The Journal of Financial Research ● Vol. XXXI, No. 2 ● Pages 113–140 ● Summer 2008

ORDER PLACEMENT STRATEGIES IN A PURE LIMIT ORDER BOOK MARKET

Charles Cao and Oliver Hansch
The Pennsylvania State University

Xiaoxin Wang
Southern Illinois University

Abstract

Using order book information from the Australian Stock Exchange (ASX), we examine whether (and to what extent) the order book affects investors' order placement strategies. We find that the top of the book always affects order submissions, cancellations, and amendments, and the rest of the book mostly affects order cancellations and amendments. The previously documented order submission aggressiveness, given a crowded first step of the book, persists to other price steps and is found in order amendments and cancellations along the book. Finally, investors tend to fill in the large price gaps in the book by submitting or amending orders.

JEL Classification: G10, G11, G19

I. Introduction

Since the 1990s electronic limit order books have become increasingly popular among major equity markets, and there has been a growing research interest in investors' order submission strategies in markets with limit order books (e.g., Biais, Hillion, and Spatt 1995; Harris and Hasbrouck 1996; Parlour 1998; Foucault 1999; Griffiths et al. 2000; Sandas 2001; Ranaldo 2004). Researchers find that (1) a large inside bid–ask spread discourages the submission of market orders and (2) a large number of limit orders at the top of the book encourages the submission of market

We would like to thank Geoffrey Booth, Tarun Chordia, Ian Domowitz, Joel Hasbrouck, Kenneth Kavajecz, Bill Kracaw, Bruce Lehmann, Mark Lipson, Chris Muscarella, Gideon Saar, Chester Spatt, Avanidhar Subrahmanyam, and seminar participants at The Pennsylvania State University, Rutgers, George Washington University, the Western Finance Association Meetings, the NBER-JFM Microstructure Conference, and the American Finance Association meetings for helpful comments. Financial support provided by Smeal Research Grants (Cao) is greatly appreciated. Special thanks to Gerald Gay (the editor) and an anonymous referee for insights that greatly improved the quality of our paper.

orders from investors. These results suggest that investors use the information from the top of the order book (the inside book) when they decide between submitting a market order and a limit order.

In recent years, markets around the world are opening up the limit order book and exposing more transparency to investors (e.g., the popular electronic communication networks (ECNs) in the U.S. equity markets, the NYSE Openbook and the NASDAQ Supermontage system). Thus, it is reasonable to believe that the activities beyond the top of the limit order book contain valuable information. Although the top of the order book has been the focus of much research attention, little work has been devoted to the study of whether the order book beyond the best bid and offer affects investors' order submission strategies. We fill this void by conducting a comprehensive analysis of the effect of the order book on investors' order strategies. Ahn, Bae, and Chan (2001) and Hall and Hautsch (2006) study limit order books from the Hong Kong Stock Exchange and ASX, respectively. Chakrabarty (2007) shows that ECNs lead the inside quotes more frequently than other dealers in the U.S. market.

Order strategies involve not only submission strategies but also cancellation and amendment strategies. To the best of our knowledge, no research examines order amendments, although order amendments (which include changes to either the price or the size of an existing order) are common in a liquid limit order market. Order cancellations, another frequent activity of traders, are only studied in a few recent papers (see Hasbrouck and Saar 2002; Ranaldo 2004; Ellul et al. Forthcoming; Hall and Hautsch 2006). We investigate whether an open limit order book contributes to an investor's decision to submit, amend, or cancel an order.

Previous research restricts both the dependent variable (the order choice) and the independent variable (the book) to the top of the order book. Our article extends this research by including the rest of the order book in the analyses. First, we examine whether traders consider the state of the book when formulating their order strategies. The state of the book includes its depth (the quantity) and its height (the price dimension along the book). Adding price dimension to the previously studied book depth provides a complete picture of the order book. Second, with regard to order choices, we not only differentiate between market orders and limit orders, but we also differentiate among limit orders according to their position in the book. Finally, in addition to order submissions, we study order amendments and cancellations.

By broadening the scope to include order cancellations and amendments, we can investigate an investor's preference for an order that has already been placed. Will the investor cancel the order, amend it, or stay put? If the investor amends, will he or she move it forward toward the top of the book, stay at the same price step but change the size of it, or amend it backward to an even less aggressive price? If the investor amends at the same price, will he or she increase the size or decrease it?

