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Competition, signaling and non-walking through the book: Effects on order choice

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ABSTRACT

We investigate the effects of competition and signaling in a pure order driven market and examine the trading patterns of agents when walking through the book is not allowed. Our results suggest that the variables capturing the cost of a large market order are not informative for an impatient trader under this market mechanism. We also document that the competition effect is not present only at the top of the book but persistent beyond the best quotes. Moreover, it dominates the signaling effect for both a limit order and a market order trader. Finally, we show that institutional investors' order submission strategies are characterized by only a few pieces of the limit order book information. This is consistent with informed traders placing orders based on their own private valuations rather than the state of the book.

1. Introduction

The limit order book and the characteristics of an asset, such as volatility, provide essential information for a trader who wants to design an appropriate order submission strategy. This in turn affects the price formation of an asset and the liquidity dynamics in the market. Following this, there has been a growing research interest on investors' choice of order submission over the last decade. By undertaking an empirical study of a pure order driven market, this paper aims to contribute to this literature. Our contribution is twofold: first, we examine the trading patterns of agents when walking through the book is not allowed, i.e. when orders that would otherwise walk through the book are converted into limit orders. Second, we test whether "competition" or "signaling" effects, two theories that have been proposed in the existing literature, dominate each other for depth beyond the best quotes. Both of these analyses are the first attempts in the literature.

In the Istanbul Stock Exchange, walking through the book is not allowed. That is, a "large" market order is first matched with the available volume at the best corresponding quote. Then, the remaining part is converted to a limit order at the quoted price instead of walking up or down the limit order book to be fully executed. This market rule obviously affects the cost of a market order. When walking down/up the book is allowed, the cost of execution of a large market order is higher since it matches with less favorable prices (Hamao and Hasbrouck, 1995). This in turn should affect the market order trader's submission strategy. By focusing on the order choice of an impatient (market order) trader, we analyze the informativeness of the price information contained in the book.

In an early work, Parlour (1998) suggests that an increase in the same-side thickness of the limit order book reveals high *competition*, which in turn increases the submission of more aggressive orders in order to jump the queue ("competition effect"). On the other hand, in their recent theoretical works, Goettler et al. (2005) and Goettler et al. (2009) argue that if the total volume of orders waiting beyond the best bid (ask) is "too high", then this *signals* to the market that the current quotes are mispriced and should decrease (increase) ("signaling effect"). By calculating the volume of orders waiting in the queue for the 10 best quotes, we analyze which effect dominates at every price level.

Our analysis requires considering the reaction of the patient (limit order) and impatient (market order) traders separately to the changing market conditions. Hence, similar to Pascual and Veredas (2009), we employ a two-stage sequential ordered probit (SOP) model. Although our methodology coincides with their

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study, our research questions are different. In order to test whether competition effect is more persistent than the best quotes, we focus on the actions of patient traders. On the other hand, to analyze whether or how non-walking through the book affects the trading strategy of a market order trader, we focus on the trading strategies of impatient traders.

Using the unprocessed order flow and trade data provided by the Istanbul Stock Exchange (ISE), we first reconstruct the limit order book dynamically. We use the order flow, trade book and limit order book to analyze the effects of the information content of the books on the order choice of the traders on a sample of 30 stocks for the period of June and July 2008. Our data set has one major advantage compared to many studies: since the ISE is a fully computerized and centralized stock exchange (unlike NYSE, there is no specialist and unlike the London Stock Exchange for instance, there is a single trading platform in the ISE), the data generated *fully* captures the order flow and the execution process. Moreover, in our data set we can distinguish whether an order is initiated by an institutional or individual investor. By using this classification we examine whether the trading behavior is different for institutional traders compared to the individual ones.

There are several papers that provide a theoretical background that the state of the limit order book contains information that shapes agents' trading decisions.[1] Ahn et al. (2001), Ranaldo (2004), Beber and Caglio (2005), Ellul et al. (2007), Fong and Liu (2010), Menkhoff et al. (2010), among others investigate the state of the book and its effects on order choice of an investor in an empirical framework. The aforementioned studies consider the informativeness of the limit order book only at the best quotes. Relevant exceptions are Cao et al. (2008), Cao et al. (2009), Pascual and Veredas (2009) and Lo and Sapp (2010).

Using data from the Australian Stock Exchange, Cao et al. (2008) show that the information contained at the best quotes affects order submissions, cancelations, and modifications. On the other hand, the rest of the book matters for order cancellations and modifications. Using the same data set, Cao et al. (2009) investigate whether the prices beyond the best bid and offer and their corresponding depths matter in price discovery. They conclude that the contribution of beyond the book to the price discovery is 22%, whereas the remaining part comes from the current bid and ask prices as well as the transaction price. Using a two-stage sequential ordered probit model, Pascual and Veredas (2009) conclude that not only the best quotes, but the information beyond the best quotes matters in explaining the degree of patience of incoming orders. Moreover, they note that although the impatient traders strongly rely on the prevailing best quotes, for patient traders, strategic decisions are primarily based on the state of the book beyond the best quotes. Lo and Sapp (2010) empirically show the trade-off between order aggressiveness and quantity. Using simultaneous equations framework in a foreign exchange market, they conclude that order size tends to be smaller when an order is more aggressive. That is, by submitting smaller size market orders, traders avoid the higher execution costs. Our paper is the first study that investigates whether the volume of orders waiting at different price distances encourage agents to submit more aggressive orders and jump the queue, or rather signal them to submit less aggressive orders. Moreover, an atypical feature of our dataset enables us to examine the order choice of a trader when walking through the book is not allowed.[2]

Our main findings can be summarized as follows:

- The competition effect dominates the signaling effect for both sides of the market, in every stage.
- For a limit order agent, the competition effect is persistent beyond the best quotes. We show that for both sides of the market, the volume up to the second best quotes has the strongest competition effect.
- While fitting the size of her market order, for an impatient trader none of the price information, neither spread or price distance variables, matter in our market. This might be a result of the non-walking through the book, since under this mechanism, the spread and the price distance variables do not capture the cost of a large market order.
- We show that volatility, previous price trend and volume accumulated beyond the best quotes on the opposite side of the book affect the aggressiveness of market orders. This result might also be explained by the non-allowance of walking through the book, since these variables affect the execution probability of the unexecuted part of a large market order.
- Institutional investors consider only the competition effect variables while they decide to submit a market or a limit order. If they are informed traders as proposed by the existing literature, this may imply that institutions place orders based more on their own private valuations than the information provided by the limit order book.

The paper is organized as follows: Next section describes data and introduce the order aggressiveness categories. Section 3 presents the econometric methodology; the two-stage sequential ordered probit model. In Section 4, we list the explanatory variables and discuss the empirical questions. Section 5 presents the empirical findings and robustness checks. Finally Section 6 concludes.

2. The market and data

2.1. Trading structure in the Istanbul Stock Exchange

The Istanbul Stock Exchange (ISE) is operating as a fully computerized pure order-driven market since November 1994. As of December 2012, the ISE index had a $358 billion value of shares traded year-to-date and $315 billion of market capitalization. The total value of shares trading and the market capitalization were 3% and 2% of NYSE respectively.[3] In terms of value of shares traded, it is the 20th largest stock exchange in the world and 5th within the emerging countries.[4]

Similar to all other major exchanges, a trading day starts with a call market matching mechanism to determine the opening price. For the rest of the day, a double auction continuous order matching mechanism is used for trading. Trading occurs in two sessions with a lunch break and every order is valid for a corresponding session or for a day. For the period under consideration, the double-continuous auction trading occurs between 9:45–12:00 in the morning session and 14:00–17:00 in the afternoon session. A given order is either matched, resulting in a trade, or queued up in a limit order book waiting to be executed based on the usual price and time priorities. The fully computerized system ensures the strict enforcement of those priority rules. The status of a given security is updated almost instantaneously on the traders' screens, whenever there is an order arrival, or execution.

[1] See Parlour (1998), Foucault (1999), Foucault et al. (2005), Goettler et al. (2005), Kaniel and Liu (2006), Goettler et al. (2009), Rosu (2009) among others.

[2] There are other studies that use intraday data from the ISE. For instance, Bildik (2001) and Ekinci (2008) provide intraday descriptive analyses for the ISE. Bildik (2001) examines the intraday seasonality of the stock returns and volatilities, whereas Ekinci (2008) focuses on the intraday liquidity patterns.

[3] Source: World Federation of Stock Exchanges.

[4] Emerging countries are classified based on the list of the International Monetary Fund July 16, 2012 report.

Similar to the Australian Stock Exchange and the Spanish Stock Exchange for instance, the ISE is an open limit order book market. In this market, both individual and institutional investors are directly connected to the ISE system and they can observe the book in real time. On the other hand, the ISE offers more pre-trade transparency compared to many other exchanges. Upon arrival, traders can observe all of the orders submitted/traded, with the corresponding prices and volumes. The information is not truncated to any price step. Moreover, for the executed orders only, they can see the name of the corresponding party who initiated the trade.[5] The open book and pre-trade transparency properties are relevant for our study since we examine the "competition" and "signaling" effects beyond the best quotes up to the 10 best prices.

The other market mechanism worth to emphasize is that walking through the book is not allowed in the ISE, similar to the Australian Stock Exchange, the Sao Paulo Stock Exchange (Bovespa), and the Stock Exchange of Hong Kong, for example. Hence, the unexecuted portion of a marketable limit order[6] is converted to a limit order. If an investor wishes to buy (sell) shares by walking up (down) the book, she needs to use appropriate limit orders. This characteristic allows us to examine the effects of this particular market mechanism on the order choice of a market order trader.

