The Market Microstructure of Illiquid Option Markets and Interrelations with the Underlying Market[+]

Draft Version

04.2005

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Abstract:

Understanding and measuring determinants of bid-ask spreads is decisive to clarifying the efficiency of the microstructure of any exchange and general market liquidity. This paper examines the market microstructure of a low liquidity, market maker driven option market, the relations to the underlying securities' market and the challenges of pricing liquidity. Comparing empirical results with prior research we find support for the "derivative hedge theory", in which option percentage spreads are inversely related to the option market maker's ability to hedge his positions and this in proportion to associated costs. We take the approach that option market makers' costs represented by the bid-ask spread are determined from market activity and individual option characteristics. In a second step cross option market and underlying asset market characteristics are incorporated in the analysis.We model the bid-ask spread with order processing and delta hedging costs, inventory holding costs and competition. We find that the option bid-ask spread positively depends on delta hedging costs and the bid-ask spread of the underlying security. Adverse to prior research we observe that larger option trading volume significantly reduces realized option bid-ask spreads.

JEL Codes: C33, G13, G14, G24

Keywords: market microstructure, bid-ask spread, option liquidity, derivative hedge theory

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[+] I would like to thank Wiener Boerse AG for generous support and the provision of data. Comments by seminar participants at the Austrian Working Group on Banking and Finance and research seminars at the University of Vienna are gratefully acknowledged.

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I. Introduction

Illiquidity, broadly defined as the cost of immediate execution,[1] is a source of risk concerning financial market participants. Liquidity analysis can be classified as part of the general research field of asset market microstructure and has been a strand for intense investigations, especially in recent years. Substantial progress has been made towards capturing the driving forces and the cross sectional dynamics of different liquidity measures and their determinants. The availability of intraday and ultra high frequency data has helped to understand quote, price and transaction dynamics in international asset markets.[2]

Mostly researchers have focused on the microstructure of liquid stock markets. Lately, option market specific research has swelled with the drastic increase in derivative markets' volume and the availability of ultra high frequency data. Nevertheless, illiquid option markets have not been researched for the obvious reason of data scarcity. The Clearing Department of the Austrian Stock Exchange provided a 128 day sample with intraday option market and intraday stock market quote and transaction data, necessary for empirically testing the hypotheses of this paper. Our paper analyzes the quoted and realized bid-ask spread as liquidity measures and their dependence on other market microstructure and liquidity parameters. We test for microstructural dependencies between illiquid but exchange traded options and the underlying stocks. The implications of the underlying assets' market and characteristics for the liquidity of the derivative will be focused on. As both, the option and the underlying stock market studied for this paper show high variability in liquidity, it is assumed that interdependencies can be more easily detected than in homogenous, highly liquid markets that are capable of absorbing a large number of transactions and high volumes in trades easily.

The empirical analysis of this paper is intended to contribute to the existing literature on the price of liquidity on illiquid, market maker driven option exchanges. Combining our empirical results with the outcomes from earlier studies provides insight on how deep and efficient markets and market integration have to be to allow for fair pricing and quoting of options. The empirical study is based on multivariate cross-sectional panel data regressions. The linkage between the illiquid option market and the underlying stock characteristics with its market microstructure is modeled for different sub-samples. We concentrate on the links between quoted and transacted option bid-ask spreads, option contract attributes, cross option market characteristics and the underlying security and market characteristics. Our findings are consistent and stable throughout all sub-samples, the signs and magnitudes of the regression coefficients support the hypotheses made. Analyzing quoted bid-ask spread and transaction price behavior we find high significance for our assumptions. The completeness of our intraday dataset helps obtaining new insights in the analysis of the order and transaction process on illiquid, market maker driven exchanges. We are not aware of any academic studies that empirically research

[1] Amihud, Mendelson (1986), p.223.

[2] The term "ultra-high frequency data" was introduced by Engle (2000) and stands for a dataset that contains intraday transactions and the associated intraday quote evolution.

illiquid option markets based on the assumption made and with the same data intensity employed. Shedding light on the sources and the dependencies of liquidity contributes to comprehend the market microstructure and the efficiency of such markets. The paper differs from other studies in that it considers liquidity determinants that have not been incorporated so far. We define order processing and hedging costs, inventory holding costs and a competition component. Delta hedging costs are classified as the cost of transacting the total amount of stocks necessary to delta neutralize positions resulting from new trades. Knowing that there are interdependencies between option and underlying markets and that hedging open option positions in the underlying market is accompanied by costs, we are interested how market makers compensate for these costs. We calculate daily aggregate traded cross option market deltas for all option series written on the same underlying stock and assume a positive relation to the bid-ask spreads. Furthermore the bid-ask spreads of the underlying security are assumed to be positively related to the option bid-ask spreads.

The rest of this paper is organized as follows: Section 2 sketches the currently accepted liquidity concepts, section 3 reviews existing literature on the behaviour and components of bid-ask spreads. Section 4 gives details on the market structure of OTOB and contains the description of the OTOB dataset, section 5 presents the regression model employed and the results obtained. Finally section 6 concludes the analysis and gives a guideline for future research.

II. Conceptual Basics of Liquidity

Perfect liquidity and complete markets guarantee continuous trading, where market participants can immediately transact desired asset amounts at a price not different from the uninformed expected value, without affecting prices. In the past, researchers have developed different liquidity concepts, parameters and determinants to describe the functioning of order and transaction flow. The evolution and the interrelations among these measures have been an intense field of academic research in the past years. The multi dimensional nature of liquidity has first been pointed out by Grossmann and Miller (1982), Kyle (1985) and Amihud and Mendelson (1986). Traditional literature has established four generally accepted and broadly applied measures of liquidity – market width, market depth, immediacy or the speed of transaction and price resiliency. [3] It is important to understand these measures apart from each other and in a second step to realize and interpret their interrelations. The described proxies can be directly related to each other and have proven to show communality over time.

Price width is measured by the bid-ask spread and can be interpreted as an investor's cost and accordingly the market maker's revenue for an immediate round-trip trade of buying one unit and immediately selling one unit of a financial asset.[4] Market or orderbook depth refers to the number of shares that can be traded for a given quoted bid-ask spread. Depth can also be described as the size of the order flow required to change prices by a given amount. Immediacy measures to the time needed to execute a given

[3] Following Kyle (1985).
[4] Demsetz (1978).

transaction size for a given cost. The higher the transaction frequency and the deeper a market, the lower the cost of immediacy will be. Resiliency refers to how quickly prices recover to former bid-ask price levels after a change due to liquidity reasons. Kyle (1985) and Glosten and Harris (1988) specify resiliency as the speed with which prices recover from a random, uninformative shock.

More recently, liquidity has not only been studied as a single asset concept. Empirically, various measures of liquidity vary over time, both for individual assets and for the market as a whole. Researchers have highlighted that co-variation in liquidity implies co-movements in trading costs. Chordia, Roll and Subrahmanyam (2000) propose commonality in liquidity parameters and that individual stock transaction costs co-vary over time. They document significant common underlying influences on variations in liquidity for a sample of 1169 New York Stock Exchange (NYSE) listed stocks. The observation period is 254 trading days in 1992 wherein (proportional) quoted and effective bid-ask spreads, quoted market depth, transacted volume and the trading frequency co-move on an individual and market wide basis. Besides the standard deviation of the stock return (-), mean price level (-), dollar trading volume in the stock (+) and market wide trading volume (+) influence a decision of specialists to quote in the orderbook. Quoted and realized absolute bid-ask spreads of individual stocks depend on the price level (+), the number of transactions in the individual stock (+) and on the aggregate level of trading in the entire market (-). The authors rationalize that a decrease in inventory risk co-moves with market wide trading activity and liquidity but that asymmetric information itself has no common determinants between individual stocks.

In most security markets market makers provide liquidity for several different instruments. Coughenour and Saad (2004) find that stock liquidity co-moves with the liquidity of other stocks handled by the same market maker. In contrast, we assume that market makers' cost of hedging increases not with the volume of a single transaction but from the net delta exposure resulting from transactions across option series on the same underlying security. Hasbrouck and Seppi (2001) employ principal component and canonical correlation analysis and detect that the returns and order flows of the 30 stocks listed in the Dow Jones Industrial Average (DJI) are partly driven by common factors. Further they document a common factor in quote-based liquidity proxies. Time variation in the information component of liquidity seems to be largely firm specific. Common factors exist for signed and absolute order flow explaining part of the common variation in signed and absolute returns. Accordingly we study the existence of any common factors that govern the liquidity characteristics of individual option series. Besides the individual options market, we define the cross options market and the market of the underlying security as possible common determinants of liquidity for each individual series. We incorporate the underlying securities' bid-ask spread and the underlying price level in the regression analyses.

Turning to option market liquidity research, the literature is not so abundant. Only a few of the issues researched in stock markets have been investigated for equity options. Vijh (1990) analyzes the impact of information based trading on the liquidity of CBOE stock options and finds that the CBOE is a highly liquid market that absorbs large trade amounts without distorting prices. Stephan and Whaley (1990), Back (1993), Easley, O'Hara and Srinivas (1998) and Chakravarty, Gulen and Mayhew (2003) concentrate on asymmetric information and information transition between markets. They investigate the informational linkage between option markets and equity markets, focusing on the lead-lag relations of option and stock market volume and returns. Some of the authors analyze option and stock trading on a high-frequency basis but do not explicitly address the option transaction costs' dependence on the underlying market and security characteristics. The evidence on market interrelations concerning information transmission is questionable. So far, theory cannot give an unambiguous answer on information transmission between option and stock markets. The question remains if informed traders prefer to trade on option markets where they can gain higher exposure through leverage effects.