If the investor amends to a more (or less) aggressive price, which price level will he or she choose? What factors affect all of these decisions? The order of these questions reveals the multistage sequential decision an investor faces for an order that has already been placed. Our article is one of the first that views an investor's order choice as a multilevel decision-making process (see also Pascual and Veredas 2004).

There are other reasons why the issues studied here are of interest. Theoretical models (see Foucault 1999; Parlour 1998) make specific predictions about how the book affects investors' order submission choices. Foucault (1999) predicts that an increase in the proportion of potential buyers will make limit buy orders less attractive. This prediction is consistent with the "crowding-out" effect illustrated in Parlour (1998). Although both models and their predictions are generated in markets with limit order books, they are mostly tested empirically using the best bid and offer of the order books. With the recent availability of limit order book data, it is now possible to test these theoretical predictions.

Next, a market consists of information about the underlying value of a security and about the order flows of the security. At a certain time, only a small portion of investors possess private information about the true value of the security; thus, the information about the order flow (the supply and demand) becomes the next best piece of information investors can pursue. Investors, especially sophisticated investors, may infer the value of a security from the order flow. An open limit order book opens up this possibility for investors. The question of whether investors use this information to enjoy the pretrade transparency of the market becomes crucial in regulatory issues with regard to trading mechanism designs.

Finally, order submission dominates the research in this area, even though order amendments and cancellations are common. This is primarily because of the unavailability of limit order book data in the past. In recent years, many brokers, including those whose clientele are retail investors (e.g., Scottrade), impose no charge for amending or canceling an order before it is executed. This makes order cancellations and amendments more commonplace. As a result, order strategies have become a combination of order submissions, cancellations, and amendments. But how do investors combine these choices, and what factors affect their order cancellations and amendments? Studying order cancellations and amendments complements previous research on order submissions and enhances our understanding of investors' order decisions.

Using limit order book data from the ASX, we find that the top of the book affects an investor's order submission decision. Large inside spread discourages market orders whereas depth at the top price step encourages more market orders. This is the documented crowding-out effect. These results are consistent with those reported in Biais, Hillion, and Spatt (1995), Parlour (1998), Foucault (1999), and Ranaldo (2004).

Furthermore, we find that the top of the book matters for order cancellations and amendments. An increased inside bid–ask spread decreases the likelihood of order cancellations at the first step. The own–opposite imbalance in the depth at step 1 discourages order-size increases at that step.[1] This effect is an extension of the crowding-out effect from order submissions to order amendments.

More important, the rest of the book also influences an investor's order choice. Though not significant in affecting an investor's order submission decision, when it comes to order cancellations and order amendments, investors consider the rest of the book. An increased own–opposite imbalance of the price gap between steps 1 and 10 increases the likelihood of order amendments backward to steps 2 through 9. This result implies that investors try to fill in large price gaps in the book. An increased own–opposite imbalance of the number of shares at steps 2 through 10 discourages order cancellations at step 1 but encourages cancellations behind step 1. This extension is another example of the crowding-out effect from the top of the book persisting along the rest of the book.

Finally, when combining forward order amendments, backward order amendments, same-price order amendments, and order cancellations, we find that the book—not only the top but also what is beyond the top—contains valuable information. An increased inside bid–ask spread discourages order cancellations while encouraging forward amendments. The own–opposite imbalance in the price gap between steps 1 and 10 encourages order cancellations while discouraging forward amendments.

II. Related Literature and Testable Hypothesis

Investors primarily trade securities for two reasons: liquidity and information. Liquidity-based models on limit order book markets include Cohen et al. (1981), Harris (1998), Parlour (1998), Foucault (1999), Sandas (2001), Hollifield, Miller, and Sandas (2004), and Foucault, Kadan, and Kandel (2005). The main predictions of these models are that (1) market orders become less attractive whereas limit orders become more attractive as the inside spread increases, and (2) own-side depth encourages the submission of market orders. Using mostly book information at its top, several empirical studies find evidence consistent with these predictions (see Biais, Hillion, and Spatt 1995; Griffiths et al. 2000; Ranaldo 2004; Beber and Caglio 2005; Ellul et al. Forthcoming).

Information-based models on limit order markets focus on how informed traders submit orders. According to Glosten (1994), Rock (1996), and Seppi (1997),

[1] We refer to the side of the book where the upcoming order action takes place as the own side, and the other side as the opposite side.

informed traders favor and actively submit market orders to profit from short-lived private information; however, recent experimental, empirical, and theoretical findings suggest that informed traders do use limit orders (see Chakravarty and Holden 1995; Barclay, Hendershott, and McCormick 2003; Bloomfield, O'Hara, and Saar 2005; Kaniel and Liu 2006).

