Depth and spreads in futures markets: relationship with executions, submissions, and cancellations

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Abstract

This paper examines how executions, submissions, and cancellations affect liquidity characteristics of the limit order book – relative bid-ask spread and best depth. The results of this study aim to provide an assessment which of the two literature strands – asymmetric information or waiting cost – best explains the impact of different order types on the determinants of market liquidity. The empirical results support the asymmetric information literature assumptions on the effect executions, submissions, and cancellations have on liquidity metrics: the spread shrinks and best depth increases with higher competition between the liquidity providers; increase in market order executions leads to the widening of spreads to compensate for higher expected losses on trades with informed agents and lower best depth to avoid being picked off; limit order cancellations decrease available depth and widen the spread stemming from decreased competition and flight before informed investors. We test the robustness of our interpretation by analysing the adverse selection component of effective spread and find supporting evidence.

Introduction

Contingent on the assumptions espoused, theory provides conflicting propositions with regard to the impact of different order types on the market liquidity. The two notable strands of literature base themselves on asymmetric information (see Copeland and Galai, 1983; Kyle, 1985; Glosten and Milgrom, 1985) and waiting cost considerations (see Foucault, 1999; Foucault, Kadan, and Kandel, 2005; Rosu, 2009).

Importance of understanding how order executions, submissions, and cancellations affect bid-ask spreads and depth is twofold. Firstly, the recent proliferation of trading venues and fragmentation of liquidity in markets has increased the incentive or innovations exchanges have established to promote liquidity and attract traders. For example, maker-taker and taker-maker markets have established asymmetric trading fees for traders provisional on whether they supply or demand liquidity. Exchanges, today mostly organized as limit order markets without the intervention of designated market makers, need to be able to understand the impact of basic order types on venue quality and attractiveness determinants – limit orders versus market orders. Understanding this impact is of paramount importance for modelling the trading venue, incentivizing the favourable behaviour and creating a liquid market that facilitates trading. Secondly, regulators and academics are interested in assuring that incentive structures imposed by the exchanges do not harm market liquidity and price discovery. O’Hara (2003) notes discovering asset values is an essential function of the financial markets in addition to liquidity. While Foucault and Cespa (2014) describe the importance of data-feed price as a price discovery driver, Frijns, Gilbert, and Tourani-Rad (2015) note that the relative value of bid-ask spreads and relative volume of trading are significant determinants of the price discovery process.

The aim of this paper is to provide an assessment which of the two literature strands – asymmetric information or waiting cost – best explains the impact of different order types on the determinants of market liquidity. Futures markets, being centralized, and not adopting a fee-rebate structure in place among equity markets provide a well-ordered setting to analyse the impact of limit orders, markets orders and cancellations on spreads and depth. Specifically, we test empirically in the most active futures contact the e-mini S&P500 futures.

Our analysis is related to work of Bae, Jang, and Park (2003) and Xu (2014). Bae et al (2003) condition the choice between limit and market orders on volatility conditions – transitory and permanent. They find that periods of increased transitory volatility increase the usage of limit orders while the effect of permanent volatility regimens does not have statistical or economic impact. In addition, they note that spreads tend to be tight after high and wider after low volatility periods. Xu (2014), analyses trading in OMXS 30 index futures traded on the Nasdaq OMX Group. She finds that the book displays a hump shape and a positive relation between the steepness of the book and number of large market order executions, consistent with evidence of a co-movement effect. In addition, Xu (2014) shows that, using a dataset sampled at 1-minute frequency, a higher proportion of patient traders leads to higher liquidity and similarly higher order arrival rate generates tighter spreads. Neither Bae et al (2003) nor Xu (2014), however, analyse the impact of individual order types on liquidity metrics. Our contributes are twofold, first we provide empirical evidence consistent with the asymmetric information-based theories on the relation between order submission and market liquidity, and second our analysis is undertaken using a finer sampling frequency consistent with trading in futures markets under regimes of colocation and high frequency trading.

The results of the analysis indicate that there is a positive relationship between the number of market orders executed and relative bid-ask spreads, consistent with Kyle (1985) and Glosten and Milgrom (1985). Relationship between limit order cancellations and relative spreads is of same sign. Limit order submissions negatively impact relative spreads. In case of depth as dependent variable, the observed relationships are the opposite, as expected given the negative correlation between depth and spreads captured in the literature and confirmed in our output. The flow of market orders and limit order cancellations negatively impacts best depth, while the limit order submissions during the interval increase best depth at the interval’s end.

The empirical results match the expectations following the asymmetric information literature implying that the spread shrinks and best depth increases with higher competition between the liquidity providers, as seen in higher number of contracts posted. Increase in market order executions can be related to higher presence of informed trading, impacting the spread to widen to compensate for higher expected losses on trades with informed agents and lower posted depth to avoid being picked off. Decreasing the competition, limit order cancellations decrease available depth and widen the spread. We test the robustness of our interpretation by analysing the adverse selection component of effective spread and find supporting evidence. Increase in executions has an adverse effect on earnings of liquidity providers and decreases best depth.