We argue that option bid-ask spreads as measure of liquidity cannot be explained by means of information asymmetry, but rather by market microstructure related characteristics and hedging costs. When opening a position, a risk avers market maker will always be concerned about the payoff characteristics of her position. Assuming uninformed risk avers market makers, they will fully hedge their exposure arising from their net option positions in each of the underlying securities' market. In this sense, the empirical analysis of our paper follows the concept of the "derivative hedge theory" introduced by Cho and Engle (1998). Risk-averse option dealers must dynamically hedge their outstanding option interest in the underlying securities market whenever the risk from open positions becomes too large. Delta hedging of portfolios has become especially important in regulatory frameworks as the Bank for International Settlements suggests a way of counterbalancing risk through a process of netting and offsetting in order to facilitate the banks' hedging activities. As first order price risks are eliminated through hedging, the market maker is assumed to be indifferent between trading with an informed or with an uninformed trader. The bid-ask will reflect costs caused by opening or closing an option position and the degree of market maker competition.

Options have a uniquely determinable price controlled by underlying security characteristics. At any point in time the input variables of the option pricing formula are exogenously given to the market maker. Implied volatility of the underlying security can be adjusted endogenously and fine tuned by market makers as they post their bid and ask quotes. Without loss of generality we can assume the mid price between the bid-ask quotes to be the fair value of an option.[5] Leland (1985) calculates the cost of imperfect, discrete hedging strategies and finds price bounds for European options. The optimal hedging strategy depends on transaction costs and the time period between portfolio revisions. Figlewski (1989) simulates the impact of discrete rebalancing, uncertain volatility and transactions costs for discretely hedging portfolios. He concludes that one can only obtain option prices with upper and lower bounds on the equilibrium level depending on transactions costs risk (+) and volatility exposure (+). Bensaid, Lesne, Pages and Scheinkman (1992) introduce the hedging concept of "super-replication", which dominates current methodologies. At a first glance the cost of the dominating

[5] To compute option prices and implied option sensitivities, we use the methodology proposed by Barone-Adesi and Whaley (1987). They propose a computationally efficient approximation for American calls and puts.

strategy appears to be higher than that of the traditional hedging strategy. As trading is costly, it may pay to weigh the benefits of super-replication against those of potential savings on transaction costs if one does not super-replicate. We follow these papers and assume the bid-ask prices to represent the price bounds for options, thereby implying that the bid-ask spread represents costs and risk associated with the market making of options.

III. Existing Literature on Bid-Ask Spread Components

The cross sectional relations of the bid-ask spread and their determinants have been a field of intense research in the past.[6] The precise constitution for different assets and market structures has not been fully revealed. The following section is intended to give a brief overview of identified cross sectional asset bid-ask spread determinants and follows Stoll (1978). We review fundamental equity market related research first and then turn to option market literature on bid-ask spreads. Traditionally spreads are assumed to compensate the market maker for three different costs: order processing costs, inventory holding costs and adverse selection costs. Furthermore, market maker competition and the regulatory exchange framework proved to be significant determinants for the bid-ask spread of stocks.

The first cost identified in the literature, is the ***order processing cost***. Fixed cost components and quote action associated costs such as installation costs, exchange seat commissions, labour costs, information provision costs or clearing commissions can be subsumed under order processing costs. Demsetz (1968) defined order processing costs as the sum of the buying premium and the selling concession linked to order execution and compares bid-ask spreads to the inventory mark-up of retailers or wholesalers. His analysis strongly indicates that bid-ask spreads depend on the intensity of trading activity measured as the logarithm of the number of individually recorded transactions (-) and the price of the transacted security (+). Higher transaction frequency reduces the fixed cost per transaction and the waiting costs. A higher asset price increases the variable trading volume dependent cost linearly as Demsetz assumes the per Dollar trading cost to be constant.

As second component we consider the ***inventory holding cost***. Some authors argue that market makers use the spread to compensate for unwanted positions. The relationship between stock bid-ask spreads and inventory costs has been studied among others by Tinic (1972), Amihud and Mendelson (1980) and Ho and Stoll (1981). Tinic defines inventory costs as a function of stock price (+), the average number of shares held per time unit (+) and the expected inventory holding time (+). Easley and O'Hara (1987) and Lin, Sanger and Booth (1995) suggest that large orders are more likely to create an inventory imbalance for market makers than small orders. Because of their role as liquidity suppliers, market makers are obliged to constantly post quotes and be ready to act as counterparts for trades at the quoted price and for the quoted volume. In order to provide investors with immediacy of execution, market makers must hold inventory positions in each security they cover. Firstly, holding inventory causes carrying cost equal to the return that could be yielded alternatively invested with the locked funds in,

[6] For a complete overview of empirical bid-ask spread analyses see Bollen (2003).

say, the money market. Secondly, each unhedged inventory position is exposed to negative price fluctuations. When market makers trade, their inventory position changes and they bear risk due to positions they have to hold differing from their desired target level. Opportunity costs of holding inventory in order to supply immediacy and expected losses from inventory positions away from the desired level justify the existence of bid-ask spreads even with zero order processing costs. Empirically, high volume equities imply less inventory risk for a market maker. As they are more frequently traded than equities with low trading volume, the expected holding period is shorter and therefore the inventory risk management becomes easier. Furthermore, restocking of the inventory is cheaper and easier to perform if the market is liquid in terms of traded volume.

The third cost component considered is the ***information asymmetry*** or ***adverse selection cost***. A lot of effort has been put in connecting and unifying the economics of information, rational expectations and competition. Early theory tries to explain the flow and the dissemination of information by studying price fluctuations, order flow innovation and other transaction related liquidity parameters. Theory differentiates between three types of agents active on asset markets: noise traders, informed traders and market makers. Noise traders trade for liquidity reasons, in order to rebalance their portfolio or they just trade randomly according to their private beliefs.[7] They have common knowledge and information sets containing public information only. The second group of market participants is composed of risk neutral, informed traders or insiders who have unique access to private, undisclosed information. Finally, market makers provide immediacy and trade with some superior knowledge of the order flow.

The basic idea, which was first developed by Bagehot (1971)[8], reasons that market makers will always lose to the informed traders with superior knowledge when fulfilling their duties. Rational market makers recover their losses with gains from widened bid-ask spreads they can extract from transactions with uninformed noise traders. The relationship between information asymmetry and the bid-ask spread has been the object of numerous theoretical studies, e.g. by Kyle (1985), Amihud and Mendelson (1986), Glosten and Milgrom (1985), Easley and O'Hara (1987), Glosten and Harris (1987) and Admati and Pfleiderer (1988). They suggest that expected asset returns are an increasing and concave function of the bid-ask spread and that prices and further bid-ask spreads are affected by private information in the order flow. Additionally adverse selection and inventory risk increase with the size of incoming orders. Large orders are more likely to create an inventory imbalance for market makers than small orders. They further assume that traders with superior information are likely to exploit any mispricing by placing large orders.[9] Market-wide changes in liquidity could closely precede informational events such as corporate earnings and macroeconomic news as there are informed traders or so called insiders. George et al. (1991) analyse 23 years of NYSE stock data and 5 years of NASDAQ end of day quote and transaction data. They find that reported adverse selection bid-ask spread components of over 40 percent are biased as the estimation procedures employed do not incorporate the variation in expected returns. Their estimation indicates adverse selection components of 8 to 13 percent of the bid-ask

[7] Kyle (1985)
[8] The author's name was Jack Treynor and he used the pseudonym Bagehot.
[9] Glosten and Harris (1988).

spread and no evidence on inventory holding costs. The authors conclude that order processing costs seem to be the dominant component of equity bid-ask spreads.

Competition has been introduced to the field of market microstructure by Demsetz (1969) and Tinic (1972). Intuitively we expect lower bid-ask spreads and trading costs when competition among market makers increases. In a perfect competition framework, the bid-ask spread is reduced to the marginal cost of providing liquidity and all profit opportunities for market makers disappear. Whereas Demsetz simply uses the number of exchanges on which a stock is listed, Tinic is the first to apply the Herfindahl Index of concentration to market microstructure research. The index measures not only the number of markets but also the overall size and distribution of trading activity across those markets. Tinic concludes that diseconomies of reduced specialisation resulting from engaging in multi-security market making may overwhelm associated economies of scale. Neal (1987) was the first to study the effects of multiple option listed on option bid-ask spreads. He concludes that multiple listed options have narrower spreads than options list on a single exchange.

Another generally accepted bid-ask spread determinant is the *market microstructure* of an exchange itself, including the relation between the price formation, the trading protocols, quote rules and market wide transparency. Researchers often end up with different results when testing NYSE and NASDAQ data for example. This is due to the different market structure and different rules governing the exchange. Neal (1987) studies the bid-ask spread difference of equity options in two separate market structures. The study emphasizes the theory of potential and not actual competition and provides empirical support for the theory of contestable markets. He finds that the specialist structure (AMEX) is more efficient than the competitive market maker structure (CBOE) when trading volume is low and equally good when trading volume rises. Grossmann and Miller (1988) discuss the relation of the cost of immediacy and market microstructure and develop a theoretical model capturing variable demand and supply for immediacy and the role of market makers in supplying immediacy. Chung and Van Ness (2001) find that the NASDAQ tick-size reduction in January 1997 led to a significant decline in spreads. The magnitude of the decline shows stable intraday-variation. The authors also find a significant decrease in quoted depths after the tick-size reduction and that the magnitude of the decline is smallest during the first hour of trading.

George and Longstaff (1993) investigate the cross sectional distribution of option bid-ask spreads for S&P index options and find significant relations with trading volume (+), option time to maturity (+) and squared delta (-). Mayhew (2002) performs matched pair sample analysis to research competition, market structure and bid-ask spreads in US stock option markets. He analyzes Chicago Board of Exchange (CBOE) intraday quote and transaction data for all stock options listed in the period from January 1986 to August 1997. He finds non-linear relations between bid-ask spreads and option price (+), traded contract volume (-) and traded volume of all contracts written on the same underlying (-). After controlling for these factors, the underlying volatility does not prove to be a significant determinant of option bid-ask spreads. Mayhew reports that competition expressed as multiple-listing incorporates narrower quoted and effective spreads compared to single-listed options. He finds that, after accounting for the other factors influencing spreads, a Designated Primary Marketmaker (DPM) structure performs better for low liquid options and the traditional open outcry crowd or trading pit appears to result in smaller bid-ask spreads for high volume options.[10] This shows the importance of the market micro structure and its regulatory framework for providing liquidity and guaranteeing low cost and immediate execution.