Informed traders face a trade-off between placing a limit order and a market order. A limit order can hide the informed trader's information and lead to a better execution price but at the risk of a delay. A market order can be executed quickly but risks revealing the trader's information too rapidly before it can be further exploited. The trade-off depends crucially on how traders view the liquidity available throughout the order book. If traders can access the book, they could be less risk averse. Limit orders can be used even if the information is short-lived, as long as the traders know that there is enough liquidity on the other side of the market. They can decide whether to "hide in the crowd" by placing a limit order without delay and still making the transaction at a sufficiently good price. In this case, choosing the optimal limit order price becomes important, and to make this decision, traders would need to view the book, not only the best bid and offer.

The predictions of models on limit order book prompt us to investigate whether traders use the order book information behind the best bid and ask in their order choice decision. Informed traders, who face the trade-off between placing a market order or a limit order, will choose to place orders strategically. Furthermore, uninformed traders, who realize their informational disadvantage, will gather all of the information they can access, including the state of the entire order book, to make their decision. This is particularly true for traders who submit large orders (e.g., institutional traders whose liquidity demands exceed the depth offered at the very top of the book), as they would benefit from assessing the state of the book when they determine their (possibly dynamic) trading strategies.

However, traders, informed or uninformed, may still focus on the best bid and offer. Possible reasons include (1) their inability to process the vast amount of information presented in the book and (2) the cost associated with monitoring and analyzing the book. If the book is highly dynamic because of rapid cancellations, amendments, or new order submissions, the current state of the book may carry little information about its future state and thus may be of limited use in formulating an order placement strategy. Therefore, it is an open empirical question whether investors use the available information on the state of the order book when formulating their order placement strategies.

Mizrach (2006) finds that orders away from the inside affect the probability of the next quote revision being uptick or downtick on the NASDAQ and shows that what happens along the order book at t affects the price on the top of the book at $t + \Delta t$. Bortoli et al. (2006) find that more market orders were submitted that exceed the depth of the best quotes after the Sydney Futures Exchange increased its disclosure of the order book from the best step to the best three steps. In this

article we examine investors' order placement strategy as a function of the order book information. Unlike most other research, we do not limit order choice to the dualism of market orders versus limit orders; rather, in addition to market orders and limit orders, we differentiate limit orders according to their aggressiveness measured by their positions in the book, which are in turn determined by their prices. We also include order amendments and order cancellations as alternative choices.

III. Data

Sample Selection

We use the fully computerized Stock Exchange Automated Trading System (SEATS) data set on the ASX in March 2000 to conduct our empirical analysis.[2] SEATS is an electronic limit order book, similar to the ECNs in the U.S. markets. Through consolidations with popular ECNs such as the Archipelago ECN and the INET ECN, NYSE and NASDAQ have embraced the ever-so-popular electronic limit order books in their trading mechanism, although the NYSE specialists and the NASDAQ dealers continue to play an important role in day-to-day trading activities. An order can be executed either through a market maker or through an ECN, reflecting a great degree of market segregation. On the contrary, there are no market makers on the ASX, as it operates a pure limit order book. London Stock Exchange's (LSE) SETS platform also operates a pure limit order book for U.K. blue chip stocks. For the less liquid mid-cap and small-cap stocks, LSE resorts to market makers or a combination of market makers and the electronic limit order book for facilitating transactions. Similarly, stocks outside of the liquid Euronext 100 index may also choose to engage a liquidity provider though stocks within the index trade continuously on the fully automated electronic limit order book.

The SEATS order book is open to the public, meaning it is widely and instantly disseminated to investors. Brokerage firms generally provide a certain degree of market depth to their clients at no extra charge. Compared with other major exchanges around the world, ASX offers more pretrade order flow transparency. Though different brokers show different numbers of price steps, most investors can at least see the aggregate first 10 steps of the book on both the buy and sell sides in real time. For example, E*TRADE Australia and TD Waterhouse Australia provide their clients with the book truncated at step 10 and National Online Trading

[2] In 2006, ASX changed its name to Australian Securities Exchange after its merge with Sydney Futures Exchange, and SEATS was updated to the Integrated Trading System (ITS) workstation that can provide more transactions per second, yet the feature of a pure open limit order book remains.

provides the book truncated at step 20.[3] The feature of ASX's pure and open limit order book prompts us to examine whether investors use the book in their order placement strategies.