This paper is organized as follows. Section 2 summarises the related literature. Section 3 describes the data and the processing that was performed in order to create the dataset used for the analysis. Section 4 describes the model and the variables used in the analysis. Section 5 reports the results of the analysis and the robustness tests and discusses them. Section 6 concludes.

Literature Review

The strand of literature discerning the impact of asymmetric information on traders' behaviour suggests that competition among liquidity providers induces a narrowing of the spread, while increased market order executions associated with immediacy cause spreads to widen. Cancellation of orders, however leads to decreased competition or withdrawal of liquidity to avoid being adversely affected by trading with an informed trader, contributing to widening of the spread. In terms of depth displayed in the market, the presence of private information revealed through market orders is expected to decrease shares on offer; limit order cancellations similarly reduce available depth. We expect, contrary to the impact of market orders and cancellations, that the competition among liquidity providers results in an increase of displayed depth.

Copeland and Galai (1983) model a market with designated market makers serving as liquidity providers and two types of liquidity takers – those possessing special information and those trading for liquidity purposes concluding that the bid-ask spread is set to compensate the market makers on losses they make on trades with informed traders by making gains on trades with liquidity traders. Kyle (1985) and Glosten and Milgrom (1985) further Copeland and Galai's work and present their models of spread determination in presence of asymmetric information. Although with differing frameworks, both papers come to the conclusion that in order to earn non-negative profits, the market maker has to charge a non-zero spread with the aim of compensating on trades with liquidity traders for the losses she makes on trading with informed traders.

Glosten and Milgrom (1985) note that the bid and ask prices include all the information from past trades, but in addition, they are forward looking as they include or price the direction of subsequent trade – bid (ask) price incorporates the assumption of next trader being a seller (buyer). All of the three papers note an increased presence of informed traders results in a higher spread.

Additionally, Copeland and Galai (1983) remark that a monopolist market maker always charges profit maximizing spread, while the presence of competition impacts the *narrowing* of the *spread* to competitive levels. Finally, Kyle (1985) notes that both depth and resiliency are consequences of the presence and mix of informed and noise traders, such that depth is proportional to the amount of noise trading and inversely proportional to the amount of private information not yet been incorporated into prices.

The strand of literature citing waiting costs as a determinant of spreads suggests that competition among liquidity providers increases waiting time, therefore causing the widening of the spread to compensate for higher costs. Increased market order executions and cancellations speed up the execution waiting times facilitating a decrease in the spread. The effect on depth is converse, cancellations and market order executions consume liquidity from the book, providing for a negative relationship, while increased submissions of limit orders add to the pool of liquidity.

Waiting costs considerations on trader's order choice and market quality determinants has roots in Demsetz (1968). Introducing the notion of waiting costs, he noted they are *"…relatively important for trading in organized markets, and would seem to dominate the determination of spreads"*. Foucault (1999) argues that the proportion of limit orders is positively related to bid-ask spreads and that increases in execution risk induce liquidity providers to post larger spreads or divert their order choice toward market orders. Foucault, Kadan, and Kandel (2005) state that, ceteris paribus, an increase in the fraction of patient traders reduces the demand for liquidity (a decrease in impatient traders reduces the percentage of traders opting for a market order) and lengthens the expected limit order time to execution. Contrarily to Foucault (1999), they note that ensuing increase in competition by the liquidity providers decreases the spread more rapidly. When comparing different markets, they note that markets dominated by impatient traders tend to have larger spreads due to their inherent lower resiliency. Roşu (2009) models an information asymmetry-free, zero-tick, continuous, order driven market model and shows that for the equilibrium to occur, the utility of every liquidity provider has to be equal. The composition of their utility functions differs, however, and traders suffering from a utility loss from higher waiting (costs) need to compensate for the utility loss via a higher payoff i.e. the higher spread mark-up charged, giving rise to the multiple level LOB existence. Roşu (2009) further notes that when there are i.e. more market orders executed, other things equal, liquidity provider's waiting time decreases, causing a narrowing of the spread.

Data

We assess the impact of order types on market quality in the E-mini S&P 500 Futures, traded on Chicago Mercantile Exchange (CME), for the sample period extending 21st December 2015 to 7th December 2016 corresponding to the chain of four nearest to maturity contracts expiring in 2016. Data is sourced from Thompson Reuters Tick History (TRTH) Trade and Quote database, maintained by Securities Research Centre of Asia-Pacific (SIRCA). Each time an order is submitted to the exchange, either improving or amending an already existing order at best quotes or initiating a trade a record is created containing information on RIC (instrument identifier), date, time (up to the nearest microsecond), update type ("Quote" or "Trade"), and the corresponding volumes and prices.