Cho and Engle (1999) study S&P 100 index call options traded at the CBOE under an open outcry auction amongst competitive market makers. The intra-day quote and transaction dataset is a rather small sample size and covers the month of May 1993. In order to address the relation between option and underlying asset market, they propose a bid-ask model called "derivative hedge theory". Asymmetric information costs are immediately passed to the other market by market maker hedging activities and become irrelevant. In this framework option liquidity becomes a function including the underlying market liquidity. Market makers' costs reflected in the option bid-ask spread include the cost of inventory risk arising from different exposures and the cost of guaranteeing liquidity. Bid-ask spreads depend on the relationship with the order processing costs (+), the hedging costs (+) and the competition (-) of the market maker. Volatility and delta hedge ratios are used to measure the relation between options and the underlying markets. Interestingly, option market volume is not significant in determining observed bid-ask spreads. This finding casts doubt on the assumption that trading volume is an appropriate liquidity measure for option contracts. In the empirical analysis of this paper we follow the thrust of the derivative hedge theory. As the specialist and market maker driven option market under analysis can be classified as illiquid, contract and underlying specific differences in hedging related costs should be more visible than on highly efficient and liquid markets.[11]

IV. Market Microstructure and Data Description

The Austrian Stock Exchange, Wiener Boerse AG, is one of the oldest stock exchanges in Europe and was founded in 1771. Stocks were first traded in 1818. It is segmented in 5 market subdivisions, namely the equity, the bond, the option and futures trading platform OTOB, the warrant and the other listings market. The equity market is split into prime and standard market, the OTOB market is divided into Austrian stock and index options and futures and also CECE[12] options and futures markets. As this paper studies the interrelations of the OTOB stock options and underlying equities listed in the

[10] Prior to 1987 the CBOE employed an "open outcry auction" market structure. It resembles the trading mechanism employed in futures pits where the incoming orders are exposed to the public trading crowd. In the Designated Primary Market Maker (DPM) structure a trader, responsible for maintaining a two-sided market, is necessary for each listed instrument. The DPM, which was introduced at CBOE in 1987, is similar to the specialist system used on the American Stock Exchange (AMEX). The specialist is responsible for the provision of liquidity by trading on his own account and constantly posting bid-ask quotes. He therefore is ascertained a prespecified percentage of the public order flow. As other market makers may also post quotes, the DPM resembles an open outcry structure when volume is high and the market is liquid.

[11] As the underlying is highly liquid Deutsche Bank trades index options with standardized spreads of 2 cents per contract for example. Data from highly liquid markets does not provide the same amount of heterogeneity as illiquid markets.

[12] CECE derivatives comprise options and futures on Central European indices, namely the Czech, Hungarian , Polish and Russian traded indices.

prime equity market, the other segments of the Wiener Boerse AG will not be discussed in more detail.

The OTOB orderbook is open to all market participants throughout the trading phase from 9:00 AM to 5:30 PM. The equity market trading hours are 8:30 AM until 5:30 PM. The analysis of this paper does not incorporate pre- and post-trade phases, as there is very little quote action recorded and no transactions can take place in these intervals. Trading on OTOB is performed via specialists and competitive market makers who electronically enter limit orders and stand ready to trade at the resulting bid and ask quotes. Whereas Vienna Stock Exchange employs the XETRA trading system for the equity market, the trading and clearing platform used at the OTOB is the Swedish OMex trading system with a continuous trading procedure for all instruments.

Three types of orders are possible: limit, market and combination orders. Both trading systems employ a fully computerised trading process that immediately checks received orders for the possibility of immediate execution. The execution of orders takes place according to price and time priority. As the orderbook is open throughout the trading phase, all trading participants have a view of the order situation ranked by price and time priority. A specialist who constantly enters firm buy and sell orders is required for each cross-options market of the underlying ATX stocks. Market makers bridge the time gaps between the market arrivals of buyers and sellers and absorb transitory excess demand or supply with their inventory positions. They are compensated by earning the bid-ask spread, which is competitively set by market participants who enter their quotes. Market participants other than the specialist and the market makers can only enter limit or market orders or combination orders but no quotes. Our results shows that market makers at OTOB quote large spreads and that realized spreads lie inside the bid and the ask quote. Each dealer trades with his customers on his own dealer account or forwards the order to another market maker or to the specialist who fills the order at the best price quote.

OTOB offers options for 18 different ATX prime market stocks. The contract size is 50 stocks and contracts are valued in EURO cents. The minimum tick-size or price increment is 1 Cent for options worth less than 5 Euros, 10 cents from 5.10 Euro to 10 Euro and 50 Cent for all options that cost more than that. Tick size should not play an important role in the ongoing discussion as illiquid options are characterized by large spreads. Observed bid-ask spreads should therefore not be biased by the relatively small tick-size. Options have monthly expiry intervals and at each point in time at least contracts with maturity on the next expiry date, the next but one, the next but two and on the next quarterly possible expiry date are available. As efficient option trading requires the constant availability of strike prices close to the price of the underlying, new option series are issued on monthly basis.

The strike prices are checked against the closing prices of the underlying securities. If the difference exceeds a quarterly adjusted percentage of the underlying securities' price, Wiener Börse issues new option series with adjusted strike prices.[13] For the 18 underlyings, Wiener Börse ensures the availability of at least five strike prices for every expiry date for puts and calls - two in- and two out-of-the-money options and one at-the-money option. If the at-the-money strike price cannot be determined precisely two at-the-

[13] 2%, 2.5% or 3%. of the underlying 's price with continous adjustments if the price of the underlying differs 15% from the last adjustment's reference price.

money option are issued for each expiry date. Once an options series has been introduced, it runs until the regular maturity date and continues to be available in the trading system even if the value of the underlying has already taken another direction or if there have been no trades in it. OTOB regulates the maximum spread for options written on the same underlying in a similar way. The new maximum option bid-ask spread is calculated on the basis of the underlying price each month.[14]

This study considers 2 liquidity measures as independent variables – quoted and realized bid-ask spreads. We analyze intraday orderbook and transaction data for all options and all underlying securities listed in the 128 trading days time span from 02.06.2003 until 01.12.2003. All stock options listed on 18 prime equity market listed stocks are included.[15] As OTOB constantly issues new options with different strike price and maturity, we have a sample pool with recorded quotes of 1908 different instruments, 8757 trades with a volume of 692,500 contracts and a option premium turnover of 32.9 million Euro.[16] As 914 series have been traded, in contrast to 896 instruments with no trade and due to the low market wide volume, the option market can definitely be characterized as illiquid. In the same period stocks traded for a total value of 4,983 million Euros. Figure 1 shows the aggregate distribution of trading volume across all option contracts from the sample. About half of the option series have no trades at all, the majority of transactions is of low volume compared to a couple of trades with large volumes.

A database with the intraday evolution of quoted orderbook depth, orderbook volume, quoted prices and resulting bid-ask spreads is constructed for options as well as for the underlying securities. Equally-weighted averages of the parameters are calculated and the two databases are matched. The trade data contains all transactions in the observation period with the exact transaction price, transaction time and the individual arrival timestamps for the two matched orders. The records show if the transaction caused opening or closing position and finally which of the orders was a buy and which order was a sell order. Additionally, information on the open interest of each option series and day is incorporated in the analysis. We calculate realized spreads and match them with liquidity variables from the orderbook and the underlying security intraday data.

In order to minimize measurement errors and to ensure data quality and avoid biased results due to outliers we apply the following data filters: Quotes are dropped, if either the ask price or the bid price is less than or equal to zero. Quotes with a percentage spread greater than 100 % of the mid price or less than zero are omitted. All trades with transaction price or volume smaller than or equal to zero are deleted. If we can not determine double sided bid-ask price different from zero or the same day at least 5 seconds prior to the transaction, the transaction is dropped as the reference option mid price can not be calculated. Trades and quotes recorded before the market open and after the close are also neglected.

[14] For underlyings with bid-ask spreads of 1% (2%) (3% and more) the absolute option spread is limited to 2% (2.5%) (3%) of the underlying reference price with continous adjustment if the price of the underlying differs 15% from the last adjustment’s reference price.

[15] No stock splits occurred during the observation period. Bank Austria Credit Anstalt AG was listed 09.07.2003.

[16] OTOB double counts each trade as buyer and seller transaction and would end up with 17,514 trades for that period and an option premium value of 66 million Euro.

V. Empirical Analysis

The following section sums up the empirical analysis performed with the data described in the previous section. First we describe the variables and the model used in the regression. Second we give descriptive statistics of the quoted spread, the realized spread and all the explanatory variables. Finally, we interpret the empirical results from the regression equations and compare them with previous findings.

A. Variable and Model Description

Most past research has utilized the quoted spread at the end of the trading day as the variable of interest but not only recent literature shows that liquidity measures systematically vary over the trading day. Numerous studies examine the observed intraday patterns in spreads, volumes, and volatility over the trading day and across trading days and markets. Variation in the bid-ask spread of NYSE-listed stocks and the way how market makers exploit their market power in setting bid-ask spreads have been modeled by Admati and Pfleiderer (1988) and McInish and Wood (1992). Brock and Kleidon (1992) and more recently Chung and van Ness (2001) empirically test these assumptions with NYSE data. The authors conclude that the spread is widest at the beginning of the trading day, narrows during the day and finally increases near the end of the trading day. The movement follows a typical U-shaped intra-day pattern. McInish and Wood (1992) are the first to analyze the bid-ask spread at an intraday frequency. Their sample consists of 6 month of intraday quote data of calendar year 1989. They isolate intra day time dependency of the bid-ask spread from other factors and describe the found pattern as a crude J-shaped one. Chan, Christie and Schultz (1995) find reversed J-shaped patterns for the bid-ask spreads of NASDAQ stocks. The variation in the patterns found can be attributed to the differing market microstructure of specialist (NYSE) and dealer markets (NASDAQ).

