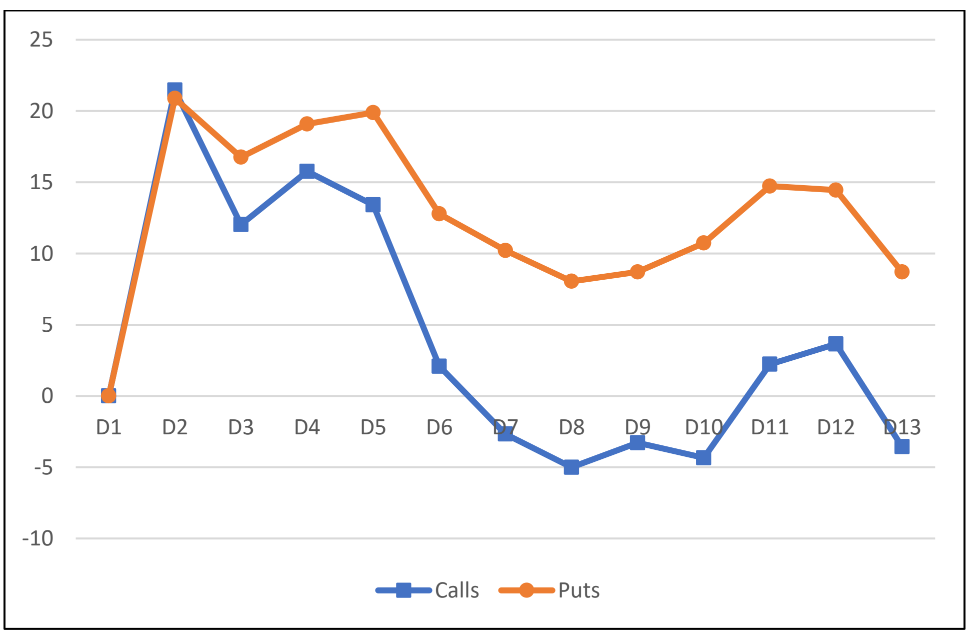

Figure 7-3: Coefficients of interval dummies in model 9 (option depth as dependent variable)

To further investigate the intraday variation of option spread and depth, we run regressions for each interval separately and report results for different intervals side-by-side. See Table 7-7 to Table 7-14. By doing so, we can study how effect of each variable on spread and depth changes throughout the day, instead of viewing them from an aggregate level. This method also allows for greater model flexibility and provide more information. Due to the amount of information, we focus on Model 8 and Model 11, both of which are the most complete models for their corresponding dependent variables, percentage option spread and option depth. We will not present similar results for option dollar spread, because we regard percentage spread as a more informative measure for spread and liquidity. It practically represents the spread investor faces for each unit ($1) of investment.

Table 7-7 and Table 7-8 present cross-interval regression results from interval 1 to interval 13 on percentage option spread for call options. Table 7-9 and Table 7-10 present cross-interval regression results from interval 1 to interval 13 on percentage option spread for put options.

Percentage stock spread has significant and positive impact on percentage option spread in all intervals for both calls and puts, as a stronger confirmation for argument in information asymmetry theory that liquidity in option market and liquidity in stock market are closely related, as well as Derivative Hedge Theory. Option depth is significant in all intervals for puts, but insignificant in all intervals for calls, which may be due to the possibility that market makers or traders perceive and handle calls and puts differently. Days to expiry, quote count and stock volatility are all shown to be consistently negatively correlated with percentage spread for both call options and put options, giving stronger results interval by interval. Like for option depth, average daily stock price, as hedging cost, is only significant across intervals for put options, potentially due to mechanisms used to hedge against call options and put options are different. The significance level varies throughout the day and is typically insignificant in the first 3 intervals, which we speculate to be an indication of intraday hedging pattern for option market makers, where they manage risks majority with low depth early in the morning, then increasingly with wide spread later during the day. VIX index, capturing market volatility, is insignificant for all intervals, consistent with results on an aggregate level. OTM dummy variable has consistent negative and significant coefficients for calls and puts, while ITM dummy variable has the same only for calls. It somehow aligns with Figure 5-9 and Figure 5-10, where OTM options have much higher percentage spread than ATM options, but the difference between ATM options and ITM options are much less evident. Adjusted R-squared stays relatively stable across intervals, stipulate that our model for percentage option spread performs reasonably well in all intervals.

Table 7-11 and Table 7-12 present cross-interval regression results from interval 1 to interval 13 on option depth for call options. Table 7-13 and Table 7-14 present cross-interval regression results from interval 1 to interval 13 on option depth for put options.

Option spread is shown to be significantly negatively correlated with option depth, a piece of evidence for the tendency of market makers to use option spread and depth jointly and oppositely at interval level. We also receive consistent results that days to expiry positively contributes to option depth, and stock volatility negatively contributes to option depth. Quote count is either insignificant or negatively significant in explaining option depth. As explained earlier, market makers may be unwilling to provide large depth when market moves quickly, given that they do not have sufficient time to process the fast-changing information. However, as suggested by the changes in significance level, their reaction to intensity of market activities differs throughout the day. VIX daily is significantly negative in all intervals for both calls and puts, providing confidence to our belief that market makers lower depth provision when faced with greater market uncertainty. Coefficients of dummy variables suggest, regardless of the time of the day, in-the-money call options tend to have higher depth than at-the-money call options, which in turn have higher depth than out-of-the-money call options, however, at-the-money put options tend to have the highest quoted depth compared to in-the-money and out-of-the-money put options. No matter for calls or puts, explanatory power of the model for depth stays stable across all intervals, a result showing the model works not only for an aggregate day, but also for each individual interval.

Table 7-7: Cross-interval Results of Model 8 for Interval 1-6

Using Call Option Data, with Percentage Option Spread as Dependent Variable

Interval #	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread
Calls or Puts	Calls	Calls	Calls	Calls	Calls	Calls
Model	Model 8	Model 8	Model 8	Model 8	Model 8	Model 8
Independent Variables						
%_stock_spread	34.25058***	38.72260***	39.45457***	39.64070***	42.53875***	50.18029***
	(6.700)	(5.105)	(5.047)	(4.834)	(5.184)	(5.803)
option_depth	0.00000	0.00001	0.00001	0.00002	0.00001	0.00002
	(0.033)	(0.463)	(0.863)	(1.365)	(0.995)	(1.168)
days_to_expiry	-0.00147***	-0.00123***	-0.00119***	-0.00115***	-0.00115***	-0.00117***
	(-13.213)	(-12.369)	(-12.591)	(-12.479)	(-12.288)	(-12.915)
quote_count	-0.03459***	-0.02579***	-0.02486***	-0.02423***	-0.02439***	-0.02103***
	(-6.047)	(-4.758)	(-4.550)	(-4.328)	(-3.850)	(-3.326)
stock_stdev	-4.39307***	-3.54371***	-3.30025***	-2.95369***	-3.00026***	-3.07631***
	(-7.786)	(-6.686)	(-6.582)	(-6.010)	(-6.170)	(-6.506)
daily_avg_stkprc	0.00002	0.00000	0.00000	0.00001	0.00000	0.00000
	(0.528)	(0.160)	(0.143)	(0.396)	(0.213)	(0.105)
VIX_daily	-0.00066	-0.00052	-0.00050	-0.00035	-0.00019	-0.00073
	(-0.741)	(-0.623)	(-0.636)	(-0.454)	(-0.238)	(-0.986)
D_ITM	-0.19653***	-0.15742***	-0.14566***	-0.12861***	-0.12489***	-0.12891***
	(-5.888)	(-5.140)	(-5.007)	(-4.507)	(-4.334)	(-4.657)
D_OTM	0.86929***	0.79854***	0.74693***	0.73756***	0.86233***	0.83248***
	(23.631)	(23.414)	(23.128)	(23.265)	(27.085)	(26.902)
Interaction Terms						
ITM_%_stock_spread	-23.33272***	-23.13246**	-22.96788**	-22.75103*	-23.75210**	-30.29383**
	(-3.100)	(-2.161)	(-2.064)	(-1.933)	(-2.013)	(-2.423)
OTM_%_stock_spread	83.66792***	103.47084***	104.98958***	105.83153***	125.75431***	138.92389***
	(12.369)	(10.283)	(9.947)	(9.514)	(11.206)	(11.675)
ITM_option_depth	-0.00000	-0.00001	-0.00001	-0.00002	-0.00001	-0.00002
	(-0.132)	(-0.442)	(-0.790)	(-1.222)	(-0.882)	(-1.072)

OTM_option_depth	-0.00015***	-0.00007***	-0.00003	0.00001	-0.00000	-0.00001
	(-5.304)	(-3.721)	(-1.527)	(0.539)	(-0.240)	(-0.692)
ITM_days_to_expiry	0.00137***	0.00114***	0.00111***	0.00107***	0.00107***	0.00109***
	(8.825)	(8.270)	(8.404)	(8.244)	(8.141)	(8.515)
OTM_days_to_expiry	-0.00464***	-0.00466***	-0.00464***	-0.00468***	-0.00509***	-0.00494***
	(-27.056)	(-30.333)	(-31.958)	(-32.602)	(-35.751)	(-35.195)
ITM_quote_count	0.01636*	0.01230	0.01059	0.00891	0.00907	0.00275
	(1.713)	(1.368)	(1.094)	(0.841)	(0.785)	(0.220)
OTM_quote_count	-0.31217***	-0.27999***	-0.30621***	-0.31516***	-0.19289***	-0.25994***
	(-21.464)	(-20.768)	(-21.476)	(-19.951)	(-12.531)	(-14.844)
ITM_stock_stdev	3.90300***	3.07644***	2.85669***	2.57755***	2.52306***	2.55877***
	(4.912)	(4.098)	(3.979)	(3.644)	(3.635)	(3.764)
OTM_stock_stdev	-17.42264***	-15.98674***	-14.35131***	-14.12344***	-17.22655***	-16.13771***
	(-20.982)	(-20.332)	(-19.075)	(-18.956)	(-23.629)	(-22.430)
ITM_daily_avg_stkprc	-0.00002	-0.00000	-0.00000	-0.00001	-0.00001	-0.00001
	(-0.495)	(-0.069)	(-0.114)	(-0.245)	(-0.232)	(-0.205)
OTM_daily_avg_stkprc	0.00011***	0.00011***	0.00015***	0.00017***	0.00009***	0.00010***
	(2.994)	(3.401)	(4.905)	(5.396)	(2.887)	(3.189)
ITM_VIX_daily	0.00073	0.00062	0.00059	0.00031	0.00025	0.00068
	(0.612)	(0.560)	(0.557)	(0.295)	(0.235)	(0.672)
OTM_VIX_daily	0.00477***	0.00427***	0.00379***	0.00338***	0.00095	0.00086
	(3.918)	(3.718)	(3.500)	(3.175)	(0.869)	(0.833)
Include Intercept	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,946	7,089	7,157	7,171	7,151	7,159
Adjusted R-squared	0.831	0.819	0.814	0.809	0.806	0.806