E-mini S&P 500 is a stock market index futures contract, fully traded on Globex – the electronic platform of Chicago Mercantile Exchange. Notional value of the contract is equal to the value of the S&P 500 index multiplied by a factor of 50. It is traded Sunday – Friday from 6:00 pm to 5:00 pm Eastern Time (ET), with a 15-minute trading halt from 4:15 pm to 4:30 pm. All Sundays and federal holidays which result in no trading or half day trading are excluded from our sample. In addition, we eliminate seven trading days prior to near contract expiration in order to remove possible effects of the rollover period as per Frino and McKenzie (2002), who find increases in mispricing of the near and deferred contracts in the period preceding near contract expiration, likely being part of rollover strategies. We focus on the most active trading period during the day - the daily session – NYSE and NASDAQ working hours – 9:30 am to 4:00 pm, using 10-second frequency of sampling to mitigate the potential bias of high number of missing values at higher sampling frequencies.

Methodology

Model Specification

Lee, Mucklow, and Ready (1993) note that inferences about liquidity of a market cannot be made without taking into account both the bid-ask spread and a measure of depth and they also recognize the interdependence between these two variables. Consequently, we adopt a two stage least squares regression analysis model to address the interdependence:

$$BAS_t = \alpha_1 + \alpha_2 M_t + \alpha_3 L_t + \alpha_4 C_t + \alpha_5 D_t + \alpha_6 BAS_{t-1} + \alpha_7 VIX_t + \sum_{i=1}^{12} \alpha_i FEint_i + \sum_{j=1}^{3} \alpha_j FEquart_j \quad (1)$$

$$D_t = \beta_1 + \beta_2 M_t + \beta_3 L_t + \beta_4 C_t + \beta_5 BAS_t + \beta_6 D_{t-1} + \beta_7 VIX_t + \sum_{i=1}^{12} \beta_i FEintr_i + \sum_{j=1}^{3} \beta_j FEquart_j \quad (2)$$

where BAS_t is the natural logarithm of the relative spread at *t*, the end of the 10-second time interval; D_t is the natural logarithm of best depth at time *t*, the end of the 10-second time interval; M_t is the volume of market orders executed at both sides of the market during the 10-second time interval ending at *t* or the change in the number of executed contracts between time-periods ending at *t-1* and *t;* L_t is the volume of limit orders submitted at both sides of the market during the 10-second time interval ending at *t* or the change in the number of submissions between time-periods ending at *t-1* and *t;* C_t is the volume of limit orders cancelled at both sides of the market during the 10-second time interval ending at *t* or the change in the number of cancellations between time-periods ending at *t-1* and *t;* VIX_t is the mid-quote of the Volatility Index Futures at time *t*, the end of the 10-second time interval; $FEint_t$ is a set of dummy variables capturing differences in intraday behaviour, based on 30-minute time buckets; and $FEquart_t$ is a set dummy variables capturing differences in quarterly behaviour of variables

Order Classification and Identification

We identify every update in our data labelled as "*Trade*" as a market order since for a trade to occur, an incoming market order has to cross with a standing limit order. When deciding whether to sign the trade as seller or buyer initiated, we use Lee and Ready (1991) algorithm by which any trade that took place at a price below the midquote is marked as seller initiated, as buyer initiated if the price is above the midquote, and unsigned otherwise. Midquote is calculated at each update as:

$$midquote_t = \frac{a_t - b_t}{2}$$

where a_t and b_t represent best *ask* and *bid* quotes at time *t*.

Limit order submissions and cancellations

Messages labelled "Quote" reflect updates to the best quotes prevailing in the limit order book. Not every one of these updates, however, results from a limit order being submitted/cancelled. Namely, following every "Trade", a quote update is automatically issued to correct the limit order book for the most recently executed trade. We exclude such updates in the calculation of limit order related variables reported below. In addition, post-update displayed values are aggregates, therefore, we compare the pre-update prevailing values with the post-update ones in order to understand the nature and value of the update. When the update is price improving we count the *entire post update volume* as a limit order submission[1]. If the prevailing quote is unchanged following the update, we record the *change in volume* as a limit order submission if positive, and as a cancellation, if negative. Finally, when the update deteriorates the best prevailing quote, and the second-best quote becomes the prevailing one, based on the assumption that the second-best quote was already present in the market and became prevailing without any new liquidity supplier activity, we do not record any changes in limit order submission variable, but record the entire pre-update volume as a cancellation. Limit order submission/cancellation variable represents the sum of all liquidity submitted to/cancelled from the book at the best quotes in the 10 second interval.