2.2. Data and descriptive analysis

Our dataset contains the order and trade books for the period of June and July 2008 for the biggest 30 stocks listed on the Istanbul Stock Exchange (ISE30 index). The 30 stocks in our sample correspond to 75% of the total trading volume of the ISE for the period under consideration. These data sets allow us to reconstruct the complete limit order book dynamically. The order book data consists of all submitted orders for a given stock and date, their corresponding prices and quantities, order submission times, an order identification number (order ID), buy/sell indicator, as well as whether the trader is an institutional or an individual one. On the other hand, the transaction data consists of all the executed orders, their corresponding prices and quantities, and execution times. These two books are linked to each other with order and trade ID numbers generated by the ISE system. Hence, our data enables us to track an order from submission to execution or modification (if any).

To reconstruct the limit order book, we incorporate every order according to the price and time priority rules and fill in the limit order book one by one. If the price of a new-coming buy (sell) order is higher (lower) than or equal to the ask (bid) price, we classify it as a market order. A market order is matched with the corresponding order(s) from the other side of the book and removed from the limit order book. Moreover, if an order revision (including the split) is submitted, the original order is removed from the limit order book. For a given limit order book snapshot, we have a list of orders submitted but not yet executed, whether they are buy or sell orders and originated by individual or institutional traders, price and volume information up to the 10th best quotes. The volume available at the best, second best, and up to the 10th best prices are calculated as the total volume of orders waiting at that price level. Hence, by reconstructing the limit order book, we have access to the information on both the length (price information) and the height (the corresponding volume information) of a limit order book, which is crucial for our analysis to understand how the information beyond the best quotes affects the order submission strategies of agents.

Table 1 reports the descriptive statistics of the order flow and trade book, averaged across the sample period. Besides the market capitalization, for which the value at the beginning of the sample period in million Turkish Liras (M TRY) is presented, all of the figures are obtained by averaging across trading days (excluding the opening sessions). The results show that, on average 2253 orders are submitted in a day, equivalent to 83 million TRY.[7] The highest number of orders is submitted and traded by Garanti Bankasi (GARAN) investors, whereas the smallest one is for Migros (MIGRS). In terms of volume of orders submitted, GARAN is 8 times bigger than the average, whereas MIGRS, is 9 times smaller than the average. Although our sample is composed by the 30 biggest stocks traded in the ISE, these results show a high degree of heterogeneity in the sample of study. On average around 1400 trades occur in a day with a total daily average trade size of 9 million shares. This corresponds to an average value traded of around 28 million TRY per day. The number of buy orders is slightly less than the number of sell orders, and the number of limit orders constitute about 68% of all the submitted orders. The average tick adjusted spread is quite narrow, being less than 2 for all of the stocks in our sample. This is similar to the findings of Griffiths et al. (2000) on the most liquid securities of the Toronto Stock Exchange, but lower than the spreads presented in Pascual and Veredas (2009)'s study of 36 stocks from the Spanish Stock Exchange.

2.2.1. Order aggressiveness

In order to analyze how the state of the book affects the order choice of an investor, we define order aggressiveness categories based on the classification of Biais et al. (1995). The first two categories are related to the market order (MO) aggressiveness, whereas the rest is defined for the limit order (LO) aggressiveness based on the limit price position.

- Category 1 ("large MO buy"): $V_{order} \geqslant V_{ask}$ and $P_{order} \geqslant P_{ask}$.
- Category 2 ("small MO buy"): $V_{order} < V_{ask}$ and $P_{order} \geqslant P_{ask}$.
- Category 3 ("buy LO within the quotes"): $P_{ask} > P_{order} > P_{bid}$.
- Category 4 ("buy LO at the quote"): $P_{ask} > P_{order} = P_{bid}$.
- Category 5 ("buy LO away from the quote"): $P_{order} < P_{bid} < P_{ask}$.

where V_{order} and P_{order} are the volume and the price of a buy order, respectively. V_{ask} is the accumulated volume of orders waiting at the best ask price, P_{ask}. Finally, P_{bid} denotes the best bid price. Sell side is constructed analogously.

Table 2 presents the descriptive statistics of the order aggressiveness categories for both buy and sell sides of the market separately. The results suggest that for the buy side, the most frequent events are small buy market orders (category 2) followed by orders submitted at the quotes, whereas for the sell side the ones away from the best quotes (category 5) have the most frequent arrivals, contradicting the findings of Biais et al. (1995), Beber and Caglio (2005), and Griffiths et al. (2000) for the Paris Bourse, the NYSE and the Toronto Stock Exchange, respectively. However this inconsistency is intuitive when we take into account the volatile nature of the ISE compared to other developed economy stock exchanges.[8] Orders placed far from the best prices may suggest that investors believe large jumps in the price of stocks are always possible, and by placing orders far from the current price they may want to take advantage of these large potential fluctuations. Table 2 also shows a very little frequency of orders within the quotes (for both sides of the book), which can be explained by the small inside spread. The results regarding the execution rate, i.e. the proportion of orders executed, suggest that only around 20% of orders away from the

[5] The non-anonymity has changed by October 2010, but for the sample under consideration, traders can identify the name of the trading parties.

[6] In this study, we call marketable limit orders as market orders following Payne (2003) and Hasbrouck and Saar (2009).

[7] On 25th of July 2008, the exchange rate was 1.20USD/TRY.

[8] The daily volatility for July 2008 was 7% for CAC40, 6% for S&P500 and 5% for DowJones, whereas it was 12% for the ISE30.

Table 1
Descriptive statistics for each stock. The table reports the summary statistics of ISE30 stocks for June–July 2008. The first and the second columns present the ticker and names of the securities in our sample, respectively. The market capitalization is the value at beginning of the sample period in million Turkish Liras (M TRY). Number of Orders (Trades) is the average of the total number of orders (trades) in a day. Volume of Orders (Trades) is the average of the daily number of shares submitted (traded). Value of Orders (Trades) is the average of the daily value of orders (trades) (volume × price). Spread is the tick-adjusted difference between the best ask and the best bid. Finally the last two columns report the average of the daily percentage of buy orders and limit orders, respectively.

Company ticker	Company name	Market capitalization (M TRY)	Number of orders	Volume of orders (M shares)	Value of orders (M TRY)
AKBNK	Akbank	16,650	2609	26	130.63
AKGRT	Aksigorta	1463	1044	4	18.35
ARCLK	Arcelik	1664	1003	2	10.51
ASYAB	Asya Katilim Bankasi	1980	1392	7	16.94
DOHOL	Dogan Holding	2160	2438	37	54.95
DYHOL	Dogan Yayin Holding	1082	2991	28	46.06
EREGL	Eregli Demir Celik	9995	2286	7	61.99
GARAN	Garanti Bankasi	14,448	9259	221	749.10
GSDHO	Gsd Holding	277	2074	33	35.77
HALKB	Halk Bankasi	7750	1656	8	49.35
HURGZ	Hurriyet Gazetesi	745	2281	29	45.50
IHLAS	Ihlas Holding	202	1975	32	18.15
ISCTR	Is Bankasi	13,165	7332	89	393.63
ISGYO	Is GMYO	459	700	5	4.94
KCHOL	Koc Holding	7629	1399	12	41.51
KRDMD	Kardemir	670	2016	34	38.73
MIGRS	Migros	3614	346	3	60.88
PETKM	Petkim	1024	1156	4	20.39
PTOFS	Petrol Ofisi	2778	507	2	8.47
SAHOL	Sabanci Holding	8676	1103	7	28.25
SISE	Sise Cam	1439	1572	10	14.73
SKBNK	Sekerbank	876	1872	10	21.47
TCELL	Turkcell	17,050	1847	15	117.95
THYAO	Turk Hava Yollari	919	1252	5	26.83
TKFNK	Tekfen Holding	2166	1172	3	25.96
TSKB	TSKB	490	707	6	5.73
TTKOM	Turk Telekom	14,350	4447	29	119.25
TUPRS	Tupras	7387	1413	3	75.11
VAKBN	Vakiflar Bankasi	4400	4813	86	151.08
YKBNK	Yapi ve Kredi Bankasi	9999	2939	42	106.19
Average		5184	2253	26.52	83.28
Median		2163	1752	10.04	40.12
Min		202	346	1.59	4.94
Max		17,050	9259	221.13	749.10

Company ticker	Number of trades	Volume traded (M shares)	Value traded (M TRY)	Spread (tick adj.)	Buy orders (%)	Limit orders (%)
AKBNK	1643	8.81	44.09	1.04	46.79	68.56
AKGRT	714	1.54	6.59	1.15	52.13	62.16
ARCLK	576	0.75	3.27	1.25	45.50	71.04
ASYAB	954	2.19	5.64	1.14	49.20	62.10
DOHOL	1546	12.37	18.45	1.06	44.11	68.74
DYHOL	1949	9.45	15.40	1.06	48.77	65.93
EREGL	1455	2.19	20.22	1.08	48.71	67.76
GARAN	6186	82.39	278.14	1.02	47.46	69.78
GSDHO	1400	10.91	11.78	1.05	47.48	64.22
HALKB	972	2.56	15.99	1.10	46.46	71.57
HURGZ	1455	9.53	15.09	1.10	47.05	67.16
IHLAS	942	7.63	4.30	1.01	47.64	70.75
ISCTR	4732	32.46	143.32	1.03	49.48	69.81
ISGYO	367	1.35	1.31	1.11	44.94	71.81
KCHOL	855	3.93	13.72	1.11	45.17	68.76
KRDMD	1150	9.91	11.39	1.05	45.80	70.28
MIGRS	152	0.48	9.84	1.03	38.90	70.28
PETKM	688	1.12	6.02	1.14	46.81	70.54
PTOFS	295	0.48	2.53	1.38	45.80	69.47
SAHOL	713	2.19	9.44	1.15	48.54	66.25
SISE	975	3.24	4.63	1.08	51.39	67.02
SKBNK	1216	3.23	7.06	1.15	44.15	64.36
TCELL	1095	5.05	40.15	1.10	46.47	71.25
THYAO	787	1.65	8.99	1.10	50.52	68.10
TKFNK	747	1.00	8.56	1.13	48.63	64.70
TSKB	448	1.72	1.62	1.06	48.98	63.23
TTKOM	2343	8.48	35.07	1.05	39.22	73.20
TUPRS	761	0.83	22.86	1.07	48.45	73.68
VAKBN	3169	31.17	54.61	1.04	47.42	68.53
YKBNK	1911	14.61	36.47	1.04	48.33	67.08
Average	1406	9.11	28.55	1.10	47.01	68.27
Median	973	3.24	11.59	1.08	47.44	68.65
Min	152	0.48	1.31	1.01	38.90	62.10
Max	6186	82.39	278.14	1.38	52.13	73.68