Significant intraday variation in liquidity parameters is also found for the OTOB market. Therefore we calculate equally weighted averages of the liquidity variables' evolution throughout the trading day instead of analyzing end of day observations. This approach allows for a more realistic estimation of the size and components of the quoted bid-ask spread than using end of day observations.

For each option series with more than 5 quote records on day *T*, we calculate the equally weighted, quoted bid-ask spread (QSPR) as

$$QSPR_{T,i} = \frac{\sum_{x=1}^{X} \left(A_x - B_x\right)}{X} \quad , \qquad (1)$$

where A_x and B_x represent the ask and the bid price of the x 'th orderbook observation of series i during the trading day T with a total amount of $X > 5$ daily bid-ask quote changes.

For computing realized spreads we have to sample the transaction data and match it with intraday quotes. Realized spreads may differ strongly within different calculation methods. The problem is to determine which midpoint should be used as reference price compared to the transaction price. As bid and ask prices contract prior a trade, one may get biased results when using the quote initially before the trade. Bessembinder (2003) compares transaction prices to earlier quotations and finds that the percentage of trades that appear to be executed within the quotes decreases monotonically. Whereas the average movement in quote midpoints is 0.44 cents during the 30 seconds prior to the trade report on NYSE, quote midpoints move away from the trade price by an average 1.51 cents on NASDAQ for the same time horizon. Werner (2002) finds that prices move significantly in the direction of the trades before execution. These results show that assumptions as to whether trade price determines the transaction initiation differ systematically. Lee and Ready (1991) recommend to use the last quote recorded at least 5-seconds prior to the trade. Especially with market makers who execute or pass on the orders of their customers, comparing trade prices to preceding quotes might be appropriate to capture any systematic pre-trade price impacts.

For all recorded transactions, we calculate the realized spread (RSPR) as

$$RSPR_{t,j} = 2\left|P_{t,j} - MID_{(t-5\sec),i}\right| \tag{2}$$

with $$MID_{(t-5\sec),i} = \left(\frac{A_{(t-5\sec),i} + B_{(t-5\sec),i}}{2}\right) \tag{3}$$

for transaction *j* recorded at time *t* with *bid-ask mid point (MID)* prevailing at time *(t - 5sec)*. The mid price is assumed to equal the fair value of the option series *i* associated with transaction *j*. $A_{(t-5sec),i}$ and $B_{(t-5sec),i}$ represent bid and ask quotes of the traded option series *i* prevailing at least 5 seconds prior to the reported trade time *t*. $P_{t,j}$ is equal to the realized transaction price. In the remainder, the subscript *j* is used for realized spreads and subscript *i* for the quoted spread

There are two widely accepted techniques for categorizing trades as buyer or seller-initiated. Lee and Ready (1991) assign trades completed at prices above (below) the preceding quote midpoint between bid-ask quote as customer buys (sells). Trades executed at the quote midpoint are classified according to a tick-test. Trades at a price higher (lower) than the mid quote of the most recent trade at a different price are classified as buys (sells). Ellis, Michaely and O'Hara (2000) propose assigning trades executed at the ask (bid) quote as customer buys (sells), while using the tick-test for all other trades. Transactions at the mid quote of the last transaction are compared with the last realized transaction price. We follow the Lee and Ready methodology and compare all transaction prices with the prevailing mid quote. As transaction frequency in the analyzed, illiquid option market is so low we exclude transactions occurring at the prevailing mid quote implying a zero spread. There are not enough trade records of individual option series in order to employ the proposed test according to Easley, Michaely and O'Hara.

We can now specify the regression equation for explaining the quoted and realized bid-ask spread [17] with

$$QSPR_{T,i} = f\left(OPDHC_{T,i}, IHC_{T,i}, COMP_{T,i}\right) \quad (4)$$

$$RSPR_{t,j} = f\left(OPDHC_{(t-5\text{sec}),j}, IHC_{(t-5\text{sec}),j}, COMP_{(t-5\text{sec}),j}\right) \quad (5)$$

The explanatory variables for the quoted spread of option series i on day T and for the realized spread for transaction j at time t with option series i are grouped into three bid-ask spread component classes: Order processing and delta hedging costs *(OPDHC)*, inventory holding costs *(IHC)* and competition *(COMP)*. The analysis of the quoted bid-ask spreads is performed with equally-weighted daily average values of all variables included in the regression equation. Except for the number of daily trades and the cross market delta, intraday values 5 seconds prior to the trade are used as explanatory variables in the realized spread regression. To avoid confusion we employ the notation for the quoted spread and utilize daily average values in the equation specification in the ongoing description.

Order processing and delta hedging costs (OPDHC) are composed of the delta hedging costs *(DHC)*, the underlying securities' bid-ask spread *(UBAS)*, the cross option trading volume *(COTV)* and the cross market delta *(CMD)*. The delta hedging costs are calculated as

$$DHC_{T,i} = \left|delta_{T,i}\right| \cdot S_{T,k} \cdot contracts \quad (6)$$

where $delta_{T,i}$ represents the option's hedge ratio and is explained in equation (9). $S_{T,k}$ denotes the average price of the underlying stock k at day T and *contracts* represents the transaction contract volume of a trade and takes the value 1 for the quoted spread regressions. DHC equals the total volume that needs to be traded in the underlying stock in order to immediately neutralize the open delta position resulting from an option trade. The higher the necessary hedging volume, the higher are the associated per contract costs and the option bid-ask spread, respectively.

A higher *underlying bid-ask spread (UBAS)* is associated with a higher option bid-ask spread. A large bid-ask spread of the underlying security result in higher hedging and re-hedging costs for the market maker and should therefore be directly reflected in the option spread. A positive relation between option bid-ask spreads with the DHC and the underlying bid-ask spread is assumed for the obvious reason that market makers' costs of hedging are directly passed on to the counterpart of the transaction.

The *daily cross option trading volume (COTV)* measures the daily number of traded contracts in the cross option market of all options written on the same underlying security. No differentiation is made between buyer and seller initiation.[18] On OTOB market makers and specialists do not cover single option series but the cross option market of each individual underlying security. Adverse selection theory would argue that

[17] The full model description, the three spread component categories, their constituents' variable definitions and the expected signs for the regression are presented in Table 1.
[18] As there are some days without trades we add 1 to the COD before taking logs.

high trading volume in the cross-option market of the same underlying is associated with higher information risk and higher bid-ask spreads. We argue that the fixed cost component of option transactions decreases with higher volume in cross option markets and economies of scale facilitate to provide immediacy for a fair price. Therefore, we expect a negative sign for the regression coefficient of the cross option trading volume. COTV is only incorporated in the realized spread regression as the correlation with the COD is 0.95 in the quoted spread sample.[19]

The aggregate traded option delta across all option series written on the same underlying security is the *cross option delta (COD)*

$$COD_{T,k} = \sum_{j=1}^{j} delta_{t,i} \cdot TV_{t,j} \cdot dummy_{buyer/seller} \qquad (7)$$

for day T with j trades occurring at time t, aggregated across all option series written on underlying k with a transaction volume of TV. The variable $delta_{t,i}$ represents the option hedge ratio as defind in equation (9). The variable $dummy_{buyer/seller}$ takes the value of 1 for buyer-initiated trades and -1 for seller-initiated transactions. It is of high importance to take into account that buyer-initiated transactions on calls (puts) result in a positive (negative) delta exposure for the market maker, whereas sales result in a negative (positive) delta exposure in the underlying stock. Mayhew (2002) reports that higher trading volume in the cross option market implies lower spreads for individual series. He argues that an incoming order can be hedged with orders from other traded options on the same underlying. We incorporate COTV in the order processing and delta hedging costs and argue that fixed cost components decrease with higher COTV.

The COD is interpreted in the same way as Mayhew interprets the volume across options on the same underlying security. Whereas Mayhew distinguishes neither type of transactions nor option types, this method of COD construction is a more precise measure for the inventory imbalance and the hedging demand prevailing in the market. The more trades offset each other on individual option and cross option basis, the lower the aggregate hedging demand and inventory risk for all market makers. With a zero net COD, market makers face less risk due to movements in the stock price except for the re-hedging costs that are measured by the gamma. The higher the absolute COD, the higher we assume the option bid-ask spread to be, as more hedging is necessary on an aggregate level.

The COD measure could also be interpreted as an adverse selection measure in a traditional sense. Aggregate delta of options written on the same underlying asset rather than volume of individual option series could be interpreted as an information signal. High positive (negative) aggregate delta could be interpreted with positive (negative) information and future asset price movements. In the regression equations we take the log of the COTV and COD as a non-linear relationship with the bid-ask spread is assumed.

[19] See Table 3.

We can now formulate the *order processing and delta hedging costs* OPDHC as

$$OPDHC = \beta_1 \cdot \log(DHC+1) + \beta_2 \cdot UBAS + \beta_3 \cdot \log(COTV+1) + \beta_4 \cdot \log(COD+1) \quad (8)$$

The *inventory holding costs (IHC)* depend on the option mid price and the hedging risks are represented by the option Greeks. The option mid price (MID) is calculated as the bid-ask mid point as described in equation (3). Given prior literature, we expect it to be the most important control variable when estimating the bid-ask spread. The positive relation between asset price and bid-ask spread has been documented in various studies. Demsetz (1968) argues that the bid-ask spread per share will tend to increase in proportion to an increase in the price per share so as to equalize the cost per dollar exchanged. Nevertheless it is surprising to find that a linear fit results in a better model, whereas most empirical studies report that spreads depend on the logarithm of the asset price.