Relative Quoted Spread and Quoted Depth

Relative spread, in basis points, is calculated as:

$$relative\ spread_t = \frac{ask_t + bid_t}{midquote_t} \times 10000$$

where ask_t and bid_t represent best quotes at the end of the time interval. We put in place the non-continuous trading filters: the data entries where the relative quoted spread is lower than or equal to zero are deleted from our sample as it indicates non-continuous trading (eliminating a total of 0.11% of quote updates from our sample of 220 trading days 8:30am-3pm).

[1] A price improving order amendment is treated as a new submission consistent with the treatment of an amended order in exchange protocol i.e. losing the priority ranking and being timestamped to the moment of amendment

Best depth is calculated as the sum of the number of contracts available to trade at best bid and at best ask at the end of the time interval and represents liquidity immediately available for trade.

Volatility Measure and Fixed Effects

Following conclusions of Handa and Schwartz (1996), Wang et al. (1997), Foucault (1999), Wang and Yau (2000) highlighting the impact of volatility on spread determination we control for volatility during the trading day using the mid-quote of the volatility index futures prevailing at the end of the interval. Volatility Index Futures is a futures contract based on the Cboe Volatility Index – a market estimate of expected volatility calculated from real-time prices of options on the S&P 500 Index listed on Cboe Exchange. Notional value of the contract is equal to the value of the Index multiplied by a factor of 1000. Total trading hours match those of Emini Futures traded on CME, with regular trading hours 9:30am-4:15pm, ET.

In addition, consistent with Wang et al. (1997), Wang and Yau (2000), Xu (2014), and others, we introduce 30-minute fixed effects to control for intraday patterns of the variables. Finally, to account for seasonality we add contract fixed effects corresponding to contract maturities: 18th December 2015 – 18th March 2016 – 17th June 2016 – 16th September 2016 – 16th December 2016.

Summary Statistics

Table I reports the summary statistics providing details on the mean, median, standard deviation, 25% and 75% percentiles and the number of observations. The sample under analysis contains data at 10 second sampling frequency in the time-period of from 21st December 2015 to 7th December 2016, 9:30am-4:00pm ET. We observe that both mean and median value of cancellations are much higher than the corresponding values of market order executions while the value of limit orders submitted at best quotes is the highest: 1990 limit orders submitted in 10 sec interval, with 1763 limit orders cancelled and 575 orders executed, on average. Relative spread is 1.21 basis points and there is, on average 630 contracts available for trade, at best quotes. Average VIX value across the sample is 17 index points.

<INSERT TABLE I>

Intraday Behaviour of Variables

Table II presents the means for each of the variables for 13 non-overlapping 30-minute trading periods during the day. As observed in second column of Table II referring to best depth, we note a pattern in intraday depth behaviour with lowest displayed depth at the beginning of the trading day, relatively stable behaviour in the course of the day and a surge in the last 30 minutes of trading, with 40% more depth displayed in the last 30 minutes over the first 30-minute time bucket. While relative spread shows stable behaviour on average, U shaped intraday behaviour is observed for limit order submissions and cancellations and market order execution averages.

<INSERT TABLE II>

Discussion

Main Results

Tables III and IV contain results of two-stage least squares estimation based on equations (1) and (2) with relative spreads and best depth as dependent variables respectively. Coefficient estimates marked with an asterisk are statistically significant at 99% confidence level. The estimates of interest are the coefficients of market order execution, limit order submission and cancellation variables in column two and changes therein reported in column three. We note that all of the coefficients in both Tables are statistically significant at 99% confidence level.

Regression results coincide with expectations based on asymmetric information theories of Copeland and Galai (1983), Kyle (1985), and Glosten and Milgrom (1985). Coefficients of market orders executed and limit order cancellations in Table III are positive in sign, implying that increased presence of informed investors causes liquidity providers to widen the spreads to compensate for the losses on trades with informed investors on trades with the uninformed ones, or to cancel their orders to avoid trading with the informed trader altogether. Limit order submissions coefficient estimate is negative indicating that higher competition among liquidity providers leads to the narrowing of spreads. The coefficient signs are consistent for absolute values and changes of the three variables of interest.

Coefficient of market order executions and limit order cancellations observed in Table IV is negative, while the limit order submissions coefficient estimate is positive in sign. Coefficients of same sign, respectively, are observed in column three of Table IV where the variables of interest are the changes in executions, submissions, and cancellations further supporting the predictions based on asymmetric information theory. The results imply that an increase in market orders, causes liquidity providers to display less depth in order to prevent being picked off. Positive sign of the limit order submissions coefficient is interpreted as higher competition among liquidity providers leading to a concentration of depth at best quotes, while cancellations signal a decrease in said competition and/or an attempt not to be picked off by the more informed trader leading to lower liquidity available.