Table 2
Descriptive statistics of the order aggressiveness categories. This table presents the descriptive statistics of the order aggressiveness categories for both sides of the market. Orders are divided into five categories based on the limit price position following Biais et al. (1995). Category 1 ("large MO buy"): $V_{order} \geqslant V_{ask}$ and $P_{order} \geqslant P_{ask}$. Category 2 ("small MO buy"): $V_{order} < V_{ask}$ and $P_{order} \geqslant P_{ask}$. Category 3 ("buy LO within the quotes"): $P_{ask} > P_{order} > P_{bid}$. Category 4 ("buy LO at the quote"): $P_{ask} > P_{order} = P_{bid}$. Category 5 ("buy LO away from the quote"): $P_{order} < P_{bid} < P_{ask}$. V_{order} and P_{order} are the volume and the limit price of the buy order, respectively. V_{ask} is the accumulated volume of orders waiting at the best ask price, P_{ask}. Finally, P_{bid} denotes the best bid price. Sell side is constructed analogously. The first two columns report the proportion of orders and order sizes for each category. Execution rate is calculated as the proportion of orders executed in each category, whereas the last column presents the average execution time (in minutes) of orders in each category.

	Number of orders (%)	Volume of orders (%)	Execution rate (%)	Execution time (min)
Buy side				
Category 1	3.77	14.82	98.05	3
Category 2	33.24	24.31	99.77	0
Category 3	0.98	1.90	86.88	18
Category 4	32.14	34.79	67.33	24
Category 5	29.87	24.17	21.31	88
Sell side				
Category 1	3.51	12.71	98.16	2
Category 2	24.44	22.42	99.77	0
Category 3	0.85	1.66	88.95	15
Category 4	28.79	32.32	60.72	21
Category 5	42.41	30.88	16.04	78

quotes are executed compared to 60% of execution rate for the orders at the quotes. That is, going from category 4 to 5; traders are facing a substantial non-execution risk. These figures are very similar to Griffiths et al. (2000) for the Toronto Stock Exchange. A similar conclusion can be derived from the average waiting times for execution.

3. Sequential ordered probit regressions

We investigate how the information content of the limit order book affects the order choice of the investor, by considering the order choice as a two-stage process. As a first step in her order choice, observing the market dynamics and limit order book information, the agent is patient, i.e. submits a limit order, or she is impatient, i.e. submits a market order.[9] In the second stage, given the agent is patient, she decides the position of her limit price (decides to submit category 3, 4 or 5 order), whereas the impatient trader decides whether to submit a large or small market order (category 1 or 2 order). To allow this sequential decision, following Pascual and Veredas (2009), we employ a sequential ordered probit (SOP) model for the empirical investigation. The attractiveness of the SOP model, compared to the ordered probit model, is that the former enables us to compare the reaction of the patient and impatient trader to the changing market conditions separately.

3.1. First stage-arrival of a market or limit order trader

In the first stage of the SOP model, the degree of patience of the incoming trader, Y^*, is unobservable. However, we assume that it is a function of K observable (limit order book) variables, Xs. We consider volatility, price trend, volume and price distances as explanatory variables. A detailed explanation of the regressors is provided in the next section.

$$Y_t^* = \sum_{k=1}^{K} \beta_k X_{k,t-1} + \varepsilon_t \tag{1}$$

$$Y_t = \begin{cases} 0 & \text{if } -\infty < Y_t^* \leqslant \delta \\ 1 & \text{if } \delta < Y_t^* < \infty \end{cases} \tag{2}$$

where δ is the threshold and t refers to the transaction time, not the clock time. The first-stage-dependent variable is equal to 1 if the trader is impatient and submits a market order or 0 if the trader is patient and submits a limit order.

Assuming that the error terms are normally distributed, the probability of the incoming trader being patient is:

$$\begin{aligned} P(Y_t = 0) &= P\left(-\infty < Y_t^* \leqslant \delta\right) \\ &= P\left(-\infty < \sum_{k=1}^{K} \beta_k X_{k,t-1} + \varepsilon_t \leqslant \delta\right) = \Phi\left(\delta - \sum_{k=1}^{K} \beta_k X_{k,t-1}\right) \end{aligned} \tag{3}$$

where Φ is the normal cumulative distribution function.

3.2. Second stage-patient trader

In the second stage, both patient and impatient traders choose their level of aggressiveness given the information content of the book. A patient trader has three choices: submitting a limit order within, at or away from the best quotes. That is;

$$LO_t^* = \sum_{k=1}^{K} \theta_k X_{k,t-1}^{lo} + \varepsilon_t^{lo} \tag{4}$$

$$LO_t = \begin{cases} 1 & \text{if } -\infty < LO_t^* \leqslant \delta_1^{lo} \\ 2 & \text{if } \delta_1^{lo} < LO_t^* \leqslant \delta_2^{lo} \\ 3 & \text{if } \delta_2^{lo} < LO_t^* < \infty \end{cases} \tag{5}$$

where δ_1^{lo} and δ_2^{lo} are the thresholds.

The dependent variable is equal to 1 if a trader submits a limit order away from the best quotes (category 5), is equal to 2, if the order is submitted at the best quotes (category 4) or is equal to 3 if the order is submitted within the quotes (category 3). Hence, our dependent variable increases as aggressiveness increases.

Assuming that the error terms are normally distributed, the probability of the incoming patient trader being type $i = 1, 2, 3$ is:

$$P(\mathrm{LO}_t = i) = \Phi\left(\delta_i^{lo} - \sum_{k=1}^{K} \theta_k X_{k,t-1}\right) - \Phi\left(\delta_{i-1}^{lo} - \sum_{k=1}^{K} \theta_k X_{k,t-1}\right) \tag{6}$$

[9] One can argue that the degree of patience is based on a trader's information level, preferences or waiting costs, hence, exogenously determined. However, recent theoretical works suggest that market conditions and the state of the book affect the degree of patience. For example Goettler et al. (2009) claim that although a patient informed agent submits a limit order, when she observes high volatility, she switches to a market order to take advantage of the mispriced quotes. Similarly, in Foucault et al. (2005), if spread increases over a cutoff level, all traders, even the ones with high waiting costs, will submit limit orders. Moreover, Ranaldo (2004), Beber and Caglio (2005) among others show empirically that a trader considers the state of the book while formulating her order strategies. Hence, we allow the arrival rate of patient and impatient agents to be influenced by the state of the book and market conditions.

Table 3
Analysis of depth beyond the best quotes. The table presents the results of the depth analysis using different cutoff values. Vcomp = $Vsame^{j} + \cdots + Vsame^{cutoff}$, where $j = 1$, if spread/tick > 1, $j = 2$ otherwise. Whereas, Vsign = $Vsame^{cutoff+1} + \cdots + Vsame^{10}$. Vcompopp and Vsignopp are constructed analogously for the opposite side of the book. All of the volume variables are scaled by 1e−6. Vola is the EWMA volatility (multiplied by 1000), Trend is the previous price change of 60 observations (multiplied by 1000), SPR is the (tick adjusted) inside spread, calculated as the difference between the lowest ask and the highest bid quotes. The median of the estimated significant coefficients for the stocks in our sample, the percentage of statistically significant coefficients at 5% level, and the percentage of positive coefficients given that they are significant are reported.

Buy	Vola	Trend	SPR	Vcomp	Vcompopp	Vsign	Vsignopp
Cutoff = 2							
Median	0.04	0.82	0.78	0.67	0.08	−0.10	0.07
Sig. (%)	50	73	97	80	27	60	37
Pos. (%)	93	100	100	100	75	6	100
Cutoff = 3							
Median	0.04	0.83	0.81	0.47	0.07	−0.14	0.05
Sig. (%)	47	77	97	67	47	53	27
Pos. (%)	93	100	100	95	79	0	88
Cutoff = 4							
Median	0.04	0.82	0.84	0.39	0.09	−0.11	0.02
Sig. (%)	47	77	97	57	43	43	40
Pos. (%)	93	100	100	82	92	15	58
Cutoff = 5							
Median	0.04	0.82	0.82	0.32	0.15	−0.09	0.06
Sig. (%)	47	80	97	53	53	47	37
Pos. (%)	93	100	100	75	100	29	64
Sell							
Cutoff = 2							
Median	0.05	−0.62	0.66	1.30	0.11	−0.19	0.05
Sig. (%)	43	60	100	83	27	83	47
Pos. (%)	85	6	100	100	63	8	79
Cutoff = 3							
Median	0.05	−0.63	0.68	0.68	0.08	−0.24	0.06
Sig. (%)	47	57	97	77	50	77	43
Pos. (%)	79	6	100	96	60	0	69
Cutoff = 4							
Median	0.05	−0.64	0.65	0.21	0.10	−0.34	0.04
Sig. (%)	43	57	97	67	43	67	47
Pos. (%)	77	6	100	85	92	0	64
Cutoff = 5							
Median	0.05	−0.65	0.65	0.12	0.07	−0.44	0.01
Sig. (%)	43	57	97	57	57	60	40
Pos. (%)	77	6	100	59	94	0	58

where $\delta_0^{lo} = -\infty$ and $\delta_3^{lo} = \infty$.