Table 7-8: Cross-interval Results of Model 8 for Interval 7-13

Using Call Option Data, with Percentage Option Spread as Dependent Variable

Interval #	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Dependent Variable	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread
Calls or Puts	Calls	Calls	Calls	Calls	Calls	Calls	Calls
Model	Model 8	Model 8	Model 8	Model 8	Model 8	Model 8	Model 8
Independent Variables							
%_stock_spread	51.50983***	53.66566***	50.94604***	52.50188***	51.87702***	56.47857***	64.72652***
	(6.016)	(6.119)	(5.609)	(5.962)	(5.787)	(5.697)	(5.127)
option_depth	0.00001	0.00002	0.00002	0.00001	0.00001	0.00001	0.00001
	(1.073)	(1.192)	(1.350)	(0.832)	(1.052)	(0.547)	(0.566)
days_to_expiry	-0.00117***	-0.00116***	-0.00115***	-0.00117***	-0.00115***	-0.00115***	-0.00120***
	(-13.210)	(-13.177)	(-13.117)	(-13.131)	(-13.056)	(-12.659)	(-13.315)
quote_count	-0.02162***	-0.02385***	-0.02404***	-0.02271***	-0.02293***	-0.02145***	-0.02824***
	(-3.321)	(-3.563)	(-3.586)	(-3.645)	(-3.641)	(-3.478)	(-4.592)
stock_stdev	-3.10663***	-3.10691***	-2.92327***	-3.18613***	-2.98846***	-3.12733***	-3.12843***
	(-6.789)	(-6.859)	(-6.441)	(-7.091)	(-6.741)	(-6.852)	(-7.072)
daily_avg_stkprc	0.00000	0.00000	0.00002	0.00001	0.00001	0.00001	0.00002
	(0.126)	(0.245)	(0.751)	(0.314)	(0.644)	(0.334)	(1.132)
VIX_daily	-0.00083	-0.00076	-0.00051	-0.00057	-0.00055	-0.00055	-0.00008
	(-1.174)	(-1.087)	(-0.712)	(-0.816)	(-0.777)	(-0.726)	(-0.107)
D_ITM	-0.12970***	-0.12848***	-0.11736***	-0.12925***	-0.12214***	-0.12622***	-0.12455***
	(-4.839)	(-4.847)	(-4.398)	(-4.889)	(-4.630)	(-4.581)	(-4.643)
D_OTM	0.81507***	0.79861***	0.83606***	0.78890***	0.80558***	0.80696***	0.79805***
	(27.172)	(26.942)	(28.072)	(26.555)	(27.050)	(26.030)	(26.727)
Interaction Terms							
ITM_%_stock_spread	-30.99423**	-31.73193**	-27.14143**	-27.62689**	-27.44219**	-30.85116**	-28.79313
	(-2.512)	(-2.483)	(-2.046)	(-2.152)	(-2.134)	(-2.149)	(-1.560)
OTM_%_stock_spread	127.48671***	127.11471***	135.73711***	130.48567***	126.77295***	130.85939***	171.08366***
	(10.753)	(10.484)	(10.836)	(10.688)	(10.204)	(9.524)	(9.834)
ITM_option_depth	-0.00001	-0.00002	-0.00002	-0.00001	-0.00001	-0.00001	-0.00001

	(-1.002)	(-1.125)	(-1.278)	(-0.788)	(-0.952)	(-0.525)	(-0.515)
OTM_option_depth	-0.00000	-0.00001	-0.00001	-0.00001	-0.00003*	-0.00001	0.00001
	(-0.153)	(-0.918)	(-0.754)	(-0.437)	(-1.697)	(-0.344)	(0.445)
ITM_days_to_expiry	0.00109***	0.00108***	0.00107***	0.00109***	0.00107***	0.00106***	0.00112***
	(8.697)	(8.667)	(8.576)	(8.651)	(8.599)	(8.295)	(8.821)
OTM_days_to_expiry	-0.00489***	-0.00475***	-0.00483***	-0.00478***	-0.00486***	-0.00517***	-0.00512***
	(-35.509)	(-34.643)	(-35.458)	(-34.650)	(-35.565)	(-36.818)	(-37.010)
ITM_quote_count	0.00424	0.00509	0.00418	0.00596	0.00764	0.00595	0.01325
	(0.330)	(0.367)	(0.293)	(0.456)	(0.628)	(0.509)	(1.163)
OTM_quote_count	-0.25750***	-0.31135***	-0.25027***	-0.28906***	-0.29766***	-0.26176***	-0.22394***
	(-14.652)	(-15.920)	(-13.514)	(-15.997)	(-16.434)	(-15.766)	(-14.243)
ITM_stock_stdev	2.53051***	2.58988***	2.30941***	2.56342***	2.43712***	2.57553***	2.56487***
	(3.855)	(3.966)	(3.520)	(3.968)	(3.849)	(3.954)	(4.073)
OTM_stock_stdev	-15.87952***	-15.35865***	-16.23687***	-14.58036***	-14.71884***	-14.69247***	-14.57330***
	(-22.798)	(-22.117)	(-23.489)	(-21.225)	(-21.607)	(-21.069)	(-21.944)
ITM_daily_avg_stkprc	-0.00001	-0.00001	-0.00002	-0.00001	-0.00002	-0.00001	-0.00003
	(-0.274)	(-0.314)	(-0.741)	(-0.444)	(-0.604)	(-0.429)	(-0.873)
OTM_daily_avg_stkprc	0.00011***	0.00012***	0.00009***	0.00014***	0.00012***	0.00014***	0.00017***
	(3.869)	(4.093)	(3.176)	(4.741)	(4.070)	(4.698)	(5.878)
ITM_VIX_daily	0.00073	0.00061	0.00042	0.00052	0.00038	0.00041	-0.00007
	(0.749)	(0.632)	(0.426)	(0.530)	(0.392)	(0.395)	(-0.069)
OTM_VIX_daily	0.00129	0.00145	0.00052	0.00100	0.00101	0.00158	0.00080
	(1.284)	(1.465)	(0.522)	(0.996)	(1.012)	(1.491)	(0.763)
Include Intercept	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,155	7,158	7,167	7,174	7,167	7,154	7,173
Adjusted R-squared	0.805	0.803	0.804	0.804	0.807	0.804	0.809

Table 7-9: Cross-interval Results of Model 8 for Interval 1-6

Using Put Option Data, with Percentage Option Spread as Dependent Variable

Interval #	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread
Calls or Puts	Puts	Puts	Puts	Puts	Puts	Puts
Model	Model 8	Model 8	Model 8	Model 8	Model 8	Model 8
Independent Variables						
%_stock_spread	25.05285***	29.87065***	30.72248***	30.76208***	32.94749***	34.27754***
	(5.521)	(4.458)	(4.416)	(4.271)	(4.577)	(4.557)
option_depth	0.00003**	0.00003**	0.00003***	0.00004***	0.00003***	0.00004***
	(1.977)	(2.519)	(2.865)	(3.308)	(3.264)	(3.736)
days_to_expiry	-0.00072***	-0.00061***	-0.00058***	-0.00059***	-0.00059***	-0.00059***
	(-7.351)	(-6.923)	(-6.910)	(-7.213)	(-7.113)	(-7.515)
quote_count	-0.02017***	-0.01325***	-0.01267***	-0.01339***	-0.01305**	-0.01307**
	(-3.868)	(-2.743)	(-2.588)	(-2.656)	(-2.367)	(-2.309)
stock_stdev	-1.53189***	-1.17701***	-1.04281**	-0.88559**	-0.93235**	-0.85950**
	(-3.128)	(-2.584)	(-2.375)	(-2.088)	(-2.222)	(-2.117)
daily_avg_stkprc	0.00004	0.00003	0.00003	0.00004*	0.00003*	0.00003*
	(1.507)	(1.549)	(1.479)	(1.880)	(1.737)	(1.863)
VIX_daily	0.00044	0.00028	0.00018	0.00012	0.00026	0.00010
	(0.564)	(0.374)	(0.256)	(0.185)	(0.370)	(0.157)
D_ITM	-0.03922	-0.02645	-0.01932	-0.01676	-0.01393	-0.01050
	(-1.276)	(-0.946)	(-0.731)	(-0.655)	(-0.536)	(-0.427)
D_OTM	0.74494***	0.69110***	0.70518***	0.68470***	0.69158***	0.67691***
	(25.204)	(25.154)	(26.578)	(26.549)	(26.590)	(27.362)
Interaction Terms						
ITM_%_stock_spread	-18.32295**	-22.16049**	-21.48578**	-22.12513**	-23.14176**	-22.93633**
	(-2.542)	(-2.253)	(-2.141)	(-2.115)	(-2.179)	(-2.089)
OTM_%_stock_spread	50.30831***	55.05381***	60.33789***	55.01824***	64.47576***	64.69874***
	(8.215)	(6.106)	(6.346)	(5.542)	(6.492)	(6.197)
ITM_option_depth	-0.00004**	-0.00003**	-0.00003**	-0.00004***	-0.00003***	-0.00004***
	(-2.182)	(-2.333)	(-2.560)	(-2.880)	(-2.818)	(-3.208)

OTM_option_depth	-0.00005**	-0.00002	-0.00002	-0.00000	-0.00001	-0.00001
	(-2.472)	(-1.399)	(-1.082)	(-0.316)	(-0.833)	(-0.874)
ITM_days_to_expiry	0.00054***	0.00041***	0.00040***	0.00042***	0.00041***	0.00042***
	(3.861)	(3.318)	(3.321)	(3.597)	(3.509)	(3.707)
OTM_days_to_expiry	-0.00560***	-0.00531***	-0.00527***	-0.00520***	-0.00528***	-0.00524***
	(-39.213)	(-41.535)	(-42.994)	(-43.050)	(-43.780)	(-45.420)
ITM_quote_count	0.00094	-0.00192	-0.00133	-0.00412	-0.00277	-0.00500
	(0.115)	(-0.259)	(-0.173)	(-0.505)	(-0.311)	(-0.517)
OTM_quote_count	-0.14101***	-0.06866***	-0.07024***	-0.07330***	-0.05810***	-0.06553***
	(-11.386)	(-5.986)	(-5.592)	(-5.210)	(-3.996)	(-4.287)
ITM_stock_stdev	0.80033	0.60268	0.38925	0.32098	0.30499	0.21812
	(1.119)	(0.910)	(0.615)	(0.521)	(0.501)	(0.371)
OTM_stock_stdev	-10.25131***	-9.43986***	-9.56435***	-9.11840***	-9.53018***	-9.27580***
	(-14.719)	(-14.304)	(-14.929)	(-14.636)	(-15.572)	(-15.672)
ITM_daily_avg_stkprc	-0.00005	-0.00004	-0.00004	-0.00004	-0.00004	-0.00004
	(-1.415)	(-1.169)	(-1.315)	(-1.531)	(-1.505)	(-1.645)
OTM_daily_avg_stkprc	0.00017***	0.00015***	0.00013***	0.00014***	0.00012***	0.00013***
	(5.183)	(5.272)	(4.853)	(5.318)	(4.690)	(5.020)
ITM_VIX_daily	0.00009	0.00022	0.00016	0.00019	0.00008	0.00005
	(0.076)	(0.209)	(0.157)	(0.192)	(0.082)	(0.053)
OTM_VIX_daily	-0.00741***	-0.00767***	-0.00843***	-0.00815***	-0.00801***	-0.00764***
	(-7.116)	(-7.815)	(-8.951)	(-8.866)	(-8.478)	(-8.654)
Include Intercept	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,925	7,072	7,208	7,232	7,206	7,263
Adjusted R-squared	0.672	0.647	0.641	0.637	0.634	0.641