Option values are sensitive to a move in the price of the underlying security, a move in the hedge ratio, a move in the volatility of the underlying security and a time move with all other price determinants being fixed. As we not aware of any analytic closed form solution for American option prices and sensitivities, we employ a discrete linear approximation of the option sensitivities defined as

$$delta_{T,i} = \frac{optionvalue(S_{T,i} + \Delta S) - optionvalue(S_{T,i} - \Delta S)}{(2 \cdot \Delta S)} \quad (9)$$

$$gamma_{T,i} = \frac{delta_{T,i}(S_{T,i} + \Delta S) - delta_{T,i}(S_{T,i} - \Delta S)}{(2 \cdot \Delta S)} \quad (10)$$

$$theta_{T,i} = \frac{optionvalue(T + \Delta T) - optionvalue(T + \Delta T)}{(2 \cdot \Delta T)} \quad (11)$$

$$vega_{T,i} = \frac{optionvalue(\sigma_{T,i} + \Delta\sigma) - optionvalue(\sigma_{T,i} + \Delta\sigma)}{(2 \cdot \Delta\sigma)} \quad (12)$$

where S represents the underlying stock price, T stands for the time to maturity and σ is the implied volatility of option series i. The simulated discrete stock price step ΔS equals a 0.1% price move, Δt represents a 1 day step in the time to maturity and $\Delta\sigma$ is associated with a 1 % change in the implied volatility, leaving all other variables of the calculation formula constant. Higher inventory and hedging costs and increased risk create costs for market makers. We expect all inventory holding cost parameters in the regression equations to have a positive sign except theta which should have a negative one. Options with large time decay are assumed to have higher spreads and we expect a negative sign for the estimated parameter theta. The complete specification of IHC is given as

$$IHC_{T,i} = \beta_5 \cdot MID + \beta_6 \cdot gamma_{T,i} + \beta_7 \cdot theta_{T,i} + \beta_8 \cdot vega_{T,i}\,. \quad (13)$$

Competition (COMP) is measured as aggregate orderbook bid-ask quote depth (OD). The number of orders on the bid and the number of orders on the ask side of the option orderbook are summed up and prove to be more significant for explaining the bid-ask spread than regressing the total contract volume of these orders. We expect increased market maker competition measured as increased orderbook depth to result in lower quoted and transacted spreads as the spread will be driven to the cost of making the market and providing liquidity to investors. Therefore, the sign of the competition coefficient in the regression equation is expected to be negative and highly significant for all sub-samples of the analysis.

We are now ready to formulate the complete specifications for the quoted and realized bid-ask spread regression equations as

$$\begin{aligned} QSPR_{T,i} &= \beta_1 \cdot \log(DHC_{T,i}+1) + \beta_2 \cdot UBAS_{T,k} + \beta_3 \cdot \log(COD_{T,i}+1) \\ &+ \beta_5 \cdot MID_{T,i} + \beta_6 \cdot gamma_{T,i} + \beta_7 \cdot theta_{T,i} + \beta_8 \cdot vega_{T,i} + \beta_9 \cdot OBD_{T,i} + \varepsilon_{T,i} \end{aligned} \quad (14)$$

$$\begin{aligned} RSPR_{t,j} &= \beta_1 \cdot \log(DHC_{t,j}+1) + \beta_2 \cdot UBAS_{t,j} + \beta_3 \cdot \log(COTV_{t,j}) + \beta_4 \cdot \log(COD_{t,j}+1) \\ &+ \beta_5 \cdot MID_{t,j} + \beta_6 \cdot gamma_{t,j} + \beta_7 \cdot theta_{t,j} + \beta_8 \cdot vega_{t,j} + \beta_9 \cdot OBD_{t,j} + \varepsilon_{t,j} \end{aligned} \quad (15)$$

We perform stepwise regression analyses to obtain least square error estimates for the coefficients $\beta_{1,\dots,9}$ for the quoted and the realized bid-ask spread. We run the regressions on the complete quoted and realized spread samples and then perform the same analysis for put, call, buyer and seller-initiated trade sub-samples. We distinguish regression equations I, II and III as defined in Table 1. As we find a non-linear relationship between the bid-ask spread and the DHC, the COTV and the COD, the logarithm of these variables is regressed. The next section presents descriptive statistics and section C reports the results of the stepwise regression analyses.

B. Descriptive Statistics

Table 2 gives summary descriptive statistics for the dataset resulting from the collection, ordering and filtering procedure described above. After the filtering and data cleaning process, we end up with 7,766 intraday realized transaction bid-ask and 31,714 equally-weighted, daily, quoted bid-ask spread observations. The quoted bid-ask spread sample represents the potential option supply whereas the realized spread sample represents the actual option demand.

We find that average observed quoted bid-ask spreads are larger than average realized spreads. Firstly the samples of the quoted and the realized spreads differ with respect to individual option characteristics and underlying securities. As mentioned before, OTOB issues new option series on a monthly basis and also whenever the underlying stock moves too far from option strike prices. Therefore, the distribution of underlyings from the quoted spread observation is different from the transaction observations. The average UBAS matched with the transactions is about 25% smaller than the UBAS associated with quoted option bid-ask spreads. Secondly we see that 74.63% of all trades are executed at the bid-ask quote, 23.67% inside the quote and a mere 1.97% of trades are transacted outside the quoted bid-ask spread. [20] As the average price of transacted options amounts to just about 70% of the average quoted option price, we draw the conclusion that investors prefer to trade cheap options with relatively small absolute bid-ask spreads.

The average hedging sensitivities of the quoted and the realized spread, gamma, vega and theta, are of similar size for the two panels. We can infer that the average characteristics of transacted options resemble the average characteristics of all listed options. The average time to maturity equals 45 days for transacted versus 39 days for the listed options. Hence, investors prefer to trade options with longer time to maturity in order to give their investments more time to pay off. The average orderbook depth of observed quotes equals 75% of the orderbook depth observed with option transactions. This points out that the QSPR sample contains options that are weakly covered by the market makers.

Table 3 shows the cross-correlations of the independent and the explanatory variables used in the regression equations (14) and (15). The first line reports the correlation for the transaction sample containing 7766 observations and the second line refers to the quoted spread option sample with 31726 observations. The first column shows the correlations of the bid-ask spread with the regressors, the other columns exhibit the cross correlations among the regressors. Realized spreads and quoted spreads have correlation coefficients of 0.51 and 0.75 with the option MID price. This verifies our assumption that the option price is the driving determinant of the quoted as well as the realized bid-ask spreads. Furthermore, option sensitivity to changes in implied volatility shows high positive correlation with the bid-ask spread. It should be mentioned that the correlation of the quoted bid-ask spread and *log(COTV+1)* and *log(COD+1)*, amounting -0.04 and -0.01, are very small compared to the correlations with the realized spread, -0.28 and -0.16. This is due to the illiquid nature of many of the listed options that are not traded at all. The underlying bid-ask spread correlates significantly with the realized bid-ask spread and the quoted option bid-ask spread exhibiting coefficients of 0.42 and 0.44. To avoid any concerns about multi-colinearity, all regressors with correlations of more than 0.8 are eliminated from the analysis. Since it is highly correlated with log(COTV+1), we exclude the log(COD+1) from the quoted spread regression equation. For the other explanatory variables used in the regression equations the correlations are well below generally accepted thresholds.

C. Empirical Results

The empirical analysis underpins the notion that option market liquidity not only depends on the market microstructure and trading activity in individual option series' markets but also on the cross option and the underlying securities' market characteristics. Stepwise regression analyses for the quoted and the realized bid-ask spread reveal important implications about the magnitude, stability and the significance of the parameters in the regression equations calculated. Regression equation I includes the OPDHC, equation II additionally incorporates the IHC and the full model specification

[20] Bollen et al. (2004) find that a large number of NASDAQ stock transactions are executed within the quoted bid-ask quotes. Volume weighted effective spreads as a proportion of equally weighted quoted spreads is 67% in 1996 and 1998 and 72% in 2001.

III adds the competition component to the regression analysis. We explore the complete sample of quoted and realized spreads, quoted put and call bid-ask spreads, realized put and call and finally realized buyer-initiated and seller-initiated trades' option bid-ask spreads.

The results of the regression equations of the complete quoted and realized bid-ask spread samples are presented in Table 4. As mentioned before, the COTV is not incorporated in the quoted spread sample as the correlation with the COD is too large and might cause multi-collinearity problems. Regression equation I shows similar explanatory power measured by the R^2 close to 0.25 for both complete samples. Adding the IHC to the model specification increases the R^2 to 0.659 for the QSPR estimation. The explanatory power of the RSPR estimation increases to not more than 0.377. Regression III incorporates the competition component of the spread and we find that adding the OBD to the regression equation increases the explanatory power of the regression by 4% for the quoted and 2% for the realized spread estimation to 0.7 and 0.4 respectively. Concurring with our expectations we find that quoted spreads show higher stability and regularity than the realized spreads and that we can explain more of their variance than for realized spreads. This can be attributed to the fact that the realized spreads are measured as intraday-observations and that quoted spreads are constructed by calculating equally-weighted daily averages. In the previous section we have discussed concerns and inaccuracies that can be related to lower accuracy of realized spread estimations. Looking at equation I, we see that OPDHC explain 25% of the QSPR versus 22% of the RSPR variation. For the QSPR this accounts for 36% of the total explanatory power whereas it accounts for 55% of the total explanatory power of the RSPR estimation. The model captures market makers' different bid-ask spread setting behavior between quoting and transacting different option series. Quoted spreads can be better explained by the option characteristics that are incorporated in the IHC whereas the OPDHC are more important for determining the realized spreads. We now turn to the statistical and economical significance of the individual parameter estimates of the two regression samples.

As expected the DHC are significantly positive in all regression specifications and for both samples. We can infer from the correlations depicted in Table 2 that log(DHC+1) are more than 50% larger for the realized spread, as the realized DHC incorporates the total contract volume of each trade whereas the DHC for the quoted spread assumes a transaction volume of 1. Therefore, the estimated parameter for the DHC impact is larger for the QSPR estimation than for the RSPR estimation.