3.3. Second stage-impatient trader

Finally, the impatient trader decides the quantity she wants to trade; whether she submits an aggressive market order (category 1), or submits a small market order (category 2). The dependent variable is equal to 1 if a category 1 order is submitted, 0 otherwise.

$$MO_t^* = \sum_{k=1}^{K} \gamma_k X_{k,t-1}^{mo} + \varepsilon_t^{mo} \tag{7}$$

$$MO_t = \begin{cases} 0 & \text{if } -\infty < MO_t^* \leqslant \delta_1^{mo} \\ 1 & \text{if } \delta_1^{mo} < MO_t^* < \infty \end{cases} \tag{8}$$

where δ_1^{mo} is the threshold.

As the coefficients of the sequential ordered probit measure the change in the latent variable with respect to a change in one of the explanatory variables, they are difficult to interpret. A direct interpretable measure is given by the marginal probabilities (marginal effects), which show how the probability of order choices is affected given a marginal change in any of the explanatory variables:

$$\frac{\partial P(Y=0)}{\partial X_j} = \frac{\partial \Phi(\delta - \sum_{k=1}^{K} \beta_k X_{k,t-1})}{\partial X_j} = -\phi\left(\delta - \sum_{k=1}^{K} \beta_k X_{k,t-1}\right)\beta_j \tag{9}$$

$$\begin{aligned} \frac{\partial P(LO=i)}{\partial X_j} &= \frac{\partial(\Phi(\delta_i^{lo} - \sum_{k=1}^{K}\theta_k X_{k,t-1}) - \Phi(\delta_{i-1}^{lo} - \sum_{k=1}^{K}\theta_k X_{k,t-1}))}{\partial X_j} \\ &= \left[\phi\left(\delta_{i-1}^{lo} - \sum_{k=1}^{K}\theta_k X_{k,t-1}\right) - \phi\left(\delta_i^{lo} - \sum_{k=1}^{K}\theta_k X_{k,t-1}\right)\right]\theta_j \end{aligned} \tag{10}$$

$$\begin{aligned} \frac{\partial P(MO=0)}{\partial X_j} &= \frac{\partial \Phi(\delta_1^{mo} - \sum_{k=1}^{K}\gamma_k X_{k,t-1})}{\partial X_j} \\ &= \phi\left(\delta_1^{mo} - \sum_{k=1}^{K}\gamma_k X_{k,t-1}\right)\gamma_j \end{aligned} \tag{11}$$

where $i = 1, 2, 3$ and $\delta_0^{lo} = -\infty$ and $\delta_3^{lo} = \infty$.

4. Empirical analysis

Empirically we ask the following questions: whether "competition" or "signaling" effects dominate each other at every level of the depth, how/whether walking through the book affects the order decision of an impatient trader, and finally, whether the limit order book information affects the trading behavior institutional investors.

4.1. Covariates for the impact of depth at and beyond the best quotes

We test whether the competition and signaling effects, proposed by Parlour (1998) and Goettler et al. (2005), Goettler et al. (2009), respectively, dominate each other for depths beyond the best quotes. To do so, we calculate the volume of orders waiting in the queue for the 10 best prices. We define a proxy for the signaling and competition effects separately for every stage of the sequential ordered probit (SOP) regressions. In the first stage of the SOP, when a trader decides whether to submit a market or a limit order, she considers only the increase of the volume at the best quotes ($Vsame^1$ and/or $Vopp^1$) as an increased competition. We therefore use the volume of orders waiting beyond the best quotes as a proxy for signaling effect. Given that the trader is impatient, in the second stage, she decides the size of her market order. In this case, since the order has the price priority, there will be no price competition and the volume of orders beyond the best quotes captures the signaling effect.

On the other hand, in the second stage, when a limit order trader decides her limit price, we consider two states: first, (tick-adjusted) inside spread greater than 1 and second, spread equal to 1. If an agent observes the inside spread greater than 1, then by submitting an order *within* the quotes (category 3 order) she can jump the queue. In this case, $Vsame^1$ and (possibly) depth beyond the best quotes captures the competition effect. However, if the spread is 1, then "mechanically" it is not possible to submit a category 3 order, i.e. a trader cannot gain priority over the orders already waiting at $Vsame^1$. In this case, while positioning her limit price, she may consider just the depth beyond the best quotes as an increased competition, at least up to some *cutoff* level, discarding the depth at the quotes as part of the competition effect. In order to determine the cutoff point, we run the SOP regressions with accumulated volume of orders from the second to the third, from the second to the fourth and from the second to the fifth best prices ($Vsame^{2\_3}$, $Vsame^{2\_4}$ and $Vsame^{2\_5}$). The signaling effect will then be captured by $Vsame^{4\_10}$, $Vsame^{5\_10}$ and $Vsame^{6\_10}$, respectively. Table 3 reports the results. For both sides of the market, the volume up to the second best quotes has the strongest competition effect. That is, the competition effect persists beyond the best quotes. The marginal effects as well as the significance of the estimated coefficients are decreasing with the additional quotes added.[10] Moreover, at every price level, competition effect dominates the signaling effect. Finally, the results suggest an asymmetry between the sell and the buy side. The signaling effect is more persistent and stronger for the sell side.

As suggested, we pick the volume at the second best quote as the cutoff level. Hence, we define the competition effect, Vcomp and the signaling effect, Vsign as follows:

- Step 1 – arrival rate of patient/impatient traders:

$$\begin{aligned} \text{Vcomp}_t &= \text{Vsame}_t^1 \\ \text{Vsign}_t &= \text{Vsame}_t^2 + \text{Vsame}_t^3 + \cdots + \text{Vsame}_t^{10} \end{aligned} \tag{12}$$

- Step 2 – order choice of patient traders:

$$\text{Vcomp}_t = \begin{cases} \text{Vsame}_t^2 & \text{if spread}_t = 1 \\ \text{Vsame}_t^1 + \text{Vsame}_t^2 & \text{if spread}_t > 1 \end{cases} \tag{13}$$

$$\text{Vsign}_t = \text{Vsame}_t^3 + \text{Vsame}_t^4 + \cdots + \text{Vsame}_t^{10}$$

- Step 2 – order choice of impatient traders:

$$\text{Vsign}_t = \text{Vsame}_t^2 + \text{Vsame}_t^3 + \cdots + \text{Vsame}_t^{10} \tag{14}$$

where $Vsame^i$ is the total volume of orders waiting at the ith best quote. Competition and signaling effects for the opposite side of the book, Vcompopp and Vsignopp are constructed analogously.

4.2. Covariates for the impact of non-walking through the book

In markets where walking through the book is allowed, an aggressive (category 1) market order has to walk up or down the order book to be fully executed. For markets in which walking through the book is not allowed, any excess that cannot be executed at the pre-specified limit price joins the queue at the quoted price instead of walking through and executed with less favorable prices. By focusing on the order choice of a market order trader, we test the relevance of price information while fitting her order size when walking through the book is not allowed. In addition to the depth variables, we define the inside spread and the price distance variables.

(i) SPR: The (tick adjusted) inside spread, calculated as the difference between the lowest ask and the highest bid quotes.
(ii) Price distances:
- $Dopp^{1\_2}$ and $Dsame^{1\_2}$: The (tick adjusted) price distance between the best and the second best quotes for the opposite and the same sides of the book.
- $Dopp^{2\_max}$ and $Dsame^{2\_max}$: The (tick adjusted) price distance between the second best ask (bid) and the highest available ask (lowest available bid) quote for the opposite and the same sides of the book.

The spread and the price distance variables for the opposite side capture the (weighted) average execution price of an aggressive order for markets in which walking through is possible. Because, in that case, when a large buy (sell) market order is submitted, it will eat up all the available volume at the best ask (bid) and then move up (down) to the second best ask (bid), and if necessary move up to third after consuming the second, etc. Since the cost of a market order increases with $Dopp^{1\_2}$ or/and $Dopp^{2\_max}$, this should lead to a submission of less aggressive market orders.

4.3. Additional explanatory variables

Besides our key explanatory variables discussed above, the current literature posits that the volatility and the previous price trend affect the order choice of an agent. We include these two variables in our analysis as explanatory variables.

4.3.1. Trading-time volatility (Vola)

Following Beber and Caglio (2005), we define the volatility as the exponential moving average of the last 60 mid-quote squared returns. The optimal decay factor λ is obtained via maximum likelihood estimation.[11]

$$\hat{\sigma}_t = \sqrt{\lambda \hat{\sigma}_{t-1}^2 + (1-\lambda) r_{t-1}^2} \tag{15}$$

Expected signs: While higher volatility implies a higher probability of execution, it also increases the adverse selection costs. Existing literature identifies a negative relationship between volatility and order aggressiveness. Foucault (1999), Wald and Horrigan

[10] For the sake of brevity we did not report the marginal effects, but only report the median coefficient for the statistically significant stocks. Note that the marginal effect of an order submitted at the quotes (category 4) is positively related to the coefficient reported.