Table 7-10: Cross-interval Results of Model 8 for Interval 7-13

Using Put Option Data, with Percentage Option Spread as Dependent Variable

Interval #	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Dependent Variable	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread
Calls or Puts	Puts	Puts	Puts	Puts	Puts	Puts	Puts
Model	Model 8	Model 8	Model 8	Model 8	Model 8	Model 8	Model 8
Independent Variables							
%_stock_spread	36.15455***	36.49514***	37.63342***	38.06843***	37.48523***	38.83632***	49.15956***
	(4.751)	(4.715)	(4.712)	(4.912)	(4.633)	(4.514)	(4.463)
option_depth	0.00003***	0.00003***	0.00003***	0.00003***	0.00003***	0.00003***	0.00003***
	(3.214)	(3.144)	(3.183)	(2.762)	(2.858)	(3.134)	(2.897)
days_to_expiry	-0.00058***	-0.00058***	-0.00059***	-0.00058***	-0.00059***	-0.00061***	-0.00061***
	(-7.357)	(-7.354)	(-7.616)	(-7.416)	(-7.492)	(-7.704)	(-7.735)
quote_count	-0.01228**	-0.01367**	-0.01457**	-0.01329**	-0.01396**	-0.01380**	-0.01601***
	(-2.096)	(-2.265)	(-2.372)	(-2.388)	(-2.423)	(-2.493)	(-2.982)
stock_stdev	-0.88533**	-0.83211**	-0.93870**	-0.97645**	-1.00170**	-0.93225**	-0.91184**
	(-2.202)	(-2.108)	(-2.389)	(-2.493)	(-2.544)	(-2.385)	(-2.382)
daily_avg_stkprc	0.00003*	0.00003*	0.00004**	0.00003*	0.00003*	0.00004**	0.00004**
	(1.735)	(1.950)	(1.980)	(1.786)	(1.846)	(1.991)	(2.454)
VIX_daily	-0.00015	-0.00001	0.00007	0.00014	0.00001	0.00015	0.00027
	(-0.241)	(-0.017)	(0.107)	(0.226)	(0.014)	(0.230)	(0.411)
D_ITM	-0.01228	-0.00533	-0.00912	-0.01081	-0.01056	-0.00369	-0.00743
	(-0.508)	(-0.226)	(-0.385)	(-0.461)	(-0.439)	(-0.152)	(-0.313)
D_OTM	0.68338***	0.66040***	0.63722***	0.65383***	0.67497***	0.67248***	0.66310***
	(27.911)	(27.649)	(26.449)	(27.392)	(27.669)	(27.409)	(27.694)
Interaction Terms							
ITM_%_stock_spread	-23.51402**	-22.33466**	-23.76294**	-23.55730**	-22.25271*	-22.13042*	-24.88692
	(-2.104)	(-1.996)	(-2.073)	(-2.095)	(-1.865)	(-1.758)	(-1.540)
OTM_%_stock_spread	69.43447***	70.07204***	59.86339***	56.05245***	59.62830***	66.33722***	90.78521***
	(6.569)	(6.497)	(5.383)	(5.152)	(5.300)	(5.535)	(5.933)
ITM_option_depth	-0.00003***	-0.00003***	-0.00003***	-0.00003**	-0.00003**	-0.00003***	-0.00003***
	(-2.831)	(-2.838)	(-2.834)	(-2.474)	(-2.494)	(-2.857)	(-2.603)

OTM_option_depth	-0.00001	0.00000	0.00002	0.00001	-0.00000	-0.00001	-0.00001
	(-0.998)	(0.350)	(1.626)	(0.415)	(-0.259)	(-0.560)	(-0.544)
ITM_days_to_expiry	0.00041***	0.00041***	0.00040***	0.00040***	0.00041***	0.00041***	0.00041***
	(3.650)	(3.666)	(3.606)	(3.534)	(3.654)	(3.626)	(3.671)
OTM_days_to_expiry	-0.00527***	-0.00523***	-0.00516***	-0.00524***	-0.00528***	-0.00524***	-0.00518***
	(-45.384)	(-45.854)	(-45.207)	(-45.542)	(-45.491)	(-45.183)	(-44.742)
ITM_quote_count	-0.00313	-0.00212	-0.00213	-0.00018	-0.00022	0.00062	0.00181
	(-0.323)	(-0.211)	(-0.209)	(-0.020)	(-0.023)	(0.071)	(0.214)
OTM_quote_count	-0.06931***	-0.07381***	-0.07966***	-0.08287***	-0.07680***	-0.09828***	-0.11503***
	(-4.279)	(-4.508)	(-4.519)	(-5.343)	(-4.816)	(-6.153)	(-7.515)
ITM_stock_stdev	0.17763	0.08971	0.19888	0.25315	0.25030	0.16086	0.19948
	(0.305)	(0.157)	(0.350)	(0.449)	(0.440)	(0.286)	(0.364)
OTM_stock_stdev	-9.41503***	-8.93179***	-8.61728***	-8.56686***	-8.93160***	-8.67184***	-8.48311***
	(-16.052)	(-15.505)	(-14.950)	(-14.985)	(-15.556)	(-15.236)	(-15.388)
ITM_daily_avg_stkprc	-0.00004	-0.00005*	-0.00005*	-0.00005*	-0.00005*	-0.00005**	-0.00006**
	(-1.595)	(-1.847)	(-1.888)	(-1.818)	(-1.787)	(-2.090)	(-2.170)
OTM_daily_avg_stkprc	0.00012***	0.00013***	0.00016***	0.00015***	0.00014***	0.00015***	0.00016***
	(4.773)	(5.395)	(6.254)	(6.228)	(5.585)	(5.909)	(6.644)
ITM_VIX_daily	0.00013	-0.00013	-0.00001	-0.00009	-0.00016	-0.00034	-0.00031
	(0.145)	(-0.148)	(-0.012)	(-0.100)	(-0.175)	(-0.361)	(-0.337)
OTM_VIX_daily	-0.00774***	-0.00746***	-0.00686***	-0.00721***	-0.00767***	-0.00781***	-0.00789***
	(-8.885)	(-8.774)	(-7.971)	(-8.425)	(-8.761)	(-8.706)	(-8.878)
Include Intercept	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,276	7,283	7,285	7,293	7,285	7,282	7,294
Adjusted R-squared	0.638	0.639	0.640	0.639	0.640	0.646	0.653

Table 7-11: Cross-interval Results of Model 11 for Interval 1-6

Using Call Option Data, with Option Depth as Dependent Variable

Interval #	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	Option depth	Option depth	Option depth	Option depth	Option depth	Option depth
Calls or Puts	Calls	Calls	Calls	Calls	Calls	Calls
Model	Model 11	Model 11	Model 11	Model 11	Model 11	Model 11
Independent Variables						
option_spread	-130.43105***	-237.78326***	-277.09557***	-284.83021***	-316.72446***	-299.14821***
	(-10.153)	(-10.795)	(-11.231)	(-11.170)	(-11.492)	(-11.070)
days_to_expiry	0.75143***	1.03521***	1.15107***	1.30251***	1.25075***	1.22432***
	(3.300)	(3.641)	(3.964)	(4.362)	(3.954)	(3.968)
quote_count	1.02168	-30.95197**	-31.44487*	-16.89772	-41.02674*	-21.90386
	(0.087)	(-2.020)	(-1.876)	(-0.945)	(-1.919)	(-1.020)
stock_stdev	-5,630.16611***	-7,189.51934***	-7,120.65484***	-7,158.46537***	-7,680.61223***	-6,903.01811***
	(-6.049)	(-6.148)	(-5.974)	(-5.862)	(-5.958)	(-5.494)
VIX_daily	-6.33511***	-5.91305***	-6.72055***	-6.18608***	-5.80428**	-6.98590***
	(-3.680)	(-2.690)	(-3.038)	(-2.737)	(-2.327)	(-3.000)
D_ITM	336.62654***	394.79702***	361.61150***	391.13021***	366.10325***	379.99692***
	(5.910)	(5.579)	(5.002)	(5.238)	(4.618)	(4.928)
D_OTM	-144.28812**	-183.51801**	-176.18889**	-139.07383*	-113.03110	-116.20340
	(-2.339)	(-2.341)	(-2.202)	(-1.681)	(-1.295)	(-1.366)
Interaction Terms						
ITM_option_spread	-37.99958***	22.00352	42.19413	32.64585	60.88701**	42.89331
	(-2.656)	(0.940)	(1.614)	(1.205)	(2.085)	(1.494)
OTM_option_spread	-108.50869***	-232.01626***	-246.95524***	-296.98102***	-249.76515***	-294.45190***
	(-3.709)	(-4.104)	(-3.793)	(-4.157)	(-3.342)	(-3.885)
ITM_days_to_expiry	-0.23056	-0.18694	-0.08937	-0.09088	-0.15271	-0.25724
	(-0.727)	(-0.472)	(-0.219)	(-0.216)	(-0.343)	(-0.590)
OTM_days_to_expiry	0.25574	0.27701	0.09272	-0.12176	-0.23564	-0.18318
	(0.732)	(0.627)	(0.205)	(-0.260)	(-0.485)	(-0.381)
ITM_quote_count	-108.61751***	-199.38334***	-277.23741***	-359.12101***	-367.91691***	-441.94736***
	(-5.810)	(-8.207)	(-9.753)	(-11.072)	(-9.796)	(-10.856)
OTM_quote_count	-124.16795***	-137.93173***	-145.09816***	-190.08729***	-131.80357**	-175.42668***

	(-4.298)	(-3.627)	(-3.298)	(-3.722)	(-2.531)	(-2.946)
ITM_stock_stdev	-8,729.02870***	-10606.29448***	-10210.46068***	-11172.71015***	-11376.98808***	-12271.07300***
	(-6.751)	(-6.470)	(-6.036)	(-6.410)	(-6.202)	(-6.824)
OTM_stock_stdev	1,478.92615	1,928.97199	1,242.46460	661.42951	320.36892	-97.38050
	(1.085)	(1.108)	(0.690)	(0.354)	(0.165)	(-0.051)
ITM_VIX_daily	3.23351	4.66300	6.20145**	7.40360**	8.16294**	9.17838***
	(1.397)	(1.582)	(2.066)	(2.394)	(2.423)	(2.870)
OTM_VIX_daily	4.97039**	4.55877	4.77092	4.71184	2.88580	4.32606
	(2.095)	(1.493)	(1.534)	(1.473)	(0.831)	(1.306)
Include Intercept	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,946	7,089	7,157	7,171	7,151	7,159
Adjusted R-squared	0.179	0.186	0.185	0.190	0.181	0.179

Table 7-12: Cross-interval Results of Model 11 for Interval 7-13

Using Call Option Data, with Option Depth as Dependent Variable

Interval #	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Dependent Variable	Option depth	Option depth	Option depth	Option depth	Option depth	Option depth	Option depth
Calls or Puts	Calls	Calls	Calls	Calls	Calls	Calls	Calls
Model	Model 11	Model 11	Model 11	Model 11	Model 11	Model 11	Model 11
Independent Variables							
option_spread	-311.42275***	-312.63846***	-309.97059***	-314.69537***	-337.31045***	-345.78583***	-319.32051***
	(-11.775)	(-12.039)	(-11.651)	(-12.106)	(-13.008)	(-12.687)	(-12.130)
days_to_expiry	1.14650***	1.15615***	1.26643***	1.26003***	1.13333***	1.14141***	1.14490***
	(3.857)	(3.951)	(4.174)	(4.222)	(3.855)	(3.736)	(3.849)
quote_count	-28.98553	-29.84217	-36.08243	-44.19473**	-48.32817**	-57.06570***	-61.15025***
	(-1.336)	(-1.346)	(-1.574)	(-2.096)	(-2.307)	(-2.751)	(-3.024)
stock_stdev	-6,925.7796***	-6,800.4531***	-6,864.9847***	-7,069.3234***	-7,648.7880***	-7,755.3380***	-7,805.0817***
	(-5.740)	(-5.727)	(-5.583)	(-5.834)	(-6.366)	(-6.216)	(-6.364)
VIX_daily	-5.61553**	-5.47200**	-5.81172**	-4.55639**	-5.77567***	-5.09088**	-4.67997**
	(-2.545)	(-2.518)	(-2.549)	(-2.028)	(-2.629)	(-2.154)	(-2.036)
D_ITM	391.46401***	387.98348***	422.32366***	417.12272***	428.31720***	459.17774***	470.96587***
	(5.280)	(5.321)	(5.583)	(5.612)	(5.872)	(6.034)	(6.381)
D_OTM	-116.04520	-94.31036	-84.36490	-180.02701**	-197.90891**	-204.80189**	-166.69842**
	(-1.425)	(-1.169)	(-1.010)	(-2.188)	(-2.453)	(-2.421)	(-2.062)
Interaction Terms							
ITM_option_spread	50.31267*	60.92866**	59.81805**	65.06532**	88.82176***	92.06034***	79.79011***
	(1.789)	(2.206)	(2.112)	(2.353)	(3.226)	(3.182)	(2.850)
OTM_option_spread	-285.81491***	-290.20700***	-277.00349***	-255.16690***	-266.60868***	-216.32429***	-155.59292**
	(-3.843)	(-3.940)	(-3.649)	(-3.417)	(-3.605)	(-2.897)	(-2.245)
ITM_days_to_expiry	-0.26837	-0.13912	0.06517	0.07664	0.04786	-0.16123	-0.28261
	(-0.638)	(-0.335)	(0.152)	(0.181)	(0.115)	(-0.373)	(-0.673)
OTM_days_to_expiry	-0.09580	-0.29924	-0.50783	-0.22016	-0.11453	-0.13667	-0.32758
	(-0.207)	(-0.654)	(-1.074)	(-0.472)	(-0.249)	(-0.288)	(-0.714)
ITM_quote_count	-443.16419***	-464.29820***	-468.93535***	-387.19526***	-337.22849***	-299.42380***	-289.31010***
	(-10.785)	(-10.641)	(-10.175)	(-9.201)	(-8.721)	(-8.001)	(-8.265)