The parameter estimates for the UBAS are of similar size for quoted and realized spread samples and have a statistically significant positive impact on the option bid-ask spread for all regression equations. The higher the associated UBAS, the higher the option bid-ask spread. Nevertheless, we find that the impact of the UBAS is not 1, as we would ideally expect. This can be explained by the fact that we do not multiply the UBAS with the option delta and therefore underestimate the direct impact of the UBAS on option bid-ask spreads. Adding the IHC in the regression specification II reduces the UBAS parameter significantly due to the positive correlation between the UBAS, MID and vega. Finally it should be mentioned that the UBAS parameter is more stable across specifications for the RSPR sample than for the QSPR sample.

The coefficient for the COTV is significantly negative in the RSPR sample for all stepwise regression specifications. From a market maker's point of view, higher contract trading volume in the cross option market reduces the fixed cost component per contract and increases the probability that the exposure resulting from a transaction may be offset with other transactions in the cross option market. Therefore we associate lower bid-ask spreads with high COTV. This result is counterintuitive to traditional stock market analyses that focus on adverse selection and associate higher bid-ask spreads with high trading volumes. In that setting, higher COTV would be interpreted as information signal. Our results do not follow that notion. Bollen et al. (2004) test NASDAQ stock data for three different tick-size regimes and conclude that the dominant component of bid-ask spreads are inventory holding costs and that the cost of adverse selection appears to be small. Neal (1992) finds a positive relation between quoted and current bid-ask spreads and transaction size for CBOE and AMEX options. In our regression estimations for the realized bid-ask spread, all of the three equation specification return a negative and statistically significant parameter for the log(COTV+1).

The COD delivers mixed results for the QSPR and significantly positive parameters in the RSPR specification. As the estimated parameter in the QSPR estimation changes from an insignificant negative value in equation I to a significant negative parameter in equation II and finally to a significant positive parameter in regression III we can infer that the QSPR does not depend on the COD. The RSPR estimation results in more stable COD parameter estimation. We had expected high hedging requirements whenever the absolute COD is large and low hedging demand with low COD. Supporting our preceding argumentation, all RSPR regression equations deliver positive, statistically significant parameter estimates.

As expected, the option MID exhibits the highest significance of all explanatory variables. The parameter is positive and statistically significant in all regression equations and for all bid-ask spread samples analyzed. This result is analogous to conclusions drawn from early stock market analyses such as Demsetz (1968) or Stoll (1978).

Gamma, representing the re-hedging risk due to underlying securities' price changes, does not seem to be an important determinant of the option bid-ask spread. Nevertheless it has a significantly positive effect on the QSPR. In the realized spread estimation it has a positive sign but it lacks statistical significance. Looking at the descriptive statistics of Table 2 we can see that the average gamma of all quoted spread observations is 0.14 with a standard deviation of 0.139. The estimated parameter in the quoted spread regression III takes the value of 4.5 and thus we infer that gamma is not an important component of the bid-ask quoted spread. Increasing the gamma by one standard deviation would result in an increase of a mere 0.5 cents of QSPR.

The estimated parameters for theta are negative and statistically significant for all estimated equations of the quoted and realized spreads. In line with intuition, options with greater time decay have larger spreads as a larger time decay is associated with high re-hedging costs. The more the price of the option changes over time with all other parameters of the pricing formula held constant, the higher the inventory holding costs of the market maker.

The last component of the IHC is the options' sensitivity to a change in the implied volatility. Unsurprisingly the vega constitutes an important determinant of option bid-ask spreads. It is highly significant for regressions II and III for the quoted as well as for the realized spread estimation. Options with higher sensitivity to the volatility exhibit higher spreads, as it is difficult and expensive to hedge volatility exposures. Market makers may increase the bid-ask spread as the inventory is exposed to value fluctuations from a change in volatility. A change of one standard deviation in the vega is associated with an increase of more than 8 cents for quoted and a little bit less than 4 cents for realized bid-ask spreads.

Finally we incorporate OBD as competition component of the bid-ask spread. Estimated parameters are significantly negative for the quoted and the realized bid-ask spread samples. The more orders in the orderbook, the lower the quoted and the realized bid-ask spread will be. Interestingly we find a linear dependence of the bid-ask spread on the OBD. An increase of 1 standard deviation in the OBD is associated with a decrease of 7 cents for the quoted and 2.4 cents for the realized bid-ask spread. We can conclude that the QSPR is more than three times as sensitive to the orderbook depth as the RSPR. This can partly be attributed to the fact that the average OBD of the RSPR is nearly 30% larger than the average for the QSPR sample. Therefore the impact of an increase in the OBD is not as high as for the QSPR.

Next we construct two sub-samples of the quoted and 4 sub-samples for the realized bid-ask spreads. The quoted bid-ask spread sample is separated in puts and calls and depicted in Table 5, the realized bid-ask sample is separated in puts and calls, Table 6, and finally in buyer and seller-initiated transactions exhibited in Table 7. In the following paragraphs we discuss the main findings from the sub-sample regression results.

The estimated parameters do not differ much between the quoted put and call bid-ask samples. Signs, sizes and the significances of the regression outputs are similar for the OPDHC components. For both put and call sub-samples in Table 5, regression specification I has explanatory power of a little more than 25%. Including IHC in equation II, the explanatory power of the quoted call sub-sample becomes 6% higher than that for the quoted put bid-ask spreads. Analogous with full sample results, only the COD is found to be insignificant for explaining quoted put and call bid-ask spreads. The estimated parameter changes its sign when adding IHC and OBD, the t-statistics are very low compared to the other parameters and we can conclude that there is no economic significance of the COD for explaining QSPR. It is interesting to see that the parameter for gamma is positive and statistically significant for the quoted call sub-sample but insignificant for the quoted put sample. Whereas the OPDHC components have very similar impact, the parameters for the implied volatility and the theta are larger in the quoted put sample than in the quoted call sub-sample. This suggests that quoted put bid-ask spreads are more sensitive to IHC than quoted call bid-ask spreads.

Analyzing the realized put and call bid-ask spread sub-samples, illustrated in Table 6, we conclude that OPDHC are of similar size. The parameters for DHC, UBAS and COTV are statistically significant for all regression specifications and for both samples. The estimated parameters for the DHC and the UBAS are slightly larger for the put sample. COD does not explain realized put bid-ask spreads but it significantly enters equation II and III for the calls. The MID price is significantly positive with similar size in equations II and III for puts and calls, the gamma does not prove to be a significant determinant of realized put and call bid-ask spreads. Whereas the estimated theta impact is larger for the call sub-sample, vega influences the put bid-ask spreads more than two times stronger than the bid-ask spread of the call options. The same pattern was also found for the quoted put and call bid-ask spreads and suggests that put options are more sensitive to changes in the implied volatility than call options. Finally we can infer from the equations III that the competition parameters for the realized put and call bid-ask spreads are highly significant. The parameter estimate for the OBD suggests that each additional double sided order book quote reduces the RSPR by a little bit more than 1.8 cents for the calls and about 1.7 cents for the puts.

Table 7 presents the regression results for the sub-samples of buyer- and the seller-initiated trades. The explanatory power of the full regression equation specification III is 0.46 for buyer-initiated trades and just 0.33 for the seller-initiated. Looking at regressions I we see that the OPDHC explain buyer and seller-initiated trades to an equal extent. High COTV is associated with lower bid-ask spreads for both sub-samples with higher parameter estimates for the buyer-initiated trades. Interestingly, COD is significant for the buyer-initiated trades whereas it is not significant for the seller-initiated sample. Adding IHC, the R^2 for the buyer-initiated trades increases to 0.44 whereas the R^^{2} of the seller-initiated trades is 0.31. This result is not surprising as market makers mainly consider the inventory risk for newly opened positions and not when closing their outstanding positions. Especially the parameters for the option MID and the volatility exposure show higher parameter values and higher statistical significance for the buyer-initiated trades. Adding the competition component in regression equations III, we can conclude that OBD is significant for both sub-samples and that the RSPR of buyer-initiated trades are dominated by IHC components and that seller-initiated RSPR do not so much depend on IHC but rather on OPDHC.

VI. Conclusion

Contrary to stock market liquidity analysis, option markets have not been researched to the same extent. This paper examines the determinants of option market liquidity and observes interrelations with the underlying securities' market characteristics. We analyze a 128 days intraday sample of quoted and realized option bid-ask spreads. The main assumption of the study puts forward, that option bid-ask spreads not only depend on the individual option contract attributes but also on cross option market and underlying security characteristics. Market makers are assumed to hedge all risk exposures arising from option transactions, option bid-ask spreads depend on order processing and delta hedging costs, inventory holding costs and competition.

Quoted bid-ask spreads show more regularity and can be better explained than realized bid-ask spread, the significance and size of the estimated parameters are very convincing for both samples. The delta hedging and order processing costs, depending on option characteristics and the underlying securities' price and the underlying securities' bid-ask spread are positively significant in explaining the quoted and realized spreads. The realized spread is negatively determined by the cross option trading volume and positively influenced by the aggregated traded delta in the cross option market. The negative sign of the cross option trading volume casts doubt on adverse selection arguments that interpret high volume in the option market as information signal and accordingly associate higher option bid-ask spreads due to adverse selection risks. The inclusion of these variables is new in the liquidity analysis of option bid-ask spreads. The option mid price and the implied volatility are the driving components of the inventory holding costs. They exhibit the highest significance of all parameters used in the regression equations. This holds for all sub samples of the analysis. This is not surprising as the asset price has traditionally been found to be the most important component of bid-ask spreads. Vega quantifies the volatility risk, the risk exposure most difficult to hedge. Finally we learn that increased market maker competition, measured as order book depth, decreases the bid-ask spread significantly. This competition effect is more potent for the quoted than for the realized bid-ask spread.