[11] Riskmetrics EWMA is a version of GARCH (1,1) where persistence parameters sum up to one and the constant term is equal to zero. In other words, the optimal decay parameter λ can be obtained by estimating the Integrated GARCH model.

Table 4
First stage sequential ordered probit. The table presents the results of the first stage of the two-stage sequential ordered probit model. In this stage, the dependent variable is equal to 1 if the incoming trader is impatient (submits a market order, MO), and 0 otherwise. Vola is the EWMA volatility (multiplied by 1000), Trend is the price change of the last 60 observations (multiplied by 1000), SPR is the (tick adjusted) inside spread, calculated as the difference between the lowest ask and the highest bid quotes, Vcomp (Vcompopp) is the volume accounting for the competition effect on the same (opposite) side of the book, Vsign (Vsignopp) is the volume accounting for the signaling effect on the same (opposite) side of the book as defined in Eq. (12). All of the volume variables are scaled by 1e-6. $Dsame^{1\_2}$ is the price distance between the best and the second best quotes, whereas $Dsame^{2\_max}$ is the price distance between the second best ask (bid) and the highest available ask (lowest available bid) quote for the same side of the book. $Dopp^{1\_2}$ and $Dopp^{2\_max}$ are constructed analogously for the opposite side of the book. All of the regressions include 5 lags of the dependent variable and the time-of-the day dummies. For the sake of brevity, those are not reported. The median, minimum, maximum and the 25th and the 75th percentile of the estimated coefficients, the percentage of statistically significant coefficients at 5% level, and the percentage of positive coefficients given that they are significant are provided. The cross-sectional median of marginal effects (scaled by 1e3) is also reported.

Buy	Vola	Trend	SPR	Vcomp	Vcompopp	Vsign	Vsignopp	$Dsame^{1\_2}$	$Dsame^{2\_max}$	$Dopp^{1\_2}$	$Dopp^{2\_max}$
Median	−0.02	−1.08	−0.31	1.64	−1.95	−0.02	0.00	−0.14	−0.01	−0.14	−0.02
Min.	−0.09	−5.67	−4.46	0.08	−8.03	−0.35	−0.56	−0.83	−0.04	−0.96	−0.75
P25	−0.04	−1.55	−0.40	0.80	−3.76	−0.06	−0.08	−0.40	−0.02	−0.36	−0.04
P75	0.01	−0.62	−0.23	3.53	−1.03	0.04	0.05	−0.09	0.00	−0.04	0.00
Max.	0.05	0.87	−0.04	7.40	−0.16	0.67	0.39	0.18	0.02	0.50	0.05
Sig. (%)	63	83	80	100	100	60	53	40	43	30	73
Pos. (%)	16	0	0	100	0	33	56	8	15	22	32
Marginal effects-median											
MO	−9.28	−406.55	−121.38	650.20	−746.44	−6.21	−0.56	−54.55	−1.99	−54.80	−6.28
Sell											
Median	−0.03	1.02	−0.37	1.76	−1.77	−0.14	0.01	−0.15	0.00	−0.25	−0.01
Min.	−0.10	−0.14	−1.26	0.14	−7.89	−0.93	−0.51	−1.02	−0.64	−0.75	−0.12
P25	−0.04	0.59	−0.41	0.73	−3.32	−0.28	−0.12	−0.41	−0.02	−0.35	−0.02
P75	−0.02	1.36	−0.24	4.15	−0.77	−0.05	0.07	−0.02	0.00	0.04	0.00
Max.	0.05	4.85	−0.05	9.97	−0.14	0.05	0.39	0.73	0.03	0.26	0.02
Sig. (%)	67	80	83	100	100	77	70	40	30	43	50
Pos. (%)	5	100	0	100	0	4	57	25	44	0	20
Marginal effects-median											
MO	−8.76	360.78	−126.33	624.97	−620.37	−50.47	2.59	−45.69	−0.88	−55.83	−2.97

Table 5
Second stage sequential probit–patient traders. The table presents the results of the second stage of the two-stage sequential ordered probit model for patient traders. Given the trader is patient, the dependent variable is equal to 1, 2 or 3 if the trader submits a category 5, category 4 or category 3 order (limit price within, at, or away from the best quotes), respectively. Vcomp (Vcompopp) is the volume accounting for the competition effect on the same (opposite) side of the book, Vsign (Vsignopp) is the volume accounting for the signaling effect on the same (opposite) side of the book as defined in Eq. (13). They are scaled by 1e-6. The rest of the explanatory variables are defined in Table 4. All of the regressions include 5 lags of the dependent variable and the time-of-the day dummies. For the sake of brevity, those are not reported. The median, minimum, maximum and the 25th and the 75th percentile of the estimated coefficients, the percentage of positive coefficients given that they are significant, and finally the percentage of stocks with a statistically significant slope at a 5% level are reported. The cross sectional median of marginal effects (scaled by 1e3) is also reported.

Buy	Vola	Trend	SPR	Vcomp	Vcompopp	Vsign	Vsignopp	$Dsame^{1\_2}$	$Dsame^{2\_max}$	$Dopp^{1\_2}$	$Dopp^{2\_max}$
Median	0.02	0.67	0.78	0.52	0.08	−0.07	0.01	0.03	0.00	0.03	0.00
Min.	−0.10	−0.14	0.08	−0.07	−0.52	−0.72	−0.20	−1.26	−0.04	−2.40	−0.06
P25	−0.01	0.42	0.56	0.20	−0.04	−0.24	−0.01	−0.31	0.00	−0.20	−0.01
P75	0.04	1.16	0.86	1.43	0.30	−0.01	0.11	0.47	0.02	0.22	0.02
Max.	0.14	2.10	1.79	4.17	2.23	0.54	0.56	1.91	0.04	5.39	1.59
Sig. (%)	50	73	97	80	27	60	37	60	50	27	43
Pos. (%)	93	100	100	100	75	6	100	44	53	50	54
Marginal effects-median											
LO-within	0.25	9.09	12.02	5.96	0.56	−0.65	0.14	0.28	0.07	0.50	0.01
LO-at	7.57	250.95	287.37	194.83	32.33	−26.76	5.33	11.31	1.41	9.85	0.21
LO-above	−8.13	−259.55	−303.69	−204.17	−32.90	27.73	−5.44	−11.87	−1.46	−10.25	−0.22
Sell											
Median	0.02	−0.42	0.66	0.58	0.02	−0.08	0.02	0.00	0.00	0.26	0.00
Min.	−0.05	−2.49	0.20	−0.03	−1.28	−1.33	−0.59	−1.00	−0.05	−0.73	−0.06
P25	0.00	−0.94	0.53	0.19	−0.03	−0.36	−0.01	−0.41	−0.01	−0.07	−0.01
P75	0.05	−0.10	0.84	1.88	0.11	−0.03	0.11	0.54	0.02	0.41	0.00
Max.	0.22	0.50	1.18	5.56	0.96	0.65	0.53	1.39	1.67	5.00	0.04
Sig. (%)	43	60	100	83	27	83	47	40	37	40	30
Pos. (%)	85	6	100	100	63	8	79	42	55	75	56
Marginal effects-median											
LO-within	0.14	−4.70	8.52	5.93	0.11	−0.89	0.08	0.00	0.01	1.80	0.02
LO-at	6.26	−158.65	256.27	221.10	8.01	−32.08	8.45	0.31	0.38	99.31	0.35
LO-above	−6.45	164.39	−264.32	−229.53	−8.61	32.53	−8.54	−0.31	−0.39	−101.07	−0.38

Table 6
Second stage sequential probit regressions, impatient traders. The table presents the results of the second stage of the two-stage sequential ordered probit model. In this stage, given the trader is impatient, the dependent variable is equal to 0 if she submits a small market order (MO) (category 2 order) or equal to 1 if she submits a large MO (category 1 order). Vcomp (Vcompopp) is the volume accounting for the competition effect on the same (opposite) side of the book, Vsign (Vsignopp) is the volume accounting for the signaling effect on the same (opposite) side of the book as defined in Eq. (14). They are scaled by 1e−6. The rest of the explanatory variables are defined in Table 4. All of the regressions include 5 lags of the dependent variable and the time-of-the day dummies. For the sake of brevity, those are not reported. The median, minimum, maximum and the 25th and the 75th percentile of the estimated coefficients, the percentage of statistically significant coefficients at 5% level, and the percentage of positive coefficients given that they are significant are provided. The cross-sectional median of marginal effects (scaled by 1e3) is also reported.

Buy	Vola	Trend	SPR	Vcomp	Vsign	Vsignopp	$Dsame^{1\_2}$	$Dsame^{2\_max}$	$Dopp^{1\_2}$	$Dopp^{2\_max}$
Median	0.18	−1.01	−0.12	−0.14	−0.05	−0.09	−0.04	0.01	−0.16	0.00
Min.	0.10	−5.57	−0.89	−2.54	−0.98	−1.62	−0.97	−0.05	−0.86	−0.65
P25	0.15	−1.52	−0.22	−0.31	−0.14	−0.69	−0.16	0.00	−0.35	−0.05
P75	0.22	−0.41	0.01	0.03	0.03	−0.04	0.08	0.04	0.11	0.02
Max.	0.41	0.56	0.46	2.79	0.26	0.46	0.53	0.09	0.56	0.11
Sig. (%)	100	67	3	27	33	70	10	27	23	47
Pos. (%)	100	0	0	13	50	5	0	88	29	43
Marginal effects-median										
Large MO	23.29	−134.84	−14.43	−8.13	−5.55	−12.14	−5.81	1.44	−12.59	0.60
Sell										
Median	0.19	1.20	−0.01	−0.51	−0.08	−0.09	0.01	0.01	−0.10	−0.01
Min.	0.10	−0.18	−0.61	−4.22	−1.37	−1.07	−0.81	−0.17	−1.56	−0.09
P25	0.17	0.44	−0.13	−0.98	−0.27	−0.27	−0.15	−0.01	−0.41	−0.03
P75	0.24	2.10	0.12	−0.12	−0.05	0.00	0.26	0.02	0.12	0.01
Max.	0.63	5.00	0.81	0.32	0.02	0.74	0.57	0.05	0.80	0.07
Sig. (%)	100	67	7	63	53	50	13	10	37	13
Pos. (%)	100	100	50	0	0	7	0	33	18	25
Marginal effects-median										
Large MO	31.36	181.68	−2.50	−71.17	−12.70	−19.65	1.68	1.02	−8.24	−0.93

(2005) and Goettler et al. (2009) among others, claim that in high volatility states, since the picking off risk increases, the aggressiveness of an incoming agent decreases.