Observed relationship between spreads and best depth is negative consistent with Lee, Mucklow, and Ready (1993), while the volatility index coefficient causes widening of the spread and a decrease in displayed depth.

<INSERT TABLE III>

<INSERT TABLE IV>

Robustness Test

To test the robustness of our findings, we decompose the spread based on Glosten (1987) and test whether higher activity of liquidity takers, resulting in lower earnings of liquidity providers, can be related to adverse selection. Based on equation:

$$realized\ spread_t = effective\ spread_t - adverse\ selection_t \quad (3)$$

where:

$$realized\ spread_t = direction_t(p_t - midquote_{t+1sec})/midquote_t \times 10000 \quad (4)$$

$$effective\ spread_t = direction_t(p_t - midquote_t)/midquote_t \times 10000 \quad (5)$$

$$adverse\ selection_t = direction_t(midquote_{t+1sec} - midquote_t)/midquote_t \times 10000 \quad (6)$$

p_t = the price at which the trade took place

$direction_t =$ equal to -1 if the trade is seller initiated and 1 if it is buyer initiated. Direction identification is based on the Lee and Ready (1991) algorithm by which any trade that took place at a price below the midquote is marked as seller initiated, as buyer initiated if the price is above the midquote

$midquote_{t+1second} =$ the prevailing midquote 1 second after the trade took place,

we observe that the realized spread (4), used in literature as a proxy for revenue of liquidity providers is equal to the effective spread (5) less the change in the midquote following the trade (6). Hendershott, Jones, and Menkveld (2011) relate this change to the presence of adverse selection. Following the same reasoning, we analyse the behaviour of the adverse spread metric and its relationship with depth using the model presented in (1) and (2) where instead of relative bid-ask spread, we use the adverse spread metric. Since adverse spread metric is calculated for each trade taking place during the 10-second time interval in the course of the trading day, we calculate a volume weighted average for each 10-second bucket.

Results of the regressions presented in Tables V and VI corroborate the initial conclusion that asymmetric information drives liquidity conditions at a high frequency intraday level. Positive and statistically significant coefficients for both absolute values and changes of market orders executed and limit order cancellations in second and third column of Table V and negative coefficients for both variables in second and third column of Table VI indicate that an increase in market order executions and limit orders cancellations leads to a higher adverse selection spread, thus decreasing the earnings of liquidity providers and causing them to display less depth, as predicted by the theory. This confirms our interpretation that an increase in market order executions coincides with increased informed traders' activity and leads to liquidity providers displaying less depth not to get picked off. Growth in cancellations points towards a less competitive and resilient book and flight before informed traders to which liquidity providers make losses, leading to an increase in adverse spreads and a decrease in depth displayed at best quotes.

A negative coefficient for both absolute and change in limit orders submitted in Table V marks a negative impact of limit order submissions on adverse spread. In Table VI we observe a positive and statistically significant limit order submissions coefficient estimate. More liquidity submitted to the market indicates tighter competition leading to a more resilient market, hence the negative impact of limit orders on the adverse spreads. Higher competition between liquidity providers results in higher displayed depth. The negative relationship between relative adverse spread and depth (as seen in both, Table V and VI) indicates that the higher the cost of dealing with more informed investors the less liquidity available for trade there will be, in line with observations by Lee, Mucklow, and Ready (1993).

<INSERT TABLE V>

<INSERT TABLE VI>

Conclusion

Our analysis aims to explain how basic order types affect the best depth and bid ask spread. In a predominantly limit order driven market describing this relationship is of paramount importance for exchanges, regulators, and academia.

The results indicate that there is a positive relationship between the number of market orders executed and the value of relative bid-ask spread at the period end as well as limit order cancellations and the value of relative bid-ask spread. Limit orders submitted negatively impact the relative spreads. The sign of relationship between the three variables of interest and best depth is the opposite, as expected given the negative correlation between depth and spreads captured in the literature and confirmed in our output.

These empirical results match the expectations following the asymmetric information literature (see Copeland and Galai, 1983; Kyle, 1985; and Glosten and Milgrom, 1985) implying that the spread shrinks and best depth increases with higher competition between the liquidity providers. Increase in market order executions interpreted as increased activity of informed traders, impacts the spread to widen to compensate for higher expected losses on trades with informed agents and lower posted depth to avoid being picked off. Limit order cancellations decrease available depth and widen the spread combining the effects of decreasing competition and avoiding trade with more informed investors. We test the robustness of the findings by analysing the impact of the three variables of interest on the adverse component of realized spreads and find that adverse spreads are positively related to market order executions while decreasing best depth, therefore supporting our interpretation of the results and further linking behaviour of liquidity metrics at high frequencies with asymmetric information theory.