Comparing the results from the different option sub-samples we can infer interesting results. Quoted and realized put bid-ask spread are more sensitive to the delta hedging costs and to volatility risk then call bid-ask spreads. For the realized spreads, the regression of the put sub-sample yields stronger impact for delta hedging cost, underlying bid-ask spread, cross option trading volume and vega parameters than the call bid-ask spread sample. This outcome adds up to the notion that the bid-ask spread of put options is more sensitive to hedging and market microstructure related characteristics than call option bid-ask spreads. Finally, the COD is an important determinant for buyer initiated trades’ bid-ask spreads but not for seller initiated trades’ bid-ask spreads. Further, the cross option market delta is more significant and shows a higher parameter estimate for the buyer- than for the seller-initiated spread. Adding the inventory holding costs in the regression equation II increases the explanatory power for the bid-ask spread of the buyer-initiated trades by more than 20 percent compared to just 10 percent for seller-initiated trades. This result confirms our intuition that market makers are concerned about inventory holding costs when opening a position and not so much when closing positions.

We are confident that the high stability and statistical significance of our regression results underpins the notion of understanding liquidity not as an individual asset concept, but rather as a theory that should be comprehended in a market wide sense. Option liquidity depends not only on the individual option series market but also on the hedging costs, the cross option market and the underlying securities’ characteristics. In that sense and with the increasing public availability of financial market specific data, more research should emphasize on market wide liquidity concepts and their implications. Interrelations between different assets, derivatives markets and commonality of liquidity will provide a field for intense research in ongoing and future academic research.

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Figure 1. Proportion of Contracts versus Proportion of Trades

The table reports the proportion of traded contracts in relation to the proportion of the number of trades. The graph includes the entire transaction data sample of OTOb equity options listed in the observed 128 day sample period. The total turnover of the 7765 transactions amounts 556,530 option contracts with a minimum transaction volume of 1 contract and a maximum transaction volume of 9000 option contracts. The mean transaction contract volume amounts 70 contracts, whereas the median contract volume amounts 20 contracts.

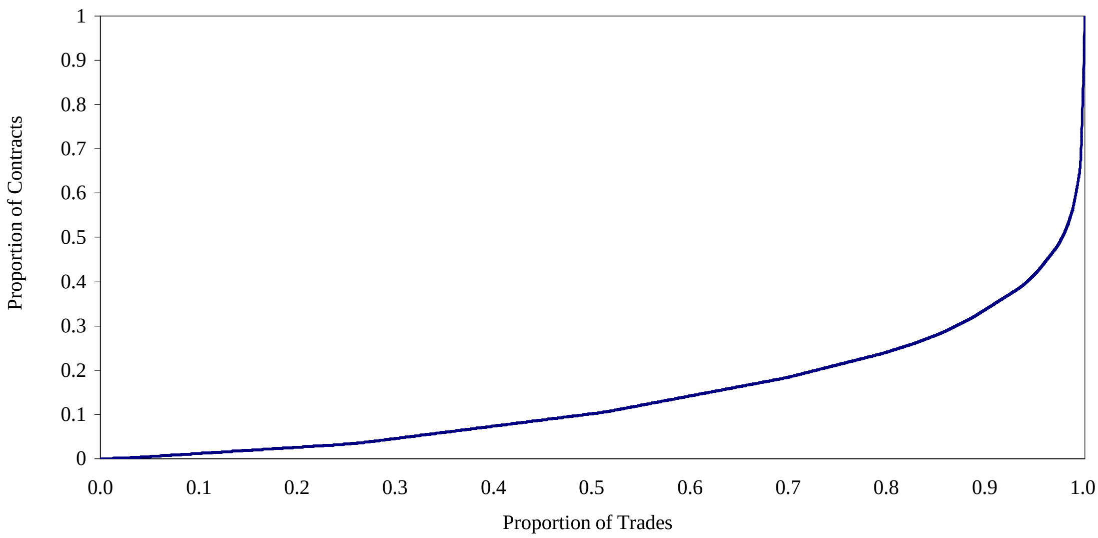

Table 1. Bid-ask Spread Cost Groups and Components

This table lists the bid-ask spread cost categories, their constituents and according quantitative measures. The expected signs for the estimated parameters from the regression analysis are given for all the listed regressors. The stepwise regression equations I, II and III for the QSPR and the RSPR are given below.

Category	Constituent	Variable definition	Expected sign
Order processing costs and delta hedging costs (OPDHC)	*Delta hedging costs (DHC)*	$DHC_{T,i} = \lvert delta_{T,i} \rvert \cdot S_{T,k} \cdot contracts$	+
	Underlying bid-ask spread (UBA)	The absolute bid-ask spread of the underlying stock	+
	Daily cross option trading volume (COTV)	The number of daily traded contracts in the cross option market of all option series written onthe same underlying. *	-
	Cross option delta (COD)	$COD_{T,k} = \sum_{j=1}^{j} delta_{t,i} \cdot TV_{t,j} \cdot dummy_{buyer/seller}$	+
Inventory holding costs (IHC)	*Option mid-price (MID)*	$MID_{(t-5\sec),i} = \left(\frac{A_{(t-5\sec),i} + B_{(t-5\sec),i}}{2} \right)$ *	+
	Gamma	$gamma_{T,i} = \frac{delta_{T,i}(S_{T,i} + \Delta S) - delta_{T,i}(S_{T,i} - \Delta S)}{(2 \cdot \Delta S)}$	+
	Theta	$theta_{T,i} = \frac{optionvalu\ e(T + \Delta T) - optionvalu\ e(T + \Delta T)}{(2 \cdot \Delta T)}$	-
	Vega	$vega_{T,i} = \frac{optionvalu\ e(\sigma_{T,i} + \Delta\sigma) - optionvalu\ e(\sigma_{T,i} + \Delta\sigma)}{(2 \cdot \Delta\sigma)}$	+
Competition (COM)	*Orderbook Depth (OBD)*	The total amount of bid and ask orders in the orderbook. *	-

The according stepwise regression equations for the quoted and the realized bid-ask spread are defined as follows:

I. $QSPR_{T,i} = \beta_1 \cdot \log(DHC_{T,i}) + \beta_2 \cdot UBAS_{T,k} + \beta_3 \cdot \log(COD_{T,i} + 1) + \varepsilon_{T,i}$

$RSPR_{t,j} = \beta_1 \cdot \log(DHC_{t,j}) + \beta_2 \cdot UBAS_{t,j} + \beta_3 \cdot \log(COTV_{t,j}) + \beta_4 \cdot \log(COD_{t,j} + 1) + \varepsilon_{t,j}$

II. $QSPR_{T,i} = \beta_1 \cdot \log(DHC_{T,i}) + \beta_2 \cdot UBAS_{T,k} + \beta_3 \cdot \log(COD_{T,i} + 1) + \beta_5 \cdot MID_{T,i} + \beta_6 \cdot gamma_{T,i} + \beta_7 \cdot theta_{T,i} + \beta_8 \cdot vega_{T,i} + \varepsilon_{T,i}$

$RSPR_{t,j} = \beta_1 \cdot \log(DHC_{t,j}) + \beta_2 \cdot UBAS_{t,j} + \beta_3 \cdot \log(COTV_{t,j}) + \beta_4 \cdot \log(COD_{t,j} + 1) + \beta_5 \cdot MID_{t,j} + \beta_6 \cdot gamma_{t,j} + \beta_7 \cdot theta_{t,j} + \beta_8 \cdot vega_{t,j} + \varepsilon_{t,j}$

III. $QSPR_{T,i} = \beta_1 \cdot \log(DHC_{T,i}) + \beta_2 \cdot UBAS_{T,k} + \beta_3 \cdot \log(COD_{T,i} + 1) + \beta_5 \cdot MID_{T,i} + \beta_6 \cdot gamma_{T,i} + \beta_7 \cdot theta_{T,i} + \beta_8 \cdot vega_{T,i} + \beta_9 \cdot OBD_{T,i} + \varepsilon_{T,i}$

$RSPR_{t,j} = \beta_1 \cdot \log(DHC_{t,j}) + \beta_2 \cdot UBAS_{t,j} + \beta_3 \cdot \log(COTV_{t,j}) + \beta_4 \cdot \log(COD_{t,j} + 1) + \beta_5 \cdot MID_{t,j} + \beta_6 \cdot gamma_{t,j} + \beta_7 \cdot theta_{t,j} + \beta_8 \cdot vega_{t,j} + \beta_9 \cdot OBD_{t,j} + \varepsilon_{t,j}$

* measured end of day for the QSPR and intrady for RSPR.

Table 2. Regressor Descriptive Statistics

The table reports summary descriptive statistics of variables used in the cross-sectional regressions of the quoted and the realized bid-ask spreads for the entire data sample of OTOB equity options listed in the observed 128 day sample period. The sample of the quoted spread contains 31656 observations, the realized spread sample includes 7767 transactions. Variables are defined in Table 1.

	RSPR (n = 7766)					**QSPR (n = 31714)**				
Variable	Mean	Median	Max	Min	Std Dev	Mean	Median	Max	Min	Std Dev
Option BAS	15.16	10.00	238.00	1.00	16.39	35.29	25.44	225.51	1.84	30.34
log(DHC+1)	10.58	10.54	15.87	0.00	1.01	7.43	7.49	9.44	0.00	1.08
UBA	18.96	14.00	148.00	1.00	17.24	25.82	20.97	198.14	1.60	19.08
log (COTV+1)	5.97	5.99	10.53	0.69	1.36	2.99	3.43	10.53	0.00	2.67
log (COD+1)	8.19	8.23	13.59	0.00	1.65	4.48	6.02	13.59	0.00	3.86
MID	136.92	93.50	1775.00	3.00	134.27	199.87	132.88	2144.38	4.00	202.20
gamma	0.167	0.126	2.567	0.000	0.164	0.140	0.100	2.494	0.000	0.139
theta	-0.118	-0.089	0.000	-3.087	0.127	-0.111	-0.075	0.000	-4.379	0.130
vega	0.042	0.029	0.293	0.000	0.042	0.041	0.025	0.273	0.000	0.043
OBD	6.53	7.00	14.00	2.00	2.66	4.93	5.51	11.87	2.00	2.35

Table 3. Regressor Ccorrelation Matrix

The table reports cross-correlations between the QSRP, the RSPR and all explanatory variables used in the cross-sectional regressions of the realized and the quoted bid-ask spreads for the entire data sample of OTOb equity options listed in the observed 128 day sample period. In the first line we report the correlations for the sample of the RSPR sample and in the second line we report the correlations for the QSPR sample.The sample of the QSPR contains 31,656 observations, the RSPR sample includes 7,767 transactions. Variables are defined in Table 1.