OTM_quote_count	-181.02255***	-207.50187***	-192.24093***	-185.17246***	-190.34341***	-159.89374***	-130.77694**
	(-3.087)	(-3.202)	(-3.021)	(-3.056)	(-3.174)	(-2.885)	(-2.546)
ITM_stock_stdev	-12788.04913***	-12120.82782***	-12387.41551***	-13120.57673***	-12862.76067***	-13234.55555***	-13562.05339***
	(-7.388)	(-7.124)	(-7.025)	(-7.562)	(-7.524)	(-7.464)	(-7.817)
OTM_stock_stdev	64.07344	-549.15883	-251.31952	1,530.44884	1,398.69854	1,581.78501	1,826.44692
	(0.035)	(-0.301)	(-0.134)	(0.827)	(0.768)	(0.837)	(1.000)
ITM_VIX_daily	8.44435***	6.97514**	5.36150*	5.70557*	4.38198	3.41234	3.44701
	(2.767)	(2.318)	(1.706)	(1.845)	(1.450)	(1.062)	(1.108)
OTM_VIX_daily	3.61669	3.79451	3.18216	4.62208	5.24869*	4.91046	3.18477
	(1.143)	(1.216)	(0.977)	(1.442)	(1.671)	(1.469)	(0.988)
Include Intercept	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,155	7,158	7,167	7,174	7,167	7,154	7,173
Adjusted R-squared	0.188	0.184	0.176	0.182	0.192	0.183	0.182

Table 7-13: Cross-interval Results of Model 11 for Interval 1-6

Using Put Option Data, with Option Depth as Dependent Variable

Interval #	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	Option depth	Option depth	Option depth	Option depth	Option depth	Option depth
Calls or Puts	Puts	Puts	Puts	Puts	Puts	Puts
Model	Model 11	Model 11	Model 11	Model 11	Model 11	Model 11
Independent Variables						
option_spread	-120.92459***	-207.22472***	-236.02425***	-246.05339***	-255.46860***	-251.81105***
	(-15.007)	(-16.102)	(-16.796)	(-16.863)	(-16.897)	(-16.553)
days_to_expiry	0.85828***	1.21015***	1.36213***	1.45300***	1.44816***	1.33433***
	(5.094)	(5.766)	(6.443)	(6.746)	(6.419)	(5.968)
quote_count	-8.15080	-45.80533***	-44.04165***	-30.16403**	-44.27982***	-31.13381*
	(-0.894)	(-3.983)	(-3.574)	(-2.275)	(-2.929)	(-1.939)
stock_stdev	-6,456.78185***	-8,163.24969***	-8,216.08110***	-8,219.23067***	-8,496.79157***	-8,369.28720***
	(-9.174)	(-9.308)	(-9.387)	(-9.283)	(-9.185)	(-9.118)
VIX_daily	-5.96462***	-5.50875***	-5.68041***	-4.92504***	-5.29041***	-6.52064***
	(-4.664)	(-3.391)	(-3.525)	(-3.013)	(-2.975)	(-3.828)
D_ITM	-133.20616***	-201.35375***	-215.22242***	-210.30274***	-193.47672***	-232.64264***
	(-2.986)	(-3.619)	(-3.878)	(-3.720)	(-3.248)	(-3.975)
D_OTM	-63.97517	-116.55507**	-113.59261**	-90.55332	-132.82073**	-121.16498**
	(-1.494)	(-2.150)	(-2.075)	(-1.615)	(-2.250)	(-2.094)
Interaction Terms						
ITM_option_spread	14.51584	85.14163***	109.10564***	110.87292***	114.55782***	112.99263***
	(1.528)	(6.027)	(7.191)	(7.044)	(7.019)	(6.890)
OTM_option_spread	-91.89837***	-190.91837***	-194.68680***	-215.40304***	-216.06562***	-225.25087***
	(-4.668)	(-4.972)	(-4.556)	(-4.662)	(-4.498)	(-4.663)
ITM_days_to_expiry	0.27661	0.30426	0.16562	0.22620	0.17325	0.45737
	(1.150)	(1.013)	(0.548)	(0.734)	(0.538)	(1.428)
OTM_days_to_expiry	-0.52237**	-0.43359	-0.55221*	-0.61022*	-0.47752	-0.58686*
	(-2.099)	(-1.380)	(-1.747)	(-1.870)	(-1.417)	(-1.760)

ITM_quote_count	-74.24212***	-85.56813***	-123.19557***	-167.85266***	-162.98016***	-232.19456***
	(-5.572)	(-5.071)	(-6.606)	(-8.070)	(-6.909)	(-8.853)
OTM_quote_count	-31.06838	-38.74537	-40.84586	-81.87532**	-92.21067**	-106.65109**
	(-1.457)	(-1.404)	(-1.279)	(-2.176)	(-2.292)	(-2.440)
ITM_stock_stdev	698.69226	911.54544	1,145.75036	1,071.95360	256.23313	38.63637
	(0.709)	(0.738)	(0.919)	(0.844)	(0.194)	(0.029)
OTM_stock_stdev	636.64179	1,445.97440	1,380.41400	1,361.94096	1,568.14189	1,452.05626
	(0.650)	(1.162)	(1.094)	(1.058)	(1.174)	(1.096)
ITM_VIX_daily	8.32461***	10.45306***	11.32174***	11.99843***	12.05325***	14.32693***
	(4.549)	(4.501)	(4.907)	(5.107)	(4.759)	(5.888)
OTM_VIX_daily	2.28642	1.73068	1.61868	1.16896	2.43519	2.76328
	(1.330)	(0.786)	(0.731)	(0.516)	(1.002)	(1.173)
Include Intercept	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,925	7,072	7,208	7,232	7,206	7,263
Adjusted R-squared	0.156	0.154	0.159	0.162	0.160	0.159

Table 7-14: Cross-interval Results of Model 11 for Interval 7-13

Using Put Option Data, with Option Depth as Dependent Variable

Interval #	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Dependent Variable	Option depth	Option depth	Option depth	Option depth	Option depth	Option depth	Option depth
Calls or Puts	Puts	Puts	Puts	Puts	Puts	Puts	Puts
Model	Model 11	Model 11	Model 11	Model 11	Model 11	Model 11	Model 11
Independent Variables							
option_spread	-264.10720***	-260.14056***	-253.15561***	-261.96335***	-263.69825***	-276.45391***	-260.98666***
	(-17.441)	(-17.474)	(-17.316)	(-17.310)	(-18.006)	(-18.165)	(-17.717)
days_to_expiry	1.34794***	1.45383***	1.48662***	1.51488***	1.40676***	1.37511***	1.35243***
	(6.139)	(6.757)	(6.924)	(6.811)	(6.459)	(6.199)	(6.269)
quote_count	-41.93798***	-34.72203**	-42.75767**	-51.25232***	-49.57861***	-68.06625***	-76.76848***
	(-2.588)	(-2.082)	(-2.525)	(-3.204)	(-3.135)	(-4.336)	(-5.205)
stock_stdev	-8,365.92652***	-8,162.75402***	-8,107.24553***	-8,289.06349***	-8,582.41569***	-8,920.55017***	-9,361.32248***
	(-9.301)	(-9.288)	(-9.236)	(-9.078)	(-9.508)	(-9.669)	(-10.284)
VIX_daily	-4.55186***	-4.26900***	-4.83038***	-3.77962**	-4.88827***	-3.94813**	-3.31095**
	(-2.794)	(-2.661)	(-2.977)	(-2.252)	(-2.985)	(-2.283)	(-1.982)
D_ITM	-176.41274***	-144.90744***	-161.13792***	-174.47089***	-161.78401***	-151.24606***	-141.16702**
	(-3.088)	(-2.588)	(-2.876)	(-3.022)	(-2.864)	(-2.609)	(-2.518)
D_OTM	-117.07107**	-89.01140	-95.97462*	-73.50500	-95.50194*	-116.01480**	-72.30233
	(-2.066)	(-1.607)	(-1.730)	(-1.282)	(-1.705)	(-2.018)	(-1.301)
Interaction Terms							
ITM_option_spread	129.42205***	127.73686***	121.37994***	130.35385***	128.12877***	142.62965***	131.75385***
	(7.951)	(7.989)	(7.723)	(8.002)	(8.106)	(8.715)	(8.310)
OTM_option_spread	-231.11197***	-238.22380***	-221.20113***	-217.45256***	-217.90781***	-186.21807***	-151.70244***
	(-4.784)	(-4.962)	(-4.651)	(-4.518)	(-4.626)	(-3.938)	(-3.389)
ITM_days_to_expiry	0.28396	0.04751	0.13049	0.22226	0.36316	0.20821	0.18564
	(0.904)	(0.154)	(0.424)	(0.696)	(1.162)	(0.655)	(0.602)
OTM_days_to_expiry	-0.49344	-0.66893**	-0.58791*	-0.73104**	-0.65424**	-0.56645*	-0.64209**
	(-1.504)	(-2.089)	(-1.825)	(-2.200)	(-2.010)	(-1.707)	(-1.987)
ITM_quote_count	-185.00211***	-184.47794***	-201.09608***	-160.76023***	-155.63460***	-123.25220***	-98.75078***
	(-7.202)	(-6.923)	(-7.477)	(-6.354)	(-6.329)	(-5.217)	(-4.481)
OTM_quote_count	-147.87313***	-152.30184***	-149.93629***	-113.01886**	-119.25244***	-103.66824**	-71.15842*

	(-3.276)	(-3.347)	(-3.057)	(-2.540)	(-2.704)	(-2.291)	(-1.685)
ITM_stock_stdev	-599.86815	-585.53189	-456.18290	-225.52529	-149.28982	-32.43020	123.41351
	(-0.462)	(-0.461)	(-0.360)	(-0.172)	(-0.116)	(-0.025)	(0.096)
OTM_stock_stdev	1,566.24746	1,118.47975	1,404.93402	868.27298	1,374.90149	2,090.07187	2,108.64327
	(1.206)	(0.880)	(1.108)	(0.661)	(1.066)	(1.588)	(1.643)
ITM_VIX_daily	11.20257***	9.98509***	10.83288***	10.47651***	9.62640***	8.46704***	7.90672***
	(4.796)	(4.352)	(4.669)	(4.394)	(4.118)	(3.468)	(3.361)
OTM_VIX_daily	2.23142	1.88753	1.40535	0.97609	1.23261	0.48343	-1.51070
	(0.978)	(0.842)	(0.623)	(0.418)	(0.541)	(0.203)	(-0.658)
Include Intercept	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,276	7,283	7,285	7,293	7,285	7,282	7,294
Adjusted R-squared	0.159	0.160	0.163	0.155	0.164	0.161	0.159

Chapter 8: Robustness Check

We conduct a robustness check to examine whether our results are affected by our choice of data. As described earlier in the data section, only options for the top 20 most actively quoted companies are chosen to construct our sample. As a robustness check, we repeat our analysis this time using data related to the top 10 most actively quoted companies. These companies are the first 10 companies in Table 4-1 which include Alphabet, United States Steel, Goldman Sachs, Potash Corporation of Saskatchewan, Goldcorp Inc., First Solar Inc., Newmont Mining Corporation, JPMorgan Chase, Freeport-McMoRan, and IBM. The sample is used to rerun Models 1 to 11.