4.3.2. Previous price trend (Trend)

An order submission strategy may also depend on recent movements in the price (Hall and Hautsch (2006)). We identify the previous price trend observed by the agents (Trend) as the change of the mid-quote prices for the last 60 observations at the time of the order arrival.

Expected signs: Given that a trader observes an increasing price trend upon arrival, this may indicate a possible future price increase as well. Since this movement will move the prices away from the current levels, a buy trader may interpret it as an increased non-execution risk of her limit order; hence, she prefers to submit a more aggressive order. This works opposite for the seller.

4.3.3. Control variables

In all of the regressions, to control the seasonality on the arrival rate of orders, we use time of the day dummy, indicating which half-an-hour of the day the order is submitted. Moreover, five previous lags of the dependent variables, determined by the Akaike information criterion (AIC) is included as control variables.[12]

5. Results

As mentioned in Section 2, the 30 stocks in our sample present a high degree of heterogeneity.Thus, we estimate the sequential ordered probit (SOP) regressions for each stock separately, for buyer and seller initiated traders. All of the regressions include 5 lags of the dependent variable and the time-of-the day dummies. For the sake of brevity, those are not reported. We report the median, minimum, maximum and the 25th and the 75th percentile of the estimated coefficients, the percentage of statistically significant coefficients at 5% level, and the percentage of positive coefficients given that they are significant. Tables 4–6 present the results of the first stage, the second stage for a limit order trader, and the second stage for a market order trader of the SOP model, respectively. Table A.1 provides the description of the explanatory variables defined in Section 4 and Table A.2 provides a summary of the major findings.

5.1. Impact of depth at and beyond the best quotes

Table 4 reveals that an increase in the depth at the best quotes (Vcomp) is perceived as an increased competition and lead to an increase in the arrival rate of market order traders for both sides of the market. On the other hand, when competition on the opposite side of the book (Vcompopp) increases, agents predict that the market order arrivals increases on the opposite side of the book, implying an increased probability of execution for their limit orders, so they submit more limit orders. These results are consistent with the findings of Ranaldo (2004), Beber and Caglio (2005), and Pascual and Veredas (2009). Our results suggest that an increase in the volume of orders waiting beyond the best quotes (Vsign) is perceived as a disagreement on the current price and discourages the market order submissions. This signaling effect is more pronounced on the sell side of the book compared to the buy side. This contradicts with the results of Pascual and Veredas (2009) find a positive relationship between the accumulated number of orders waiting from the second to the fifth best quotes and the arrival rate of market order traders. They conclude that this finding supports the hypothesis that the book beyond the best quotes may reinforce the competition effect predicted by Parlour (1998).

Table 5 presents the regression results for a patient trader. It suggests that only the same side of the book matters for both, buyer and seller. Vcomp and Vsign has expected signs. An increase in the competition lead to a submission of aggressive limit orders to jump the queue, whereas an increase on the same side depth away from the quotes (Vsign) is perceived as a possible mispricing of the best quotes as Goettler et al. (2005) and Goettler et al. (2009) predict and lead to a submission of less aggressive limit orders.

Table 7
First stage sequential ordered probit-institutional vs. individual investors. The table presents the results of the first stage of the two-stage sequential ordered probit model for institutional (INS) and individual (IND) investors for the sell side of the market. For both set of regressions, the dependent variable is equal to 1 if the incoming trader is impatient (submits a market order, MO), and 0 otherwise. All of the explanatory variables are defined in Table 4. All of the regressions include 5 lags of the dependent variable and the time-of-the day dummies. For the sake of brevity, those are not reported. The median, minimum, maximum and the 25th and the 75th percentile of the estimated coefficients, the percentage of statistically significant coefficients at 5% level, and the percentage of positive coefficients given that they are significant are provided. The cross-sectional median of marginal effects (scaled by 1e3) is also reported.

INS	Vola	Trend	SPR	Vcomp	Vcompopp	Vsign	Vsignopp	$Dsame^{1\_2}$	$Dsame^{2\_max}$	$Dopp^{1\_2}$	$Dopp^{2\_max}$
Median	−0.05	1.06	−0.41	2.51	−2.78	0.04	0.02	−0.06	−0.01	0.19	0.01
Min.	−0.17	−2.02	−5.39	0.40	−13.45	−0.93	−1.24	−1.66	−2.09	−1.63	−0.20
P25	−0.09	0.04	−0.82	1.44	−4.54	−0.11	−0.18	−0.56	−0.05	−0.88	−0.03
P75	0.06	1.72	0.10	5.14	−1.63	0.17	0.10	0.17	0.03	0.57	0.05
Max.	0.12	5.59	4.08	14.84	−0.48	1.97	0.69	0.76	0.15	2.01	0.24
Sig. (%)	10	24	3	93	83	14	28	7	21	10	38
Pos. (%)	33	100	0	100	0	75	38	0	17	0	55
Marginal effects-median											
MO	−17.80	403.50	−137.50	962.00	−929.50	10.36	7.70	−23.70	−2.67	72.90	4.19
IND											
Median	−0.03	1.05	−0.35	1.78	−1.74	−0.15	0.01	−0.12	0.00	−0.17	−0.01
Min.	−0.11	−0.13	−1.22	0.14	−8.03	−0.99	−0.52	−1.03	−0.60	−0.73	−0.12
P25	−0.05	0.59	−0.42	0.70	−3.51	−0.37	−0.12	−0.34	−0.02	−0.33	−0.02
P75	−0.02	1.37	−0.26	4.09	−0.75	−0.05	0.07	−0.01	0.01	0.02	0.00
Max.	0.05	4.80	−0.07	10.02	−0.14	0.04	0.40	0.73	0.03	0.26	0.02
Sig. (%)	70	87	77	100	100	83	70	37	40	43	50
Pos. (%)	5	100	0	100	0	4	57	27	42	0	20
Marginal effects-median											
MO	−9.96	367.50	−125.00	632.50	−610.00	−52.00	1.93	−41.50	−0.26	−57.80	−3.11

Marginal effects regarding the depth variables reveal that the volume at the best quotes is particularly emphasized while determining the degree of patience of the incoming trader compared to depth beyond the best quotes. Moreover, the competition effect is stronger compared to the signaling effect for both sides of the market in all stages of the SOP.

5.2. Impact of non-walking through the book

Table 6 shows that, while fitting the size of her market order for an impatient trader, none of the price information, neither spread nor price distance variables, matter. This is intuitive, since when walking through the book is not allowed, the spread and the price distance variables for the opposite side do not alter the execution price of a large market order compared to a small one. To analyze this further, we first test the joint significance of these variables and second, we use a different proxy to capture the price and volume information contained beyond the best quotes. For the majority of the stocks, we cannot reject the null hypothesis $\gamma_{SPR} = \gamma_{Dopp^{1\_2}} = \gamma_{Dopp^{2\_max}} = 0$ with a median $\chi^2 = 4.63$ (p-val = 0.1759) and $\chi^2 = 2.88$ (p-val = 0.4112) for buy and sell sides, respectively, where γ is defined in Eq. (7). This suggests that the price information contained in the limit order book is even jointly uninformative for a market order trader. As a different proxy, we fit a second degree polynomial for the total volume available at each price and the corresponding quotes. Then the coefficients of the quadratic term for both sell and buy sides of the book is used in the SOP regressions. As expected, the fit of the quadratic trend for the same and the opposite sides of the book are insignificant at 5% level.

Our results suggest that a market order trader only considers volatility, previous price trend, and volume accumulated beyond the best quotes on the opposite side of the book. In high volatility states impatient trader submits more aggressive market orders. This can be explained by two: first, an impatient trader may benefit from a high volatility state since it increases the probability of fully execution of large size orders. This is due to the fact that the excess is converted to a limit order and the execution probability of a limit order increases with volatility.[13] This result is consistent with findings of Hall and Hautsch (2006). In their analysis conducted on Australian Stock Exchange, another market with non-walking through the book, they focus only on the aggressive market and limit orders. Their results suggest an increase in the volatility is followed by an increase in the aggressive market orders. Second, given that the trader submits a market order in a high volatility state, it is more likely that she is informed as Goettler et al. (2009) predict. She would like to take advantage of the mispricing at the quotes, which makes her to submit an aggressive market order.

The accumulated volume of orders on the opposite side of the book (Vsignopp) and the change of the mid-quote prices for the last 60 observations (Trend) are negatively related with the buy market order aggressiveness. In other words, an impatient buyer splits her orders into several small quantities rather than submitting a large market order when Vsignopp or Trend increases. Because, an increase in Vsignopp or Trend signals a possible future price increase, increasing the non-execution risk for the limit-order-converted-part of the aggressive market order. The opposite is true for the seller.