Variable	*BAS*	*log(IHC)*	*UBA*	*ln(COTV+1)*	*log(COD+1)*	*MID*	*gamma*	*theta*	*vega*
log(DHC+1)	0.1871								
	0.4596								
UBA	0.4195	0.1261							
	0.4430	0.4901							
log (COTV+1)	-0.2813	0.0925	-0.3905						
	-0.0387	-0.0185	-0.1807						
log (COD+1)	-0.1612	0.1165	-0.2833	0.6976					
	-0.0066	0.0147	-0.1304	0.9565					
MID	0.5075	0.3470	0.3385	-0.2257	-0.1112				
	0.7489	0.5060	0.3286	0.0208	0.0460				
gamma	-0.3093	-0.0811	-0.3360	0.2792	0.2123	-0.4419			
	-0.4059	-0.3291	-0.3777	0.0017	-0.0211	-0.4516			
theta	-0.1658	-0.0954	-0.3228	0.2343	0.2297	-0.0401	-0.0300		
	-0.2110	-0.3037	-0.3755	0.0211	-0.0111	-0.0730	0.0510		
vega	0.4791	0.0614	0.5586	-0.3847	-0.3180	0.3739	-0.3862	-0.2460	
	0.4876	0.3865	0.5606	-0.0357	0.0032	0.2546	-0.3421	-0.3984	
OBD	-0.2336	0.0155	-0.0154	0.0270	-0.0108	-0.2190	0.0714	-0.2177	-0.1393
	-0.2021	0.1947	0.2268	0.1557	0.1554	-0.1322	-0.0261	0.1729	-0.3035

Table 4. **Stepwise Regresison Results - QSPR and RSPR Full Samples.**

The table reports the parameter estimates for the cross-sectional least square regressions of the quoted and the realized bid-ask spread for the entire data sample of OTOB equity options listed in the observed 128 day sample period. The sample of the quoted spread contains 31656 observations, the realized spread sample includes 7767 transactions. The last column reports adjusted R^2 values for each of the regression specifications. The regression equations I, II and III refer to the models specified in table 1. The first regression I incorporates the OPHC, regression II adds the IHC to the equation and finally specification III represents the full model regression equation. The explanatory variable log (COTV+1) is not included in the quoted spread estimation due to multi-colinearity concerns. The t-statistics are reported below the parameter estimates.

		OPHC				**IHC**				**COMP**	
		log(DHC+1)	*UBAS*	*log (COTV+1)*	*log (COD+1)*	*MID*	*gamma*	*theta*	*vega*	*OBD*	**adj R^2**
QSPR full sample											
(n = 31365)											
I		3.275	0.534		-0.071						0.253
	t-stat	69.014	57.745		-1.838						
II		0.646	0.098		-0.194	0.100	5.402	-6.329	198.954		0.659
	t-stat	14.065	12.980		-7.418	162.142	6.612	-7.276	66.247		
III		2.559	0.148		0.131	0.086	3.880	-15.908	194.750	-2.993	0.700
	t-stat	49.155	20.845		5.212	139.966	5.058	-19.184	69.084	-65.497	
RSPR full sample											
(n = 7765)											
I		1.971	0.313	-2.589	0.475						0.218
	t-stat	21.961	29.845	-14.824	3.446						
II		0.429	0.119	-1.197	0.631	0.042	-0.525	-4.967	97.589		0.377
	t-stat	4.728	10.778	-7.505	5.089	31.296	-0.493	-3.888	21.860		
III		0.956	0.127	-1.130	0.662	0.037	-1.630	-9.622	90.145	-0.884	0.396
	t-stat	9.997	11.641	-7.192	5.416	27.117	-1.550	-7.434	20.375	-15.411	

Table 5. Stepwise Regresison Results - QSPR Put and Call Sub-Samples.

The table reports the parameter estimates for the cross-sectional least square regressions of the quoted bid-ask spread sample of all options listed in the observed 128 day sample period. The sample of the quoted bid-ask spreads is divided in a call and a put subsample. The calls contain16246 observations, the realized put bid-ask spread sample includes 15411 transactions. The last column reports adjusted R^2 values for each of the regression specifications. The regression equations I, II and III refer to the models specified in table 1. The first regression I incorporates the OPHC, regression II adds the IHC to the equation and finally specification III represents the full model regression equation. The explanatory variable log (COTV+1) is not included in the quoted spread estimation due to multi-colinearity concerns. The t-statistics are reported below the parameter estimates.

	OPHC				IHC				COMP	
	log(DHC+1)	*UBAS*	*log (COTV+1)*	*log (COD+1)*	*MID*	*gamma*	*theta*	*vega*	*OBD*	**adj R^2**
QSPR calls										
(n = 16246)										
I	3.518	0.525		-0.089						0.254
t-stat	50.137	38.543		-1.573						
II	0.640	0.121		-0.215	0.102	6.218	-5.928	179.869		0.697
t-stat	9.886	11.589		-5.954	130.149	5.395	-5.049	43.681		
III	2.464	0.169		0.080	0.088	4.506	-13.829	176.953	-2.773	0.730
t-stat	33.519	17.066		2.315	110.590	4.139	-12.321	45.520	-44.594	
QSPR puts										
(n = 15411)										
I	3.032	0.542		-0.069						0.254
t-stat	47.652	43.598		-1.307						
II	0.671	0.075		-0.181	0.097	4.540	-6.725	218.644		0.612
t-stat	10.250	6.922		-4.774	96.365	3.916	-5.218	49.958		
III	2.680	0.127		0.176	0.083	3.227	-18.316	212.994	-3.239	0.663
t-stat	36.252	12.473		4.858	84.887	2.985	-14.950	52.187	-48.212	

Table 6. Stepwise Regresison Results - RSPR Put and Call Sub-Samples.

The table reports the parameter estimates for the cross-sectional least square regressions of the realized bid-ask spread sample of all option trades in the observed 128 day sample period. The sample of the realized spread is divided in a call and a put subsample. The calls contain 4172 observations, the realized put bid-ask spread sample includes 3593 transactions. The last column reports adjusted R^2 values for each of the regression specifications. The regression equations I, II and III refer to the models specified in table 1. The first regression I incorporates the OPHC, regression II adds the IHC to the equation and finally specification III represents the full model regression equation. The t-statistics are reported below the parameter estimate.

	OPHC				**IHC**				**COMP**	
	log(DHC+1)	*UBAS*	*log (COTV+1)*	*log (COD+1)*	*MID*	*gamma*	*theta*	*vega*	*OBD*	**adj R^2**
RSPR calls										
(n = 4172)										
I	1.795	0.301	-2.502	0.618						0.212
t-stat	15.027	21.047	-10.228	3.176						
II	0.377	0.110	-1.155	0.802	0.045	-2.626	-8.284	59.063		0.368
t-stat	3.137	7.248	-5.153	4.534	25.990	-1.758	-4.460	9.276		
III	0.908	0.118	-0.943	0.779	0.040	-3.639	-12.470	54.184	-0.920	0.386
t-stat	7.148	7.890	-4.260	4.473	22.446	-2.469	-6.687	8.623	-11.512	
RSPR puts										
(n = 3593)										
I	2.205	0.327	-2.773	0.331						
t-stat	16.172	21.245	-11.086	1.691						0.227
II	0.455	0.128	-1.320	0.535	0.039	1.516	-2.341	131.858		0.404
t-stat	3.323	7.951	-5.839	3.097	18.590	1.008	-1.343	21.051		
III	1.001	0.135	-1.392	0.586	0.035	0.246	-7.168	122.631	-0.846	0.421
t-stat	6.897	8.477	-6.241	3.435	16.288	0.165	-4.020	19.649	-10.215	

Table 7. Stepwise Regresison Results - RSPR Buyer and Seller Initiated Trades Sub-Samples.

The table reports the parameter estimates for the cross-sectional least square regressions of the realized bid-ask spread sample of all option trades in the observed 128 day sample period. The sample of the realized spread is divided in a buyer and a seller initiated trade subsample. The buyer initiated trade sample contain 4370 observations, the seler initiated trade sample includes 3395 transactions. The last column reports adjusted R^2 values for each of the regression specifications. The regression equations I, II and III refer to the models specified in table 1. The first regression I incorporates the OPHC, regression II adds the IHC to the equation and finally specification III represents the full model regression equation. The t-statistics are reported below the parameter estimates.

		OPHC				IHC				COMP	
		log(DHC+1)	*UBAS*	*log (COTV+1)*	*log (COD+1)*	*MID*	*gamma*	*theta*	*vega*	*OBD*	**adj R^2**
RSPR buyer initiated											
(n = 4370)											
I		2.041	0.303	-2.837	0.600						0.230
	t-stat	17.031	22.879	-12.636	3.370						
II		0.139	0.107	-1.167	0.822	0.049	1.390	-0.767	118.501		0.442
	t-stat	1.201	8.067	-5.962	5.370	28.471	1.029	-0.448	21.638		
III		0.687	0.109	-1.201	0.870	0.045	0.514	-5.807	112.581	-0.862	0.460
	t-stat	5.607	8.411	-6.240	5.773	25.588	0.386	-3.349	20.818	-12.205	
RSPR seller initiated											
(n = 3395)											
I		1.885	0.326	-2.233	0.279						0.201
	t-stat	13.895	19.129	-8.026	1.274						
II		0.678	0.142	-1.037	0.319	0.035	-1.732	-7.599	72.983		0.311
	t-stat	4.769	7.538	-3.904	1.565	17.017	-1.023	-3.942	9.800		
III		1.206	0.157	-0.824	0.316	0.030	-3.197	-12.098	62.186	-0.952	0.331
	t-stat	8.066	8.448	-3.137	1.571	13.981	-1.911	-6.201	8.386	-10.105	