ASX's opening auction starts at 10:00 am group by group for five stock groups based on the alphabetical order of each stock symbol. The vast majority of trading on ASX takes place until 4:00 pm. Submitted orders are either matched, resulting in trades, or stored in the order book waiting to be matched. At 4:00 pm, the market gets ready for a closing auction. To avoid confounding effects from the opening procedure, we focus on the period from 10:15 am to 4:00 pm.

We obtain data on the top 100 ASX stocks for March 2000 using the Securities Industry Research Centre Asia-Pacific (SIRCA). These data provide historical details of all orders placed on SEATS as well as any resulting trades. Each record is time stamped to the nearest 0.01 second and includes price, size, and direction. The data also include information on order cancellations and amendments. Although the data include order amendments and cancellations, investors do not see the tag or flag of amendments or cancellations.[4] They do see the book up to a certain number of price steps, and this is the only information we use as independent variables in the regressions in later sections. Investors can amend or cancel existing orders, and we model these choices as the dependent variables. If an investor cancels an order and then resubmits, we treat these as a cancellation and a submission, though in the investor's mind, he or she might intend to amend an order. Because there is no extra cost to amend an order, a cancel and a re-submission may indeed represent two actions. Though investors are not charged for canceling or amending an order that has not been filled or partially filled, order amendments to a new price step need to join the back of that step. If it is only the size of an order that is increased, the original portion stays where it is, and the increased portion is added to the back of the price step. Priority of an order will not change if only its size is reduced. We reconstruct the book in intraday event time, and an event is classified as an order action, such as an order submission, cancellation, or amendment. The limit order book, up to 10 price steps on each side of the market, is built right before an event. The book updates right after the event and stays unchanged until the next event. Cao, Hansch, and Wang (2007) also use the ASX SEATS data to examine

[3]For our sample period, unlike institutional ASX participants, individual investors in Australia cannot view each order or trader identity, but as of March 2007, all orders can be shown to the public, for example, on the Active Trader Platform offered by E*TRADE Pro or Power E*TRADE of E*TRADE Australia. The Singapore Stock Exchange also displays the entire book. The Korea Stock Exchange discloses the 10 best steps to all investors, and Euronext.Paris and the Hong Kong Stock Exchange disclose the 5 best steps to investors, though on Euronext.Paris, member firms such as institutional investors have access to the entire content of the book, with the exception of hidden orders and trader identification. Michayluk and Sanger (2006) provide further description on the Paris Bourse.

[4]Because institutional investors have access to trader identities, they can actually trace what has happened to a particular order, such as amendment or cancellation.

the limit order market but they focus on price discovery and short-term stock return prediction.

Summary Statistics

Traders can take three actions toward an order: submitting a new order, canceling an existing order, or amending an existing order by choosing a new quantity, a new price, or other terms such as the time span of an order.[5] We report summary statistics of orders that are submitted, amended, or canceled in this subsection and categorize the position of each order by comparing its price with the price steps on the book right before the order action. If a newly submitted order falls at step k, then step $= k$. If an order becomes the best order on the book, then step $= 0$. If the order is a market order that goes on the other side of the market, then step $= -1$. Similarly, if an order is deleted from step k, then step $= k$. If an order is amended from step k_1 to k_2, then step $= k_2$.

Depending on whether k_1 is greater than k_2, we divide the amendments into three sub groups: amend-forward, which includes amendments where $k_1 > k_2$ and the amended price is better than the original price as it moves closer to the top of the book; amend-backward, which includes amendments where $k_1 < k_2$ and the amended price is less aggressive; and amend-same, which includes amendments where $k_1 = k_2$. An amendment in the last group does not change the price of an order, it only changes its number of shares. Orders submitted, amended, or deleted at or beyond step 10 are labeled step ≥ 10.

Table 1 reports the distribution of order actions for the 100 sample stocks. There are 1,177,040 order actions during the sample period. New order submission is the most common activity with a frequency of 75.34%. Forward amendment follows with a frequency of 12.88% and order cancellation comes third with a frequency of 7.83%. Amendments at the same price and backward amendments are not as common.

We calculate the frequency distribution within each category. About half (50.98%) of new order submissions are market orders. The other half are limit orders submitted to different positions on the book, with about 18% (3.79% + 13.96%) of them submitted to steps behind the top step. A similar distribution exists in orders that have been amended forward. Among order cancellations, 56% (42.55% + 13.16%) of them are removed from steps behind the best price. These statistics reveal that there are a lot activities going on behind the top of the book, justifying an investigation of this part of the book.