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Table I

Summary statistics

	Mean	Median	Standard Deviation	Q1	Q3	N
Best Depth	630.6943	593	339.2990	386	812	507773
Relative Spread	1.2117	1.1955	0.0966	1.1584	1.2299	507773
Limit Orders Submitted (in '000)	1.9901	1.5420	2.0508	0.7990	2.6310	507773
Market Orders Executed (in '000)	0.5751	0.3800	0.8584	0.1360	0.7460	507773
Limit Order Cancelled (in '000)	1.7626	1.375	1.6690	0.7020	2.3520	507773
VIX	17.1785	16	3.4304	14.925	18.3750	507773

Note: This Table presents summary statistics for a timeseries of variables pertaining to E-mini S&P 500 Futures contract grouped in 10 second time buckets across the sample period extending 21st December 2015 to 7th December 2016 corresponding to the chain of four nearest to maturity contracts expiring in 2016 and during the daily session – 9:30 am to 4:00 pm. Best Depth represents the number of contracts available for trade at best quotes at both sides of the market at the end of the time interval. Relative Spread is calculated as $relative\ spread_t = \frac{ask_t + bid_t}{midquote_t} \times 10000$, where ask_t and bid_t represent best quotes at the end of the time interval. Market Orders Executed is the volume of market orders executed at both sides of the market during the 10-second time interval ending at; Limit Orders Submitted is the volume of limit orders submitted at both sides of the market during the 10-second time interval ending at t; Limit Orders Cancelled is the volume of limit orders cancelled at both sides of the market during the 10-second time interval ending at t; VIX_t is the mid-quote of the Volatility Index Futures at time t, the end of the 10-second time interval.

Table II

Intraday Summary of Behaviour

30 min Bucket ending at	Best Depth	Relative Spread	Limit Orders Submitted (in '000)	Market Orders Executed (in '000)	Limit Order Cancellations (in '000)	VIX
09:00	587.5837	1.2155	3.9335	1.1387	3.4245	17.2004
09:30	598.3978	1.2118	3.1020	0.8307	2.7991	17.1973
10:00	619.9601	1.2113	2.6664	0.7024	2.4331	17.1872
10:30	642.7952	1.2114	2.2942	0.6034	2.0821	17.1904
11:00	615.7204	1.2111	1.7875	0.4964	1.6090	17.1710
11:30	622.6572	1.2109	1.3839	0.3883	1.2399	17.1753
12:00	606.8962	1.2111	1.2225	0.3431	1.0990	17.1769
12:30	606.7282	1.2110	1.2025	0.3424	1.0717	17.1813
13:00	606.0073	1.2124	1.1787	0.3444	1.0445	17.1974
13:30	607.0169	1.2117	1.5117	0.4527	1.3280	17.1909
14:00	615.9075	1.2111	1.3753	0.4245	1.1988	17.1764
14:30	646.3446	1.2124	1.5105	0.4763	1.3046	17.1598
15:00	823.0064	1.2100	2.7023	0.9329	2.2799	17.1168

Note: This Table presents intraday averages for a timeseries of variables pertaining to E-mini S&P 500 Futures contract based on thirteen 30-minute time-buckets during the daily session – 9:30 am to 4:00 pm across the sample period extending 21st December 2015 to 7th December 2016 corresponding to the chain of four nearest to maturity contracts expiring in 2016. Best Depth represents the number of contracts available for trade at best quotes at both sides of the market at the end of the time interval. Relative Spread is calculated as $relative\ spread_t = \frac{ask_t + bid_t}{midquote_t} \times 10000$, where ask_t and bid_t represent best quotes at the end of the time interval. Market Orders Executed is the volume of market orders executed at both sides of the market during the 10-second time interval ending at; Limit Orders Submitted is the volume of limit orders submitted at both sides of the market during the 10-second time interval ending at t; Limit Orders Cancelled is the volume of limit orders cancelled at both sides of the market during the 10-second time interval ending at t; VIX_t is the mid-quote of the Volatility Index Futures at time t, the end of the 10-second time interval.

Table III

Two Stage Least Squares Regression Analysis Results

Natural logarithm of relative bid-ask spread as the dependent variable

	(1)	(2)
Intercept	0.080871*	0.081569*
Market Orders Executed (in '000)	0.002774*	
Limit Orders Submitted (in '000)	-0.0023*	
Limit Order Cancellations (in '000)	0.002024*	
Logarithm of Depth at Best Quotes	-0.00692*	-0.00707*
Lag of Logarithm of Relative Spread	0.066522*	0.066984*
Change in Market Orders Executed (in '000)		0.002234*
Change in Limit Orders Submitted (in '000)		-0.00254*
Change in Limit Order Cancellations (in '000)		0.002439*
VIX	0.009177*	0.009227*
R squared	0.57938	0.5793
Fixed Effects	Yes	Yes
Number of observations	507556	507556