The results related to the determinants of the option dollar spread are presented in Table 8-1 for calls and Table 8-2 for puts.

Table 8-1: Robustness Check for Model 1, Model 2, Model 3 and Model 4, Based on the Call Option Data of the First 10 Companies listed in Table 4-1 - Option Dollar Spread is Dependent Variable

Column #	(1)	(2)	(3)	(4)
Dependent Variable	Option dollar spread	Option dollar spread	Option dollar spread	Option dollar spread
Calls or Puts	Calls	Calls	Calls	Calls
Model	Model 1	Model 2	Model 3	Model 4
Independent Variables				
stock_spread	2.25405***	1.68015***	1.07420***	1.02932***
	(129.359)	(97.329)	(32.105)	(29.916)
option_depth	-0.00010***	-0.00008***	-0.00003***	-0.00002
	(-14.305)	(-8.520)	(-3.193)	(-1.537)
days_to_expiry	0.00022***	0.00108***	0.00098***	0.00096***
	(3.447)	(18.237)	(17.715)	(17.323)
quote_count	0.00516	-0.00786**	-0.01698***	-0.02286***
	(1.435)	(-2.570)	(-5.944)	(-7.506)
stock_stdev	-9.24839***	-0.93229***	1.72176***	1.99032***
	(-41.487)	(-4.688)	(7.540)	(8.511)
daily_avg_stkprc			0.00042***	0.00046***
			(20.286)	(20.971)
VIX_daily				0.00209***
				(4.852)
D_ITM		0.68020***	0.41332***	0.39183***
		(79.151)	(41.192)	(23.711)
D_OTM		-0.03525***	-0.00667	0.01666

		(-3.617)	(-0.606)	(0.893)
Interaction Terms				
ITM_stock_spread		3.13735***	1.35423***	1.32826***
		(133.223)	(29.583)	(28.333)
OTM_stock_spread		-1.17406***	-0.87591***	-0.85239***
		(-49.881)	(-19.192)	(-18.341)
ITM_option_depth		-0.00011***	-0.00005***	-0.00006***
		(-10.182)	(-4.433)	(-5.346)
OTM_option_depth		0.00005***	0.00003*	0.00001
		(3.609)	(1.792)	(1.027)
ITM_days_to_expiry		-0.00137***	-0.00155***	-0.00152***
		(-16.689)	(-20.150)	(-19.871)
OTM_days_to_expiry		-0.00056***	-0.00042***	-0.00036***
		(-6.193)	(-4.985)	(-4.251)
ITM_quote_count		-0.09144***	-0.11416***	-0.11785***
		(-17.231)	(-23.053)	(-23.013)
OTM_quote_count		0.02036***	0.02197***	0.02120***
		(2.627)	(3.000)	(2.726)
ITM_stock_stdev		-22.00342***	-13.17427***	-13.06286***
		(-78.106)	(-40.746)	(-39.716)
OTM_stock_stdev		0.96748***	-0.12053	-0.15854
		(3.102)	(-0.348)	(-0.442)
ITM_daily_avg_stkprc			0.00131***	0.00133***
			(45.239)	(44.095)
OTM_daily_avg_stkprc			-0.00021***	-0.00022***
			(-7.041)	(-7.393)
ITM_VIX_daily				0.00092
				(1.591)
OTM_VIX_daily				-0.00124**
				(-2.053)
Include Intercept	Yes	Yes	Yes	Yes
Interval Dummies	Yes	Yes	Yes	Yes
Observations	47,173	47,173	47,173	47,173
Adjusted R-squared	0.363	0.819	0.843	0.844

t-statistics in parentheses, ***, ** and * indicate significance at 1%, 5% and 10% significance level respectively.

Quote_count captures the frequency of quote revisions, stock_stdev captures the standard deviation of daily returns of underlying stock, daily_avg_stkprc captures the daily average stock price of underlying stock, VIX_daily captures the daily VIX index price. The Interaction terms capture either the interaction of in-the-money dummy and corresponding independent variable or the interaction of out-of-the-money dummy and corresponding independent variable.

Table 8-2: Robustness Check for Model 1, Model 2, Model 3 and Model 4, Based on the Put Option Data of the First 10 Companies listed in Table 4-1 - Option Dollar Spread is Dependent Variable

Column #	(1)	(2)	(3)	(4)
Dependent Variable	Option dollar spread	Option dollar spread	Option dollar spread	Option dollar spread
Calls or Puts	Puts	Puts	Puts	Puts
Model	Model 1	Model 2	Model 3	Model 4
Independent Variables				
stock_spread	2.22118***	1.95262***	1.14457***	1.08435***
	(87.863)	(71.712)	(21.557)	(19.968)
option_depth	-0.00054***	-0.00008***	-0.00001	0.00000
	(-38.388)	(-5.362)	(-0.971)	(0.046)
days_to_expiry	0.00008	0.00078***	0.00064***	0.00060***
	(0.867)	(8.337)	(7.232)	(6.825)
quote_count	0.06344***	-0.01309***	-0.02371***	-0.03292***
	(13.110)	(-2.660)	(-5.126)	(-6.636)
stock_stdev	-14.70778***	-2.69425***	0.75143**	1.01092***
	(-48.417)	(-8.651)	(2.092)	(2.785)
daily_avg_stkprc			0.00056***	0.00061***
			(17.085)	(17.784)
VIX_daily				0.00236***
				(3.515)
D_ITM		1.21991***	0.80553***	0.62636***
		(90.928)	(51.235)	(24.072)
D_OTM		-0.10564***	-0.04552***	-0.06310**
		(-7.435)	(-2.762)	(-2.317)
Interaction Terms				
ITM_stock_spread		3.53556***	0.46016***	0.36950***
		(91.453)	(6.101)	(4.836)
OTM_stock_spread		-1.30300***	-0.78113***	-0.79341***
		(-35.643)	(-10.879)	(-10.827)
ITM_option_depth		-0.00068***	-0.00048***	-0.00049***
		(-34.960)	(-25.472)	(-25.777)
OTM_option_depth		0.00005**	0.00001	0.00001
		(2.056)	(0.343)	(0.385)
ITM_days_to_expiry		-0.00173***	-0.00210***	-0.00203***
		(-13.211)	(-17.101)	(-16.481)
OTM_days_to_expiry		-0.00001	0.00021	0.00032**
		(-0.105)	(1.626)	(2.458)
ITM_quote_count		-0.16482***	-0.13679***	-0.16828***
		(-22.625)	(-19.968)	(-22.581)

OTM_quote_count		0.00211	-0.01281	-0.02119*
		(0.176)	(-1.131)	(-1.796)
ITM_stock_stdev		-33.82443***	-20.82905***	-19.79405***
		(-76.342)	(-41.134)	(-38.520)
OTM_stock_stdev		3.07592***	1.03495**	1.32504**
		(6.748)	(2.000)	(2.505)
ITM_daily_avg_stkprc			0.00215***	0.00224***
			(46.032)	(46.722)
OTM_daily_avg_stkprc			-0.00037***	-0.00036***
			(-8.143)	(-7.688)
ITM_VIX_daily				0.00776***
				(8.221)
OTM_VIX_daily				0.00014
				(0.152)
Include Intercept	Yes	Yes	Yes	Yes
Interval Dummies	Yes	Yes	Yes	Yes
Observations	47,759	47,759	47,759	47,759
Adjusted R-squared	0.283	0.747	0.778	0.779

t-statistics in parentheses, ***, ** and * indicate significance at 1%, 5% and 10% significance level respectively.

Quote_count captures the frequency of quote revisions, stock_stdev captures the standard deviation of daily returns of underlying stock, daily_avg_stkprc captures the daily average stock price of underlying stock, VIX_daily captures the daily VIX index price. The Interaction terms capture either the interaction of in-the-money dummy and corresponding independent variable or the interaction of out-of-the-money dummy and corresponding independent variable.

The results related to the determinants of the option percentage spread are presented in Table 8-3 for calls and Table 8-4 for puts.

Table 8-3: Robustness Check for Model 5, Model 6, Model 7 and Model 8, Based on the Call Option Data of the First 10 Companies listed in Table 4-1 - Percentage Option Spread is Dependent Variable

Column #	(1)	(2)	(3)	(4)
Dependent Variable	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread
Calls or Puts	Calls	Calls	Calls	Calls

Model	Model 5	Model 6	Model 7	Model 8
Independent Variables				
%_stock_spread	-3.37061	8.48296***	7.26855**	6.04585*
	(-0.980)	(2.775)	(2.295)	(1.848)
option_depth	-0.00013***	0.00001	0.00001	0.00001*
	(-32.936)	(1.383)	(1.545)	(1.853)
days_to_expiry	-0.00194***	-0.00088***	-0.00088***	-0.00088***
	(-53.139)	(-27.390)	(-27.421)	(-27.465)
quote_count	-0.21251***	-0.01974***	-0.02034***	-0.02129***
	(-103.225)	(-11.885)	(-12.236)	(-11.944)
stock_stdev	-5.03191***	-2.64023***	-2.57972***	-2.52844***
	(-37.027)	(-22.468)	(-18.249)	(-17.350)
daily_avg_stkprc			0.00000	0.00001
			(0.633)	(1.007)
VIX_daily				0.00035
				(1.378)
D_ITM		-0.11134***	-0.11588***	-0.12675***
		(-25.999)	(-21.134)	(-13.758)
D_OTM		0.93325***	0.89788***	0.92172***
		(197.933)	(146.344)	(87.732)
Interaction Terms				
ITM_%_stock_spread		-10.57384**	-12.71573***	-14.85534***
		(-2.539)	(-2.921)	(-3.310)
OTM_%_stock_spread		-27.50139***	-39.99166***	-37.59772***
		(-6.489)	(-9.010)	(-8.301)
ITM_option_depth		-0.00001	-0.00001	-0.00001
		(-1.335)	(-1.026)	(-1.238)
OTM_option_depth		-0.00020***	-0.00018***	-0.00018***
		(-26.425)	(-21.199)	(-21.294)
ITM_days_to_expiry		0.00079***	0.00079***	0.00079***
		(17.695)	(17.626)	(17.694)
OTM_days_to_expiry		-0.00558***	-0.00556***	-0.00558***
		(-113.431)	(-112.930)	(-111.519)
ITM_quote_count		0.00038	-0.00067	-0.00213
		(0.133)	(-0.234)	(-0.713)
OTM_quote_count		-0.09871***	-0.09669***	-0.09249***
		(-22.724)	(-22.275)	(-20.155)
ITM_stock_stdev		2.48197***	2.65654***	2.73136***
		(15.129)	(13.234)	(13.283)
OTM_stock_stdev		-15.70647***	-14.54319***	-14.71781***
		(-91.297)	(-68.139)	(-66.207)
ITM_daily_avg_stkprc			0.00001	0.00001
			(1.330)	(1.586)
OTM_daily_avg_stkprc			0.00007***	0.00006***
			(8.117)	(7.081)
ITM_VIX_daily				0.00049
				(1.454)

OTM_VIX_daily				-0.00097***
				(-2.757)
Include Intercept	Yes	Yes	Yes	Yes
Interval Dummies	Yes	Yes	Yes	Yes
Observations	47,173	47,173	47,173	47,173
Adjusted R-squared	0.263	0.812	0.813	0.813

t-statistics in parentheses, ***, ** and * indicate significance at 1%, 5% and 10% significance level respectively.