[5] We focus on amendments that only change the price or size of an order. Amendments that change other terms are rare.

TABLE 1. Frequency Distributions of Order Activities.

				Amend-Same				
Steps	Cancel	Amend-Backward	Amend-Forward	Quantity Increases	Quantity Decreases	Quantity Remains the Same	Submit	Total
Steps ≥ 10	13.16%	18.37%	2.01%	0.80%	3.56%	8.66%	3.79%	
Steps 2–9	42.55%	81.61%	14.91%	21.71%	36.68%	49.69%	13.96%	
Step 1	44.29%		24.42%	77.49%	59.76%	41.65%	22.83%	
Step 0			10.63%				8.44%	
Step -1			48.03%				50.98%	
Sum	100%	100%	100%	100%	100%	100%	100%	
Share	7.83%	1.12%	12.88%	1.20%	0.84%	0.79%	75.34%	100%
Counts	92,216	13,165	151,623	14,165	9,898	9,240	886,733	1,177,040

Note: This table presents the frequency distribution of each order activity at different positions on the limit order book. We categorize the position of each order by comparing its price with the price steps on the book right before the order action. Submit = submitted orders; Cancel = canceled orders; Amend = amended orders. If a newly submitted order falls at step k, then step = k; if an order becomes the best order on the book, then step = 0; if an order is a market order that goes on the opposite side of the market, then step = -1. Similarly, if an order is deleted from step k, then step = k; if an order is amended from step k_1 to k_2, then step = k_2. Depending on whether k_1 is greater than k_2, we divide amendments into three subgroups: Amend-Forward includes amendments where $k_1 > k_2$ and the amended price is better than the original price, Amend-Backward includes amendments where $k_1 < k_2$ and the amended price is less aggressive, and Amend-Same includes amendments where $k_1 = k_2$. An amendment in the last group does not change the price of an order but only changes its number of shares. Orders submitted, amended, or deleted at or beyond step 10 are labeled Step ≥ 10.

IV. Order Book and Order Strategies

Ordered Probit Model

We study investors' order strategies using an ordered probit model in the spirit of Ranaldo (2004). The different actions available to traders are inherently ordered in terms of their aggressiveness, with a market order as the most aggressive type. Among limit orders, a ranking can be established according to their limit prices. If the price of an order is amended, the aggressiveness of the amendment depends on whether the order is amended backward or forward. When the size of an order is amended, the aggressiveness of the amendment can be assessed by whether the order size is reduced or increased. Finally, limit order cancellations can be considered as the least aggressive, as traders who cancel their orders remove liquidity from the book. Consistent with the extant theoretical literature, our approach implicitly assumes that traders arriving in the market have decided whether they want to be active on the buy or sell side of the market, independent of the state of the book. In effect, we investigate whether the state of the book, conditional on order direction and other control variables such as volatility and return, has any effect on where the order is placed, canceled, or amended.

The ordered probit model consists of two parts. The first part relates the observable action type (R) to the latent variable (Z), which is continuous and whose domain is the set of real numbers:

$$\begin{aligned} R &= 1, \text{ if } Z = (-\infty, \mu_1), \\ &\ldots, \\ R &= j, \text{ if } Z = [\mu_{j-1}, \mu_j), \\ &\ldots, \\ R &= k, \text{ if } Z = [\mu_{k-1}, \infty), \end{aligned} \tag{1}$$

where $\mu_j (j = 1 \text{ to } k-1)$ are partition points to be estimated. The second part of the model relates the latent variable (Z) to the observable explanatory variables (x):

$$Z = \beta_0 + \beta_1 x_1 + \cdots \beta_n x_n + \varepsilon = \beta' x + \varepsilon. \tag{2}$$

The error terms are assumed to be normally distributed across observations with mean and variance normalized to 0 and 1, respectively. With this formulation, the probability for each action is then,

$$\begin{aligned} &\text{Probability}(R = 1 \mid X) = \Phi[\mu_1 - \beta' X], \\ &\ldots, \\ &\text{Probability}(R = j \mid X) = \Phi[\mu_j - \beta' X] - \Phi[\mu_{j-1} - \beta' X], \\ &\ldots, \\ &\text{Probability}(R = k \mid X) = 1 - \Phi[\mu_{k-1} - \beta' X], \end{aligned} \tag{3}$$

where the probability of each rank is calculated at the means (X) of the explanatory variables (x), and $(\cdot)$ is the cumulative density function of the standard normal distribution. We then shock each individual explanatory variable (x_j) by its standard deviation while holding other variables at their means, and we calculate the new probability of each rank. The difference in the two probabilities, the impulse sensitivity of an action i with regard to variable j, quantifies the effect from x_j on a trader's order choice.