Note: This Table reports results of two-stage least squares estimation based on equation:

$$BAS_t = \alpha_1 + \alpha_2 M_t + \alpha_3 L_t + \alpha_4 C_t + \alpha_5 D_t + \alpha_6 BAS_{t-1} + \alpha_7 VIX_t + \sum_{i=1}^{12} \alpha_i FEint_i + \sum_{j=1}^{3} \alpha_j FEquart_j$$

where BAS_t is the natural logarithm of the relative spread at *t*, the end of the 10-second time interval; D_t is the natural logarithm of best depth at time *t*, the end of the 10-second time interval estimated from the first stage least squares regression on natural logarithm of Best Depth at time *t-1*; M_t is the volume of market orders executed at both sides of the market during the 10-second time interval ending at *t* or the change in the number of executed contracts between time-periods ending at *t-1* and *t;* L_t is the volume of limit orders submitted at both sides of the market during the 10-second time interval ending at *t* or the change in the number of submissions between time-periods ending at *t-1* and *t;* C_t is the volume of limit orders cancelled at both sides of the market during the 10-second time interval ending at *t* or the change in the number of cancellations between time-periods ending at *t-1* and *t;* VIX_t is the mid-quote of the Volatility Index Futures at time *t*, the end of the 10-second time interval; $FEint_t$ is a set of dummy variables capturing differences in intraday behavior, based on 30-minute time buckets; and $FEquart_t$ is a set dummy variables capturing differences in quarterly behaviour of variables. Results displayed in the second column show the coefficient estimates of regression (1) with absolute values of market order execution, limit order submission and cancellation variables as independent variables of interest. In the third column market order execution, limit order submission, and cancellation variables are changes from time t-1 to t. Coefficient estimates are marked with an asterisk in case of significance at α=0.99.

Table IV

Two Stage Least Squares Regression Analysis Results

Natural logarithm of best depth as the dependent variable

	(1)	(2)
Intercept	2.15324*	2.104495*
Market Orders Executed (in '000)	-0.17939*	
Limit Orders Submitted (in '000)	0.197983*	
Limit Order Cancellations (in '000)	-0.16256*	
Logarithm of Relative Spread	-1.17103*	-1.19586*
Lag of Logarithm of Depth at Best Quotes	0.729124*	0.742552*
Change in Market Orders Executed (in '000)		-0.13466*
Change in Limit Orders Submitted (in '000)		0.17761*
Change in Limit Order Cancellations (in '000)		-0.15131*
VIX	-0.01807*	-0.01821*
R squared	0.82158	0.82111
Fixed Effects	Yes	Yes
Number of observations	507556	507556

Note: This Table reports results of two-stage least squares estimation based on equation:

$$D_t = \beta_1 + \beta_2 M_t + \beta_3 L_t + \beta_4 C_t + \beta_5 BAS_t + \beta_6 D_{t-1} + \beta_7 VIX_t + \sum_{i=1}^{12} \beta_i FEintr_i + \sum_{j=1}^{3} \beta_j FEquart_j$$

where D_t is the natural logarithm of best depth at time *t*, the end of the 10-second time interval; BAS_t is the natural logarithm of the relative spread at *t*, the end of the 10-second time interval; estimated from the first stage least squares regression on natural logarithm of the relative spread at time *t-1*; M_t is the volume of market orders executed at both sides of the market during the 10-second time interval ending at *t* or the change in the number of executed contracts between time-periods ending at *t-1* and *t;* L_t is the volume of limit orders submitted at both sides of the market during the 10-second time interval ending at *t* or the change in the number of submissions between time-periods ending at *t-1* and *t;* C_t is the volume of limit orders cancelled at both sides of the market during the 10-second time interval ending at *t* or the change in the number of cancellations between time-periods ending at *t-1* and *t;* VIX_t is the mid-quote of the Volatility Index Futures at time *t*, the end of the 10-second time interval; $FEint_t$ is a set of dummy variables capturing differences in intraday behaviour, based on 30-minute time buckets; and $FEquart_t$ is a set dummy variables capturing differences in quarterly behavior of variables. Results displayed in the second column show the coefficient estimates of regression (1) with absolute values of market order execution, limit order submission and cancellation variables as independent variables of interest. In the third column market order execution, limit order submission, and cancellation variables are changes from time t-1 to t. Coefficient estimates are marked with an asterisk in case of significance at α=0.99.