Quote_count captures the frequency of quote revisions, stock_stdev captures the standard deviation of daily returns of underlying stock, daily_avg_stkprc captures the daily average stock price of underlying stock, VIX_daily captures the daily VIX index price. The Interaction terms capture either the interaction of in-the-money dummy and corresponding independent variable or the interaction of out-of-the-money dummy and corresponding independent variable.

Table 8-4: Robustness Check for Model 5, Model 6, Model 7 and Model 8, Based on the Put Option Data of the First 10 Companies listed in Table 4-1 - Percentage Option Spread is Dependent Variable

Column #	(1)	(2)	(3)	(4)
Dependent Variable	Percentage option spread	Percentage option spread	Percentage option spread	Percentage option spread
Calls or Puts	Puts	Puts	Puts	Puts
Model	Model 5	Model 6	Model 7	Model 8
Independent Variables				
%_stock_spread	23.74601***	10.66326***	6.33457**	8.15367***
	(10.211)	(3.775)	(2.194)	(2.764)
option_depth	-0.00000	-0.00000	0.00001*	0.00001
	(-0.917)	(-0.097)	(1.751)	(1.460)
days_to_expiry	-0.00182***	-0.00040***	-0.00042***	-0.00041***
	(-75.239)	(-13.417)	(-14.073)	(-13.984)
quote_count	-0.10065***	-0.00522***	-0.00663***	-0.00514***
	(-77.235)	(-3.329)	(-4.282)	(-3.111)
stock_stdev	-4.47001***	-0.88135***	-0.58713***	-0.63211***
	(-50.044)	(-8.060)	(-4.572)	(-4.881)
daily_avg_stkprc			0.00002***	0.00002***
			(3.989)	(3.530)
VIX_daily				-0.00002
				(-0.083)
D_ITM		-0.01962***	-0.00798	-0.01322

		(-4.952)	(-1.617)	(-1.590)
D_OTM		0.58139***	0.49947***	0.67475***
		(141.139)	(95.775)	(77.686)
Interaction Terms				
ITM_%_stock_spread		-8.85844**	-4.51755	-5.16954
		(-2.239)	(-1.118)	(-1.267)
OTM_%_stock_spread		-2.47646	-34.82931***	-11.92817***
		(-0.644)	(-8.772)	(-2.954)
ITM_option_depth		-0.00000	-0.00002**	-0.00001**
		(-0.578)	(-2.406)	(-2.297)
OTM_option_depth		-0.00002***	0.00005***	0.00002***
		(-2.729)	(7.000)	(2.943)
ITM_days_to_expiry		0.00027***	0.00028***	0.00028***
		(6.349)	(6.877)	(6.832)
OTM_days_to_expiry		-0.00481***	-0.00477***	-0.00494***
		(-110.765)	(-111.273)	(-115.328)
ITM_quote_count		-0.00469**	-0.00348	-0.00500**
		(-2.020)	(-1.510)	(-2.015)
OTM_quote_count		-0.03647***	-0.03600***	-0.00266
		(-9.452)	(-9.466)	(-0.676)
ITM_stock_stdev		0.21777	-0.17538	-0.15882
		(1.418)	(-0.969)	(-0.868)
OTM_stock_stdev		-11.09576***	-8.41137***	-9.73463***
		(-71.838)	(-45.552)	(-51.722)
ITM_daily_avg_stkprc			-0.00003***	-0.00003***
			(-4.113)	(-3.883)
OTM_daily_avg_stkprc			0.00018***	0.00013***
			(23.168)	(17.070)
ITM_VIX_daily				0.00030
				(0.947)
OTM_VIX_daily				-0.00703***
				(-22.795)
Include Intercept	Yes	Yes	Yes	Yes
Interval Dummies	Yes	Yes	Yes	Yes
Observations	47,759	47,759	47,759	47,759
Adjusted R-squared	0.239	0.627	0.638	0.646

t-statistics in parentheses, ***, ** and * indicate significance at 1%, 5% and 10% significance level respectively.

Quote_count captures the frequency of quote revisions, stock_stdev captures the standard deviation of daily returns of underlying stock, daily_avg_stkprc captures the daily average stock price of underlying stock, VIX_daily captures the daily VIX index price. The Interaction terms capture either the interaction of in-the-money dummy and corresponding independent variable or the interaction of out-of-the-money dummy and corresponding independent variable.

The results related to the determinants of the option depth are presented in Table 8-5 for calls and Table 8-6 for puts.

Table 8-5: Robustness Check for Model 9, Model 10 and Model 11, Based on the Call Option Data of the First 10 Companies listed in Table 4-1 - Option Depth is Dependent Variable

Column #	(1)	(2)	(3)
Dependent Variable	Option depth	Option depth	Option depth
Calls or Puts	Calls	Calls	Calls
Model	Model 9	Model 10	Model 11
Independent Variables			
option_spread	-142.89875***	-454.05894***	-450.95345***
	(-56.505)	(-50.142)	(-50.063)
days_to_expiry	0.66533***	1.50396***	1.50784***
	(15.875)	(22.467)	(22.647)
quote_count	19.76755***	26.70856***	51.21796***
	(8.346)	(7.697)	(14.059)
stock_stdev	-6,386.43757***	-4,075.22661***	-4,077.76339***
	(-43.957)	(-18.260)	(-18.370)
VIX_daily			-9.99309***
			(-20.459)
D_ITM		347.34081***	188.65988***
		(36.787)	(11.799)
D_OTM		-36.42046***	-106.44570***
		(-3.647)	(-5.966)
Interaction Terms			
ITM_option_spread		226.26522***	222.96483***
		(23.833)	(23.608)
OTM_option_spread		-181.74919***	-209.53874***
		(-6.788)	(-7.828)
ITM_days_to_expiry		-0.56723***	-0.57356***
		(-6.070)	(-6.170)
OTM_days_to_expiry		-1.06169***	-1.24213***
		(-10.416)	(-12.083)
ITM_quote_count		-83.82822***	-101.39800***
		(-13.984)	(-16.475)
OTM_quote_count		-62.54486***	-50.80257***
		(-7.103)	(-5.382)
ITM_stock_stdev		-10417.73439***	-10454.43032***

		(-31.864)	(-32.134)
OTM_stock_stdev		631.20231*	111.86420
		(1.838)	(0.324)
ITM_VIX_daily			8.68079***
			(13.004)
OTM_VIX_daily			5.15797***
			(7.375)
Include Intercept	Yes	Yes	Yes
Interval Dummies	Yes	Yes	Yes
Observations	47,173	47,173	47,173
Adjusted R-squared	0.089	0.229	0.237

t-statistics in parentheses, ***, ** and * indicate significance at 1%, 5% and 10% significance level respectively.

Daily_avg_stkprc is not included in regression on option depth due to lack of theoretical arguments and stock price's strong correlation with option dollar spread. Quote_count captures the frequency of quote revisions, stock_stdev captures the standard deviation of daily returns of underlying stock, VIX_daily captures the daily VIX index price. The Interaction terms capture either the interaction of in-the-money dummy and corresponding independent variable or the interaction of out-of-the-money dummy and corresponding independent variable.

Table 8-6: Robustness Check for Model 9, Model 10 and Model 11, Based on the Put Option Data of the First 10 Companies listed in Table 4-1 - Option Depth is Dependent Variable

Column #	(1)	(2)	(3)
Dependent Variable	Option depth	Option depth	Option depth
Calls or Puts	Puts	Puts	Puts
Model	Model 9	Model 10	Model 11
Independent Variables			
option_spread	-98.80293***	-400.06947***	-400.16198***
	(-72.905)	(-70.128)	(-70.614)
days_to_expiry	0.70094***	1.55735***	1.58163***
	(23.497)	(32.166)	(32.878)
quote_count	34.18553***	35.08697***	55.68064***
	(21.179)	(13.667)	(20.458)
stock_stdev	-3,818.41435***	-4,087.62134***	-4,000.67918***
	(-37.460)	(-24.833)	(-24.460)
VIX_daily			-7.71643***
			(-21.598)

D_ITM		77.69749***	-106.53691***
		(10.795)	(-8.672)
D_OTM		-34.38646***	-83.84677***
		(-5.046)	(-7.046)
Interaction Terms			
ITM_option_spread		293.56852***	294.88086***
		(49.447)	(49.959)
OTM_option_spread		-172.67081***	-166.77478***
		(-10.535)	(-10.241)
ITM_days_to_expiry		-0.80819***	-0.81963***
		(-11.851)	(-12.089)
OTM_days_to_expiry		-1.09611***	-1.23018***
		(-15.323)	(-17.184)
ITM_quote_count		-80.88833***	-108.00228***
		(-21.767)	(-26.887)
OTM_quote_count		-36.45977***	-33.21164***
		(-5.767)	(-5.054)
ITM_stock_stdev		-2,252.40797***	-2,218.59365***
		(-9.192)	(-9.071)
OTM_stock_stdev		606.80651***	293.27874
		(2.578)	(1.250)
ITM_VIX_daily			9.89665***
			(19.423)
OTM_VIX_daily			3.60795***
			(7.316)
Include Intercept	Yes	Yes	Yes
Interval Dummies	Yes	Yes	Yes
Observations	47,759	47,759	47,759
Adjusted R-squared	0.126	0.244	0.254

t-statistics in parentheses, ***, ** and * indicate significance at 1%, 5% and 10% significance level respectively.

Daily_avg_stkprc is not included in regression on option depth due to lack of theoretical arguments and stock price's strong correlation with option dollar spread. Quote_count captures the frequency of quote revisions, stock_stdev captures the standard deviation of daily returns of underlying stock, VIX_daily captures the daily VIX index price. The Interaction terms capture either the interaction of in-the-money dummy and corresponding independent variable or the interaction of out-of-the-money dummy and corresponding independent variable.

Overall, this robustness check using data for only 10 companies gives similar results to our main regression results with one exception. In the main regressions, the depth for in-the-money calls and puts is negatively related to the quote count but in the robustness test the depth for in-the-money calls and puts is positively related to the quote count. The results for ITM or OTM options is the same in the main analysis and in the robustness test.

Therefore, the robustness test suggests that the impact of the quote count on the depth for the 10 most active companies is different from the impact of the quote count on the depth for the next 10 most active companies. We offer one possible interpretation for this observation. The depth for the options of the 10 most active companies could be simply a function of the supply and demand conditions and the nature of the orders. In a highly active environment, the supply and demand for the options may increase leading to high limit order sizes. In such an environment the depth is no longer controlled by market makers and it is not a source of risk to them. Therefore, the depth increases and decreases in response to market activity. We leave further investigation of this observation to future studies.