In comparison to the study of Pascual and Veredas (2009), which is conducted on the Spanish Stock Exchange, we have different results. The authors show that the spread and the price distances on the opposite side of the market matters for an impatient trader's decision. In addition, in his study on the Swiss Stock Exchange, Ranaldo (2004) demonstrates that the sensitivity of a large market order with respect to volatility is more negative compared to a small one. Thus, in high volatility states an impatient trader prefers to submit a small market order, which contradicts our finding. One plausible explanation of the discrepancy in the results could be the walking through the book mechanism, which is allowed in both of the markets.[14]

[13] For example Cho and Nelling (2000) show that execution probability of limit orders are increasing with volatility.

[14] Non-walking through the book is not the only difference between the ISE and the other markets mentioned. Hence, we can only conjecture that the findings might be driven by non-walking through the book.

Table 8
Robustness. This table reports the results for the robustness analysis for the sell side of the market for the first stage and the second stage-limit order (LO) trader. The first three rows repeat the results for the benchmark model, whereas the following three rows present the results for the logistic regression (Logit). The robustness analyses on the definition of volatility (Vola_std60, Vola_abs60) and on the previous trend (Trend100) are provided. Vola_std60 is the standard deviation of the last 60 mid-quote returns. Vola_abs60 is the absolute change in the last 60 mid-quote prices and Trend100 is the previous price change of the last 100 observations. All of the regressions include 5 lags of the dependent variable and the time-of-the day dummies. For the sake of brevity, those are not reported. The median of the estimated coefficients, the percentage of statistically significant coefficients at 5% level, and the percentage of positive coefficients given that they are significant are provided.

1st stage	Vola	Trend	SPR	Vcomp	Vcompopp	Vsign	Vsignopp
Benchmark							
Median	−0.03	1.02	−0.37	1.76	−1.77	−0.14	0.01
Sig. (%)	67	80	83	100	100	77	70
Pos. (%)	5	100	0	100	0	4	57
Logit							
Median	−0.05	1.67	−0.65	3.08	−3.08	−0.24	0.02
Sig. (%)	67	80	83	100	100	77	67
Pos. (%)	5	100	0	100	0	4	60
Vola_std60							
Median	−0.06	1.02	−0.36	1.80	−1.78	−0.14	0.01
Sig. (%)	77	80	83	100	100	80	70
Pos. (%)	0	100	0	100	0	4	57
Vola_abs60							
Median	−0.01	1.05	−0.36	1.79	−1.74	−0.13	0.01
Sig. (%)	83	83	83	100	100	77	70
Pos. (%)	0	100	0	100	0	4	57
Trend100							
Median	−0.03	0.43	−0.36	1.71	−1.67	−0.13	0.01
Sig. (%)	63	67	80	100	100	80	70
Pos. (%)	5	100	0	100	0	8	62
2nd stage LO							
Benchmark							
Median	0.02	−0.42	0.66	0.58	0.02	−0.08	0.02
Sig. (%)	43	60	100	83	27	83	47
Pos. (%)	85	6	100	100	63	8	79
Logit							
Median	0.03	−0.68	1.02	0.94	0.04	−0.14	0.04
Sig. (%)	43	57	93	83	30	83	47
Pos. (%)	85	6	100	100	44	8	79
Vola_std60							
Median	0.02	−0.40	0.67	0.58	0.01	−0.08	0.02
Sig. (%)	33	60	97	83	33	83	47
Pos. (%)	90	6	100	100	50	8	79
Vola_abs60							
Median	0.00	−0.41	0.66	0.56	0.00	−0.09	0.02
Sig. (%)	37	60	97	83	30	83	47
Pos. (%)	64	6	100	100	44	8	79
Trend100							
Median	0.02	−0.14	0.67	0.63	0.02	−0.08	0.02
Sig. (%)	43	47	100	90	27	80	47
Pos. (%)	85	29	100	100	38	8	79

5.3. Effects of the additional variables

In line with the existing literature, we find that the probability of an incoming agent being patient increases with volatility, since the picking off risk increases in high volatility states. On the other hand, Table 5 shows that, given that the agent is patient and submits a limit order, she prefers to submit more aggressive limit orders when volatility is higher since submitting orders away from the quotes decreases the execution probability significantly.[15] This result is weak for both sides of the market.

Our results suggest that, when the previous price trend increases, a buyer submits more limit orders whereas a seller submits more market orders. This contradicts the expected sign proposed. One possible interpretation is the expectation of mean reversion in the prices. If a seller, for instance, believes that prices will revert back, she would submit an aggressive market order to take advantage of this "mispricing", instead of waiting and to be compensated by a limit order.

Consistent with the majority of the literature, the first stage SOP regressions show that wider spread increases the probability of an incoming trader being patient. On the other hand, Table 5 shows that, the importance of the inside spread is more pronounced for the limit order trader while positioning their limit price. We find that a wider spread persuades patient traders to compete more heavily to jump the queue when spreads are wide, which confirms the predictions of Foucault et al. (2005) and Goettler et al. (2005).

5.4. Trading behavior of institutions

The current literature points out that individual and institutional investors may differ in their level of information implying

[15] For instance, Table 2 suggests that submitting an order away from the quotes instead of at the quotes decreases the execution probability from 60% to 20%.

Table 9
Robustness. This table reports the results for the robustness analysis for the sell side for the second stage-market order (MO) trader. The first three rows repeat the results for the benchmark model, whereas the following three rows present the results for the logistic regression (Logit). The robustness analyses on the definition of volatility (Vola_100, Vola_std60, Vola_std100, Vola_abs60, Vola_abs100) and on the previous trend (Trend100) are provided. Vola_100 is the exponential moving average of the previous 100 squared returns with optimal decay parameter. Vola_std60 (Vola_std100) is the standard deviation of the last 60 (100) mid-quote returns. Vola_abs60 (Vola_abs100) is the absolute change in the last 60 (100) mid-quote prices and Trend100 is the previous price change of the last 100 observations. All of the regressions include 5 lags of the dependent variable and the time-of-the day dummies. For the sake of brevity, those are not reported. The median of the estimated coefficients, the percentage of statistically significant coefficients at 5% level, and the percentage of positive coefficients given that they are significant are provided.

2nd stage MO	Vola	Trend	SPR	Vcomp	Vsign	Vsignopp	$Dsame^{1\_2}$	$Dsame^{2\_max}$	$Dopp^{1\_2}$	$Dopp^{2\_max}$
Benchmark										
Median	0.19	1.20	−0.01	−0.51	−0.08	−0.09	0.01	0.01	−0.07	−0.01
Sig. (%)	100	67	7	63	53	50	13	10	37	13
Pos. (%)	100	100	50	0	0	7	0	33	18	25
Logit										
Median	0.37	2.06	−0.05	−1.00	−0.17	−0.17	0.05	0.01	−0.15	−0.01
Sig. (%)	100	67	7	57	50	50	13	20	43	10
Pos. (%)	100	100	50	0	0	7	0	50	23	33
Vola_100										
Median	0.23	1.20	0.00	−0.32	−0.09	−0.10	0.02	0.01	−0.08	−0.01
Sig. (%)	100	67	3	47	50	50	10	20	30	13
Pos. (%)	100	100	0	0	0	7	0	50	22	25
Vola_std60										
Median	0.22	1.09	−0.02	−0.41	−0.08	−0.09	0.01	0.01	−0.07	−0.01
Sig. (%)	100	67	7	43	50	50	13	23	37	13
Pos. (%)	100	100	50	0	0	7	0	43	18	25
Vola_std100										
Median	0.22	1.21	0.00	−0.40	−0.09	−0.09	0.02	0.01	−0.07	−0.01
Sig. (%)	100	67	7	47	47	43	7	20	30	10
Pos. (%)	100	100	50	0	0	0	0	50	22	33
Vola_abs60										
Median	0.02	1.18	0.00	−0.55	−0.12	−0.13	0.07	0.01	−0.03	−0.01
Sig. (%)	77	67	7	70	63	50	10	13	30	17
Pos. (%)	100	100	50	0	0	7	0	25	22	20
Vola_abs100										
Median	0.01	1.37	0.01	−0.54	−0.12	−0.15	0.10	0.01	−0.04	−0.01
Sig. (%)	70	67	7	70	57	53	7	13	23	30
Pos. (%)	100	100	50	0	0	13	0	25	29	11
Trend100										
Median	0.20	0.62	−0.01	−0.36	−0.12	−0.11	0.03	0.01	−0.08	−0.01
Sig. (%)	100	57	7	57	53	50	10	17	30	17
Pos. (%)	100	94	50	0	0	13	0	20	22	20

that institutions are informed traders (Lo and MacKinlay (1990), Cornell and Sirri (1992), Koski and Scruggs (1998), and Chakravarty (2001)). In our data we can distinguish whether an order is initiated by an institutional or individual investor, with a limitation however. Due to internal regulations, some of foreign institutional investors are classified as individual instead of institution. Thus, whenever it is marked as an institutional investor in our data set, it is an institutional investor for sure. However, individual traders are pooled with foreign institutions.[16] This in turn reduces our sample size significantly, but does not affect the conclusions we derived. In our sample, on average 3.7% of all orders are initiated by institutional investors.