Table V

Two Stage Least Squares Regression Analysis Robustness Results

Adverse selection component of realized spread as the dependent variable

	(1)	(2)
Intercept	1.073308*	1.030856*
Market Orders Executed (in '000)	0.24122*	
Limit Orders Submitted (in '000)	-0.23453*	
Limit Order Cancellations (in '000)	0.249862*	
Logarithm of Depth at Best Quotes	-0.14435*	-0.13522*
Lag of Relative Adverse Spread	0.040882*	0.148898*
Change in Market Orders Executed (in '000)		0.137788*
Change in Limit Orders Submitted (in '000)		-0.11624*
Change in Limit Order Cancellations (in '000)		0.15111*
VIX	0.008031*	0.014046*
R squared	0.2106	0.1814
Fixed Effects	Yes	Yes
Number of observations	505464	505464

Note: This Table reports results of two-stage least squares estimation based on equation:

$$BAS_t = \alpha_1 + \alpha_2 M_t + \alpha_3 L_t + \alpha_4 C_t + \alpha_5 D_t + \alpha_6 BAS_{t-1} + \alpha_7 VIX_t + \sum_{i=1}^{12} \alpha_i FEint_i + \sum_{j=1}^{3} \alpha_j FEquart_j$$

where BAS_t is the volume weighted average relative adverse spread between time-periods ending at *t-1* and *t*; D_t is the natural logarithm of best depth at time *t*, the end of the 10-second time interval estimated from the first stage least squares regression on natural logarithm of Best Depth at time *t-1*; M_t is the volume of market orders executed at both sides of the market during the 10-second time interval ending at *t* or the change in the number of executed contracts between time-periods ending at *t-1* and *t;* L_t is the volume of limit orders submitted at both sides of the market during the 10-second time interval ending at *t* or the change in the number of submissions between time-periods ending at *t-1* and *t;* C_t is the volume of limit orders cancelled at both sides of the market during the 10-second time interval ending at *t* or the change in the number of cancellations between time-periods ending at *t-1* and *t;* VIX_t is the mid-quote of the Volatility Index Futures at time *t*, the end of the 10-second time interval; $FEint_t$ is a set of dummy variables capturing differences in intraday behavior, based on 30-minute time buckets; and $FEquart_t$ is a set dummy variables capturing differences in quarterly behaviour of variables. Results displayed in the second column show the coefficient estimates of regression (1) with absolute values of market order execution, limit order submission and cancellation variables as independent variables of interest. In the third column market order execution, limit order submission, and cancellation variables are changes from time t-1 to t. Coefficient estimates are marked with an asterisk in case of significance at α=0.99.

Table VI

Two Stage Least Squares Regression Analysis Robustness Results

Natural logarithm of best depth as the dependent variable

	(1)	(2)
Intercept	2.259532*	2.269976*
Market Orders Executed (in '000)	-0.17735*	
Limit Orders Submitted (in '000)	0.194399*	
Limit Order Cancellations (in '000)	-0.15749*	
Relative Adverse Spread	-0.36813*	-0.52473*
Lag of Logarithm of Depth at Best Quotes	0.719732*	0.733401*
Change in Market Orders Executed (in '000)		-0.14245*
Change in Limit Orders Submitted (in '000)		0.182717*
Change in Limit Order Cancellations (in '000)		-0.15814*
VIX	-0.02483*	-0.02417*
R squared	0.7882	0.74976
Fixed Effects	Yes	Yes
Number of observations	505464	505464

Note: This Table reports results of two-stage least squares estimation based on equation:

$$D_t = \beta_1 + \beta_2 M_t + \beta_3 L_t + \beta_4 C_t + \beta_5 BAS_t + \beta_6 D_{t-1} + \beta_7 VIX_t + \sum_{i=1}^{12} \beta_i FEintr_i + \sum_{j=1}^{3} \beta_j FEquart_j$$

where D_t is the natural logarithm of best depth at time *t,* the end of the 10-second time interval; BAS_t is the volume weighted average relative adverse spread between time-periods ending at *t-1* and *t* estimated from the first stage least squares regression on volume weighted average relative adverse spread between time-periods ending at *t-2* and *t-1*; M_t is the volume of market orders executed at both sides of the market during the 10-second time interval ending at *t* or the change in the number of executed contracts between time-periods ending at *t-1* and *t;* L_t is the volume of limit orders submitted at both sides of the market during the 10-second time interval ending at *t* or the change in the number of submissions between time-periods ending at *t-1* and *t;* C_t is the volume of limit orders cancelled at both sides of the market during the 10-second time interval ending at *t* or the change in the number of cancellations between time-periods ending at *t-1* and *t;* VIX_t is the mid-quote of the Volatility Index Futures at time *t,* the end of the 10-second time interval; $FEint_t$ is a set of dummy variables capturing differences in intraday behavior, based on 30-minute time buckets; and $FEquart_t$ is a set dummy variables capturing differences in quarterly behavior of variables. Results displayed in the second column show the coefficient estimates of regression (1) with absolute values of market order execution, limit order submission and cancellation variables as independent variables of interest. In the third column market order execution, limit order submission, and cancellation variables are changes from time t-1 to t. Coefficient estimates are marked with an asterisk in case of significance at α=0.99.