Chapter 9: Summary, Conclusions, and Directions for Future Research

This research uses quote-level intraday data to analyze the intraday variation of quoted dollar spread, percentage spread, and depth for options that are ranked as the top actively quoted options listed on the Chicago Board Options Exchange (CBOE). Our data cover the period of January, February, and March 2010 and include all quote level data of options related to the 20 companies. The initial data we started with consists of a huge number of market quotes. After filtering the data and summarizing the observations within a single 30-minute intraday interval into single data points for the intraday variables such as option spread, option depth, underlying stock spread and quote count, our data set was reduced to 186,725 observations.

Combining graphical and descriptive analysis, we reinforce some arguments made by previous studies and arrive at some new findings. Our descriptive and graphical analysis suggest that, on average, option depth follows a reverse U-shaped pattern. The depth starts low at the open and increases until it reaches a maximum sometime mid-day and then it drops during the last trading interval. The drop of option depth at market close is usually much less than the jump at the market open. Our analysis also reveals that option spread is several times wider than stock spread, while option spread proportionate to option price is far greater than stock spread proportionate to stock price. Option spread and percentage option spread have L-shaped intraday patterns, which start high in the first 30-minute session, then drop sharply and hold steady for the rest of the day. In contrast, stock spread and percentage stock spread have a reverse S-shaped intraday pattern, which start high at market open, drop sharply immediately after, then continue to decline slowly and finally experience another sharp drop near the market close. The difference between option spread and stock spread may be attributed to different market making structures (Chan et al., 1995), different strategies by market makers on different markets to divert intraday risks, or the hedging activities associated with option writing but irrelevant to stock trading.

In addition to descriptive and graphical analysis, we use regression analysis to examine the determinants of the spread and the depth of puts and calls. We extend the intraday models of Cho and Engle (1999) by including interval dummy variables to capture time-of-the-day effects as have been done in many intraday stock studies, categorize options into three groups based on moneyness, add variables to interact the moneyness dummy variables with other variables of interest, and test for the first time the impact of the underlying price level and the overall market expected volatility on the spread and the depth. The inclusion of moneyness dummies and moneyness interaction terms improved the fitness significantly.

A unique contribution of this study is examining the impact of the underlying stock price on option dollar spread and percentage option spread. We propose that stock price serves as a proxy for hedging costs. Option spread and percentage option spread are both positively correlated with the level of underlying stock prices, confirming the cost of hedging as a component of option spread (Hait, 1999). Previous studies have argued that option spread increases with option price, but we further show that the stock price also increases the spread. Our finding applies to both dollar option spread and percentage option spread (already accounting for option price). This confirms our proposition that options with high stock prices are more expensive to hedge in the stock market both in dollar and in percentage, so they have wider spreads. Our result is consistent with the findings of Wei and Zheng (2010) that the option volatility, measured as the hedge ratio multiplied by the volatility of the underlying, is a significant positive contributor to the spread.

Another unique contribution of this study is examining the impact of expected market volatility on dollar spread, percentage option spread and option depth. Using the Chicago Board Options Exchange Volatility Index (VIX) as a proxy, we show that high expected market volatility significantly increases option dollar spread but it is not significant for percentage spread, possibly due to its positive impact on option premiums. Market volatility also depresses option depth levels, a reaction consistent with the desire of market makers to avoid market risks through lower supply. Overall, the inclusion of the *Daily VIX* variable in our analysis leads to minimal increase in model fitness, which we believe could be ascribed to the fact that option depth may already capture most of the effect of market volatility in explaining option spread.

In addition to the unique contributions, the results confirm several findings of previous studies. First, we show that both dollar and percentage option spread is significantly positively associated with underlying stock spread, which supports the theory that information flows into both stock and option markets simultaneously and is consistent with the arguments of the Derivative Hedge Theory proposed by Cho and Engle (1999).

Second, similar to stocks, the spread and depth for options are two dimensions of liquidity and are imperfectly and reversely related. They are two tools market makers may use to adjust their risk exposure at their discretion. Market makers seem to adjust option depth, option spread, or both when they expect changes in the company-specific information asymmetry, but they seem to change the depth more aggressively when they expect changes in the overall market volatility. Nevertheless, the negative relationship is not perfect, for example, they tend to quote wide spreads for options that have long time to expiry due to greater risks embedded in those options, but at the same time they offer more depth.

Third, we find that the percentage option spread is positively associated with option depth after other factors are controlled, which is different from a negative relationship between option dollar spread and option depth. It could be explained by the argument made by Verousis et al. (2016) that option market makers sometimes quote large depth, but also set a wide spread to compensate some of the risks.

Fourth, we find strong and consistent supporting evidence for positive relationship between option dollar spread and time to expiration, as suggested by Pinter (2003) and Kodippili (2004). However, we find that percentage option spread decreases with time to expiration, possibly because premiums increase faster than dollar spread as the expiry date moves further into the future.

Fifth, our analysis shows that, generally, ITM call dollar spread is higher than ATM call dollar spread and ATM call spread is higher than OTM call spread. This result also applies to put options. However, this conclusion is reversed for the percentage call and put spread, as the percentage spread increases as an option moves from ITM to ATM and from ATM to OTM. This observation is consistent with the argument that both the dollar spread and option premium both increase with moneyness but the increase in the premium is much faster than the increase in the spread.

Sixth, we examine the impact of the intensity of market activities on the dollar spread, percentage spread, and the depth. We choose the frequency of quote revision (quote count) as the proxy, instead of the traditionally used option volume. Chan et al (2002) argues that quote revision is more informative than option volume. Our results suggest that percentage option spread and dollar option spread for at-the-money options are negatively related to the quote revisions. For percentage spread, in-the-money options are insignificantly different from at-the-money options, but out-of-the-money options are more significantly negatively affected by the quote count.

Seventh, our regression results suggest a strong and negative relationship between volatility of the underlying asset and the percentage option spread of at the money options. For out-of-the-money options, this impact is stronger, but for in-the-money options it is significantly weaker. The same result applies for both puts and calls. At the same time, we observe that increased volatility of the underlying stock increases dollar spread for at-the-money options, but this impact is weaker for in-the-money options and stronger for out-of-the-money options. The same result applies to both puts and calls. We propose that the driving force for the difference is that increased underlying stock volatility boosts the premiums of put and call options, while the increase in premiums is much more significant for out-of-the-money options compared to the increase in premiums for both at-the-money and out-of-the-money options, because the premiums of deep-in-the-money options are less sensitive to volatility changes because the intrinsic value is the main component of the premiums.

In our study, we have found several occasions where option spread and option depth can go in the same direction. For example, long-term options are reported to have wider dollar spread and higher depth on average. Another example is the observation that high volatility of underlying stocks sometimes leads to lower depth level and lower percentage spread as well as lower dollar spread. Tannous et al. (2013) argue that market makers in the stock market use a dynamic strategy, by which they may utilize the spread and the depth separately or jointly to manage their risk. Our findings indicate the same applies to the options market.

In terms of theoretical framework, we refer extensively to information asymmetry and the risk management behaviors of market makers, who are risk-averse and provide liquidity based on their perception of risks that include but are not limited to information risk. Our explanations of the empirical results assume that market makers adjust their strategies throughout the day in reaction to changes in the market. We demonstrate that market makers employ different strategies using option spread and option depth to deal with the risks they face.

This study has some practical implications for market participants. The intraday magnitude and patterns of the spread and the depth suggest that option market is inefficient and it may be wise for uninformed investors to avoid trading in early morning sessions, during which information asymmetry level and option spread are high. Also, near the end of the day, option market movements become unpredictable due to factors that are not included in this study and are rarely discussed in the option literature. Chung and Van Ness (2001) point out that there are more limit orders at the middle of a typical trading day, suggesting higher liquidity, compared to the beginning and the end of the day. Thus, it may be better to avoid trading near market close when there is high level of uncertainty while mid-day may be the best time for uninformed investors to place trades. However, superior information held by informed investors may still justify making trades when spread level is high or when the market is unpredictable. The superior information may predict the market with great confidence and have foresight of a price movement in the underlying stock and option price greater than the magnitude of the corresponding option spread. So informed traders can still use options as leveraged investments to capitalize on their superior information.

This research focuses on the microstructure of the most active equity options. It would be rewarding for future research to investigate the intraday spread and depth of less active equity options.

References

Breen, W. J., Hodrick, L. S., & Korajczyk, R. A. (2002). Predicting equity liquidity. Management Science, 48(4), 470-483.

Brock, W. A., & Kleidon, A. W. (1992). Periodic market closure and trading volume: A model of intraday bids and asks. Journal of Economic Dynamics and Control, 16(3), 451-489.

Chakravarty, S., Gulen, H., & Mayhew, S. (2004). Informed trading in stock and option markets. The Journal of Finance, 59(3), 1235-1257.

Chan, K., Chung, Y. P., & Fong, W. M. (2002). The informational role of stock and option volume. The Review of Financial Studies, 15(4), 1049-1075.

Chan, K., Chung, Y. P., & Johnson, H. (1995). The intraday behavior of bid-ask spreads for NYSE stocks and CBOE options. Journal of Financial and Quantitative Analysis, 30(03), 329-346.

Cho, Y. H., & Engle, R. F. (1999). Modeling the impacts of market activity on bid-ask spreads in the option market (No. w7331). National bureau of economic research.

Chung, K. H., Chuwonganant, C., & Jiang, J. (2008). The dynamics of quote adjustments. Journal of Banking & Finance, 32(11), 2390-2400.

Chung, K. H., & Van Ness, R. A. (2001). Order handling rules, tick size, and the intraday pattern of bid–ask spreads for NASDAQ stocks. Journal of Financial Markets, 4(2), 143-161.

De Fontnouvelle, P., Fishe, R. P., & Harris, J. H. (2003). The behavior of bid–ask spreads and volume in options markets during the competition for listings in 1999. The Journal of Finance, 58(6), 2437-2464.

Dupont, D. (2000). Market making, prices, and quantity limits. Review of Financial Studies, 13(4), 1129-1151.

Foster, F. D., & VISWANATHAN, S. (1993). Variations in trading volume, return volatility, and trading costs; Evidence on recent price formation models. The Journal of Finance, 48(1), 187-211.

Garvey, R., & Wu, F. (2009). Intraday time and order execution quality dimensions. Journal of Financial Markets, 12(2), 203-228.

Giot, P. (2005). Relationships between implied volatility indexes and stock index returns. The Journal of Portfolio Management, 31(3), 92-100.

Hait, D. J. (1999). Essays on options markets (Order No. 9948047). Available from ProQuest Dissertations & Theses Global. (304565292). Retrieved from http://cyber.usask.ca/login?url=http://search.proquest.com/docview/304565292?accountid=14739

Harris, L. E., & Panchapagesan, V. (2005). The information content of the limit order book: evidence from NYSE specialist trading decisions. Journal of Financial Markets, 8(1), 25-67.

Heflin, F., Shaw, K. W., & Wild, J. J. (2007). Disclosure policy and intraday spread patterns. Review of Accounting and Finance, 6(3), 285-303.

Heston, S. L., Korajczyk, R. A., & Sadka, R. (2010). Intraday Patterns in the Cross-section of Stock Returns. The Journal of Finance, 65(4), 1369-1407.

Heston, S. L., Korajczyk, R. A., Sadka, R., & Thorson, L. D. (2011). Are you trading predictably? Financial Analysts Journal, 67(2), 36-44.

Hora, M. (2006). Tactical liquidity trading and intraday volume. Social Science Research Network Working Paper Series.

Kaul, G., Nimalendran, M., & Zhang, D. (2004). Informed trading and option spreads.

Kodippili, A. (2004). Analysis of intraday dynamics of options trading (Order No. 3142683). Available from ProQuest Dissertations & Theses Global. (305160923). Retrieved from http://cyber.usask.ca/login?url=http://search.proquest.com/docview/305160923?-accountid=14739

Lee, C. M., Mucklow, B., & Ready, M. J. (1993). Spreads, depths, and the impact of earnings information: An intraday analysis. Review of Financial Studies, 6(2), 345-374.