In order to formally test whether we can separate the sample as individual and institutional trading, we run the following two-stage sequential ordered probit (SOP) regression for both buy and sell sides of the market and test the null hypothesis $\mu = \gamma_1 = \gamma_2 = \cdots = \gamma_K = 0$.

$$Y_t^* = \alpha + \mu D_{t-1}^{INS} + \sum_{k=1}^{K} \beta_k X_{k,t-1} + \sum_{k=1}^{K} \gamma_k D_{t-1}^{INS} X_{k,t-1} + \varepsilon_t \qquad (16)$$

where Xs are the observable (limit order book) variables defined in Section 4, and $Y_{s,t}^*$ is the dependent variable introduced in Eq. (2). We define a dummy variable, D^{INS} which takes the value 1 if the order is initiated by an institutional trader.[17] The hypothesis is rejected at 5% of significance level with a median $\chi^2 = 46.65$ (p-val = 0.0009) for 76% of the stocks for the sell side of the market. Similar conclusion holds for the buy side of the market. The joint hypothesis is rejected for the 83% of the stocks with a median $\chi^2 = 41.49$ (p-val = 0.0000). These reveal that the information contained in the limit order book affects the trading behavior of institutions and individuals differently.

Following this, we separate the sample into two groups: orders initiated by institutional investors and by individual investors and re-run the first stage SOP regressions introduced in Eq. (2) for each of the groups separately. The results for the sell side of the market are presented in Table 7. Buy side results are qualitatively similar. The same explanatory variables, introduced in Section 4, are employed as in the analysis using the whole sample. The dependent variable is equal to 1 if the incoming trader is impatient (submits a market order) and 0 if she submits a limit order.

[16] According to the information provided on the web page of the ISE, for the June and July 2008, on average, 10% of the trading value is originated by foreign investors. The maximum and minimum ratios are around 30% and 2%, respectively.

[17] It is not possible to run this regression for one of the stocks in our sample (IHLAS) due to limited number of observations. Hence, we excluded that stock from our analysis in this section.

When we examine the results for the sample of individual investors, we see that volatility, the previous price trend, the inside spread, the competition variables, and the signaling variables are highly significant at a 5% level. On the other hand, the regression results for institutions reveal that only the depth available at the same and at the opposite side of the book, (Vcomp and Vcompopp), are significant for institutional investors. The joint hypothesis $\beta^{INS}_{Vcomp} = \beta^{INS}_{Vcompopp} = 0$ is rejected with a median $\chi^2 = 51.07$

Table A.1
Definitions of explanatory variables. This table presents the abbreviation and description of the explanatory variables used in the two-stage sequential ordered probit model.

Regressors	Definition
Covariates for the depth at and beyond the best quotes	
Vcomp	The total volume of orders *at the best quote* in the first stage and second stage-MO and the accumulated volume of orders *up to the second best quotes* in the second stage-LO for the same side of the book
Vcompopp	The total volume of orders *at the best quote* in the first stage and the accumulated volume of orders *up to the second best quotes* in the second stage-LO for the opposite side of the book
Vsignal	The accumulated volume of orders *from the second up to the tenth best quotes* in the first stage and second stage-MO and the accumulated volume of orders *from the third up to the tenth best quotes* in the second stage-LO for the same side of the book
Vsignalopp	The accumulated volume of orders *from the second up to the tenth best quotes* in the first stage and second stage-MO and the accumulated volume of orders *from the third up to the tenth best quotes* in the second stage-LO for the opposite side of the book
Covariates for walking through the book	
SPR	The (tick size adjusted) difference between the lowest ask and the highest bid quotes
$Dsame^{1\_2}$	The price distance between the best and the second best quotes for the same side of the book
$Dsame^{2\_max}$	The price distance between the second best ask (bid) and the highest available ask (lowest available bid) quote for the same side of the book
$Dopp^{1\_2}$	The price distance between the best and the second best quotes for the opposite side of the book
$Dopp^{2\_max}$	The price distance between the second best ask (bid) and the highest available ask (lowest available bid) quote for the opposite side of the book
Additional variables	
Vola	The exponential moving average of the last 60 mid-quote squared returns
Trend	The change of the mid-quote prices for the last 60 observations

Table A.2
Summary of the main findings. This table presents the summary of our main findings along with the corresponding table. All the variables are defined in Table A.1.

Regressors	Main Findings	Table	Consistent with	Inconsistent with
Covariates for the depth at and beyond the best quotes				
Vcomp	Encourages market orders	Table 4	Parlour (1998), Ranaldo (2004), Beber and Caglio (2005), Pascual and Veredas (2009)	
	It persists beyond the best quotes and it is the strongest up to the 2nd best quote	Table 3		
Vcompopp	Discourages market orders	Table 4	Parlour (1998), Ranaldo (2004), Pascual and Veredas (2009)	
Vsign	(weakly) discourages market orders	Table 4	Goettler et al. (2005), and Goettler et al. (2009)	Pascual and Veredas (2009)
	Discourages the limit order aggressiveness	Table 5	Goettler et al. (2005), Goettler et al. (2009), and Pascual and Veredas (2009)	
Vcomp/ Vsign	The competition effect is stronger compared to the signaling effect	Tables 4–6		
Covariates for walking through the book				
SPR	Discourages MOs	Table 4	Ranaldo (2004), Beber and Caglio (2005), Ellul et al. (2007) Cao et al. (2008), and Pascual and Veredas (2009)	
	Encourages aggressive LOs	Table 5	Ellul et al. (2007) and Pascual and Veredas (2009)	
	No significant effect on the market order aggressiveness	Table 6		Pascual and Veredas (2009)
$Dopp^{1\_2}$/ $Dopp^{2\_max}$	No significant effect on MOs	Table 4	Cao et al. (2008)	Pascual and Veredas (2009)
	No significant effect on the market order aggressiveness	Table 6		Pascual and Veredas (2009)
Additional variables				
Vola	Discourages MOs	Table 4	Foucault (1999), Ahn et al. (2001), Ranaldo (2004), Beber and Caglio (2005),	
	Encourages aggressive MOs	Table 6	Hall and Hautsch (2006)	Ranaldo (2004)
Trend	Discourages (encourages) buy (sell) MOs	Table 4		Beber and Caglio (2005), Cao et al. (2008)
	Encourages (discourages) aggressive buy (sell) LOs	Table 5		
	Discourages (encourages) aggressive buy (sell) MOs	Table 6		

(p-val = 0.0000) for all of the stocks except one. In other words, competition matters in their decision to submit a limit or a market order. Other features of the results presented in Table 7 are worth to underline. Volatility is not informative for an informed agent. This may suggest that institutional traders do not face the picking off risk that drives them to submit more limit orders rather than a market order in high volatility states. Similarly, the signaling variables (Vsign and Vsignopp) are not informative as expected. Informed agents do not rely on the signaling on the current prices provided by the market. Finally, the coefficients on volatility, price trend, spread, signaling variables, and price distance variables are jointly insignificant for 62% of the stocks with a median $\chi^2 = 13.42$ (p-val = 0.0967).

To sum up, we conclude that, similar to the individual investors, institutional investors consider the information provided by the limit order book while designing their trading strategies. However, their decision to submit a market or a limit order is based on only a few pieces of the limit order book information. They take into account other traders' actions only for competition. This suggests that institutional investors' order submission strategies are based on their own private valuations rather than the state of the book.

5.5. Robustness

We provide several robustness checks to conclude that our findings are not driven by an arbitrary choice. The first robustness check is related to the model specification. Instead of estimating the model with ordered probit, we use ordered logit. The second robustness checks are on the definitions of the transient volatility and the price trend. Throughout the paper, we proxy the price fluctuations by using the exponential-weighted moving average (EWMA) volatility and the price trend as the percentage change in the mid-quote prices for the last 60 observations. First, we re-estimate the optimal decay parameter λ by using 100 mid-quote returns instead of 60. Similarly, as a robustness check for the price trend, we employ different window sizes of 100 and 120. Moreover, we re-estimate the two-stage sequential ordered probit model with different transient volatility measures, namely the standard deviation and absolute value of the mid-quote changes of the previous 60, 100 and 120 orders prior to the order submission.

Table 8 presents the robustness test results for the first stage and second stage patient trader, whereas Table 9 reports the results for the second stage impatient trader for the sell side of the market. For the sake of brevity, buy side is not reported since the results are qualitatively similar. All of the results are qualitatively robust, except for the volatility in the second stage-limit order trader. To sum up, we conclude that all of our main findings are remarkably robust to different proxies.

6. Conclusion

This paper investigates how the information content of a limit order book affects the order choice of an investor. By employing a two-stage sequential ordered probit model, we first answer whether the competition or signaling effects dominate each other. Second, we examine the order decision of a trader under the non-walking through the book mechanism. Finally, we study the trading behavior of institutional and individual investors separately.

By reconstructing the limit order book for the Istanbul Stock Exchange, we show that the competition effect is present only at the best quotes while determining the arrival rate of a market or a limit order. On the other hand, a patient trader perceives an increase in the depth up to the second best quotes as an increased competition and submits a more aggressive limit order. An increase in the same-side-depth behind the top of the book is perceived as a signal of a possible mispricing of the current quotes and encourages agents to submit less aggressive orders. This is consistent with the predictions of Goettler et al. (2005) and Goettler et al. (2009). We show that, at every stage, the competition effect is stronger than the signaling effect.

In our market, in her decision to submit a "large" or "small" market order, only volatility, previous price trend and volume accumulated on the opposite side of the book matter for an impatient trader. In other words, none of the price information affects the order choice of an impatient trader. This result might be explained by the non-walking through the book property of our market. Because under this mechanism, the spread and the price distance variables do not capture the execution price of an aggressive market order.

Finally, the results show that institutional investors trading strategies are affected by fewer pieces of the limit order book information compared to individual investors. An institutional investor considers other traders' actions only for competition and signaling does not influence her order choice. Moreover, since they have informational advantages over individual investors, they do not face the picking off risk that makes the market order trading is more costly in high volatility states.

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Appendix A

Tables A.1 and A.2.

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