Lee, C., & Ready, M. J. (1991). Inferring trade direction from intraday data. The Journal of Finance, 46(2), 733-746.

Levin, E. J., & Wright, R. E. (1999). Explaining the intra-day variation in the bid–ask spread in competitive dealership markets–A research note. Journal of Financial Markets, 2(2), 179-191.

Li, Y., Van Ness, B. F., & Van Ness, R. A. (2005). Daily and intraday patterns in spread and depth for limit orders and specialists. Quarterly Journal of Business and Economics, 3-14.

Lubnau, T. M., & Todorova, N. (2015). The calm after the storm: implied volatility and future stock index returns. The European Journal of Finance, 21(15), 1282-1296.

Madhavan, A., & Smidt, S. (1991). A Bayesian model of intraday specialist pricing. Journal of Financial Economics, 30(1), 99-134.

Madhavan, A. (1992). Trading mechanisms in securities markets. Journal of Finance, 47(2), 607-641.

Mayhew, S. (2002). Competition, Market Structure, and Bid-Ask Spreads in Stock Option Markets. The Journal of Finance, 57(2), 931-958.

Mayhew, S., Sarin, A., & Shastri, K. (1999). What drives option liquidity?.

McInish, T. H., & Wood, R. A. (1992). An analysis of intraday patterns in bid/ask spreads for NYSE stocks. The Journal of Finance, 47(2), 753-764.

Mishra, S., & Daigler, R. T. (2014). Intraday Trading and Bid–Ask Spread Characteristics for SPX and SPY Options. The Journal of Derivatives, 21(3), 70-84.

Pinder, S. (2003). An empirical examination of the impact of market microstructure changes on the determinants of option bid–ask spreads. International Review of Financial Analysis, 12(5), 563-577.

Sheikh, A. M., & Ronn, E. I. (1994). A characterization of the daily and intraday behavior of returns on options. The Journal of Finance, 49(2), 557-580.

Tannous, G., Wang, J., & Wilson, C. (2013). The intraday pattern of information asymmetry, spread, and depth: Evidence from the NYSE. International Review of Finance, 13(2), 215-240.

Verousis, Thanos, & Gwilym, Owain AP, & Chen, X. (2016). The intraday determination of liquidity in the NYSE LIFFE equity option markets. The European Journal of Finance, 22(12), 1164-1188.

Verousis, Thanos, & Gwilym, Owain AP (2013). The Microstructure of Individual Equity Options: Firm-Level and Common Effects on Liquidity. Available at SSRN 2270635.

Vijh, A. M. (1990). Liquidity of the CBOE equity options. The Journal of Finance, 45(4), 1157-1179.

Wee, M., & Yang, J. W. (2012). Order size, order imbalance and the volatility–volume relation in a bull versus a bear market. Accounting & Finance, 52(1), 145-163.

Wei, J., & Zheng, J. (2010). Trading activity and bid–ask spreads of individual equity options. Journal of Banking & Finance, 34(12), 2897-2916.

Appendix

An Example to Illustrate Illiquidity of Options

This study is partially motivated by the observation that the bid-ask spreads for options are much larger than the bid-ask spreads for the stocks underlying those options, which represents much higher trading costs associated with option trading. This appendix illustrates this observation with an example, contrasting the spreads of options with the spreads of the underlying stock.

Table A.1 presents the market data for options of Apple Inc., a very large and liquid technology stock, usually believed to have superior liquidity on options. We selected a random time, 02:45:01 PM EST, on a random date, February 14, 2017, to retrieve this data on all options available from Toronto Dominion Bank market research webpage. We selected my sample to be all call and put options that would expire on Friday March 17 2017, in approximately a month from the observation date of February, 14 2017. It is necessary to exclude a large number of illiquid valueless out-of-the-money options, whose bid prices equaled to $0.00 and ask prices equaled to $0.01. Nobody was willing to even bid for those options, so the spread of $0.01 should not be perceived as a narrow spread resulted from high liquidity, instead it is merely a product of inactivity of trading for those options. In fact, the volumes for them are usually zero or very minimal.

Table A.1: Option Chain for Apple Inc. stock on Feb 14, 2017

Call Options (expires March 17, 2017)						
Symbol	Bid	Ask	Last	Change	Volume	Strike
AAPL	$89.75	$90.20	$86.68	$0.00	---	45
AAPL	$87.25	$87.70	$58.27	$0.00	---	47.5
AAPL	$84.75	$85.20	$81.67	$0.00	---	50

AAPL	$79.70	$80.15	$76.95	$0.00	---	55
AAPL	$74.75	$75.25	$72.00	$0.00	---	60
AAPL	$69.75	$70.25	$52.00	$0.00	---	65
AAPL	$64.75	$65.25	$63.07	$0.00	---	70
AAPL	$59.75	$60.25	$57.35	$0.00	---	75
AAPL	$54.75	$55.20	$52.50	$0.00	---	80
AAPL	$52.25	$52.75	$49.25	$0.00	---	82.5
AAPL	$49.75	$50.25	$47.50	$0.00	---	85
AAPL	$47.30	$47.75	$44.88	$0.00	---	87.5
AAPL	$44.85	$45.10	$45.00	$1.41	7	90
AAPL	$42.30	$42.75	$39.45	$0.00	---	92.5
AAPL	$39.80	$40.25	$37.50	$0.00	---	95
AAPL	$37.30	$37.75	$36.31	$0.00	---	97.5
AAPL		$35.15	$35.00	$1.63	213	100
AAPL	$29.90	$30.10	$30.02	$1.32	47	105
AAPL	$24.95	$25.15	$24.95	$1.55	33	110
AAPL	$19.95	$20.10	$20.10	$1.39	211	115
AAPL	$15.05	$15.25	$15.15	$1.60	339	120
AAPL	$10.25	$10.40	$10.30	$1.65	1,131	125
AAPL	$5.80	$5.85	$5.84	$1.34	5,763	130
AAPL	$2.50	$2.51	$2.50	$0.86	27,010	135
AAPL	$0.78	$0.79	$0.79	$0.32	4,559	140
AAPL	$0.22	$0.23	$0.24	$0.10	813	145
AAPL	$0.07	$0.08	$0.08	$0.02	1,014	150
AAPL	$0.02	$0.03	$0.03	$0.00	95	155
AAPL	$0.01	$0.02	$0.01	$0.00	---	160
AAPL	$0.00	$0.01	$0.02	$0.01	2	165
AAPL	$0.00	$0.01	$0.02	$0.00	---	170
AAPL	$0.00	$0.01	$0.01	$0.00	---	175
AAPL	$0.00	$0.01	$0.01	$0.00	---	180
AAPL	$0.00	$0.01	$0.00	$0.00	---	185
AAPL	$0.00	$0.01	$0.00	$0.00	---	190
AAPL	$0.00	$0.01	$0.00	$0.00	---	195
AAPL	$0.00	$0.01	$0.00	$0.00	---	200
AAPL	$0.00	$0.01	$0.00	$0.00	---	205
AAPL	$0.00	$0.01	$0.01	$0.00	---	210
AAPL	$0.00	$0.01	$0.00	$0.00	---	220
AAPL	$0.00	$0.01	$0.00	$0.00	---	230

AAPL	$0.00	$0.01	$0.00	$0.00	---	240
Put Options (expires March 17, 2017)						
Symbol	Bid	Ask	Last	Change	Volume	Strike
AAPL	$0.00	$0.01	$0.01	$0.00	---	45
AAPL	$0.00	$0.01	$0.03	$0.00	---	47.5
AAPL	$0.00	$0.01	$0.02	$0.00	---	50
AAPL	$0.00	$0.01	$0.04	$0.00	---	55
AAPL	$0.00	$0.01	$0.02	$0.00	---	60
AAPL	$0.00	$0.01	$0.02	$0.00	---	65
AAPL	$0.00	$0.01	$0.02	$0.00	---	70
AAPL	$0.00	$0.01	$0.01	$0.00	---	75
AAPL	$0.00	$0.01	$0.01	$0.00	---	80
AAPL	$0.00	$0.01	$0.01	$0.00	---	82.5
AAPL	$0.00	$0.01	$0.01	$0.00	---	85
AAPL	$0.00	$0.01	$0.01	$0.00	---	87.5
AAPL	$0.00	$0.01	$0.01	$0.00	504	90
AAPL	$0.01	$0.02	$0.01	($0.01)	20	92.5
AAPL	$0.01	$0.02	$0.01	$0.00	---	95
AAPL	$0.01	$0.02	$0.02	$0.00	---	97.5
AAPL	$0.02	$0.03	$0.02	($0.01)	536	100
AAPL	$0.03	$0.04	$0.04	$0.01	45	105
AAPL	$0.05	$0.06	$0.05	($0.01)	142	110
AAPL	$0.08	$0.09	$0.09	($0.01)	177	115
AAPL	$0.13	$0.14	$0.14	($0.01)	4,907	120
AAPL	$0.27	$0.28	$0.27	($0.06)	1,359	125
AAPL	$0.80	$0.81	$0.81	($0.26)	8,854	130
AAPL	$2.46	$2.48	$2.46	($0.81)	14,452	135
AAPL	$5.75	$5.85	$5.80	($1.07)	140	140
AAPL	$10.15	$10.25	$10.26	($1.35)	40	145
AAPL	$15.05	$15.25	$16.52	$0.00	---	150
AAPL	$19.95	$20.30	$21.40	$0.04	4	155
AAPL	$24.85	$25.30	$0.00	$0.00	---	160
AAPL	$29.85	$30.30	$0.00	$0.00	---	165
AAPL	$34.85	$35.30	$0.00	$0.00	---	170
AAPL	$39.85	$40.30	$0.00	$0.00	---	175
AAPL	$44.85	$45.30	$0.00	$0.00	---	180
AAPL	$49.85	$50.30	$0.00	$0.00	---	185
AAPL	$54.85	$55.30	$0.00	$0.00	---	190

AAPL	$59.85	$60.30	$0.00	$0.00	---	195
AAPL	$64.85	$65.30	$0.00	$0.00	---	200
AAPL	$69.85	$70.30	$0.00	$0.00	---	205
AAPL	$74.85	$75.30	$0.00	$0.00	---	210
AAPL	$84.85	$85.30	$0.00	$0.00	---	220
AAPL	$94.85	$95.30	$0.00	$0.00	---	230
AAPL	$104.85	$105.30	$0.00	$0.00	---	240

The spreads for displayed options ranged from $0.01 to $0.50, with a mean of $0.282 and a median of $0.40. In contrast, Apple's stock at the same moment had a best bid price of $134.94 and a best ask price of $134.95, which displayed bid-ask spread of $0.01. The example here showed that Apple's options had much wider spreads than the spread of its stock on this randomly chosen date. The result can be generalized to options and stocks of other companies, because Apple's options have been one of the most liquid among all. Therefore, it is safe to conclude that the spreads for options are generally far larger than the spreads for stocks. Additionally, for the same company, the prices of options are always cheaper than (in most of the cases, much cheaper than) the price of the stock, so the percentage spreads of options are much larger compared to the percentage spreads of stocks, when the price levels of options and stocks are taken into account. Use the same example in Table A.1. The percentage spreads for those options with non-zero quote for Apple range from 0.40% to 66.67% with a median of 0.86% for calls, and range from 0.43% to 66.67% with a median of 1.28% for puts. On the contrary, given a best bid price of $134.94 and a best ask price of $134.95, the percentage spread for Apple's stock is only 0.0074%, which is significantly lower.