$$\begin{aligned} &\partial \text{ Probability}(R = 1 \mid X)/\partial x_j = -\varphi[\mu_1 - \beta' X]\beta_j, \\ &\ldots, \\ &\partial \text{ Probability}(R = j \mid X)/\partial x_j = -\varphi[\mu_j - \beta' X]\beta_j + \varphi[\mu_{j-1} - \beta' X]\beta_j, \\ &\ldots, \\ &\partial \text{ Probability}(R = k \mid X)/\partial x_j = \varphi[\mu_{k-1} - \beta' X]\beta_j, \end{aligned} \tag{4}$$

where $\varphi(\cdot)$ is the probability density function of the standard normal distribution.

We focus on the impulse sensitivity of each variable instead of its coefficient estimate for the following reason. Unlike ordinary least squares (OLS) regressions, neither the magnitude nor the sign of the coefficient estimate β_j corresponds to its marginal effect on the dependent variable in an ordered probit model. Only when the dependent variable takes on one of the two border values (e.g., 1 or k in our model) can the sign of β_j imply whether there is an increase or decrease in the likelihood of the border event. For completeness, we report the coefficient estimates and their associated p-values in our tables. The p-values are computed based on the χ^2 distribution with 1 degree of freedom.

Variables

Turning to the dependent variables in equation (2), we distinguish among five categories of trader actions as suggested by Table 1. The five types are order submission, cancellation, amendment forward to a better price, amendment backward to a worse price, and amendment by a new quantity at the same price. We include several order book statistics as explanatory variables. The first variable is the relative inside spread (*rspread*), which is the inside spread normalized by the mid-price of the best bid and offer (*MIDP*). According to previous studies, we expect that a wider inside spread discourages traders from placing costly market orders.

We include the imbalance between supply and demand at the first step of the book, $Q^{own}{}_1$ and $Q^{opposite}{}_1$, as explanatory variables; *own* and *opposite* are in respect to the upcoming order actions. For example, if the upcoming action is on the buy side, *own* refers to the demand side of the book right before the action. $Q^{own}{}_1$ (or $Q^{opposite}{}_1$) is scaled by the total number of shares from step 1 to step 10 on the same side of the book to obtain $RQ^{own}{}_1$ (or $RQ^{opposite}{}_1$), the relative depth of step 1. Finally, we calculate $Q^{imb}{}_1$ as

$$\left(RQ^{own}{}_1 - RQ^{opposite}{}_1\right)/\left[\left(RQ^{own}{}_1 + RQ^{opposite}{}_1\right)/2\right]. \tag{5}$$

Together, the relative inside spread and the imbalance in depth at step 1 capture the state of the book at its top. Similar to our choice of order imbalance, Hall and Hautsch (2004) study the buy–sell pressure on the ASX and find that it is affected by the status of the order book.

To gauge the influence of the subsequent steps in the book, we include variables that summarize both the depth and height of the book beyond step 1. The depth refers to the quantity dimension of the book and the height refers to the price dimension. Specifically, we include the imbalance in the number of shares from steps 2 to 10 as:

$$Q^{imb}{}_{2\text{-}10} = \left(RQ^{own}{}_{2\text{-}10} - RQ^{opposite}{}_{2\text{-}10}\right)/\left[\left(RQ^{own}{}_{2\text{-}10} + RQ^{opposite}{}_{2\text{-}10}\right)/2\right], \tag{6}$$

where $RQ^{own}{}_{2\text{-}10}$ (or $RQ^{opposite}{}_{2\text{-}10}$) is the sum of the number of shares from steps 2 to 10, normalized by the total number of shares on the first 10 steps on the same side of the book. To capture the price dimension of the book, we compute the imbalance in the price gap between steps 1 and 10 as the following:

$$P^{imb}{}_{1\text{-}10} = \left(P^{own}{}_{1\text{-}10} - P^{opposite}{}_{1\text{-}10}\right) \Big/ \left[\left(P^{own}{}_{1\text{-}10} + P^{opposite}{}_{1\text{-}10}\right)/2\right], \quad (7)$$

where $P^{own}{}_{1\text{-}10}$ (or $P^{opposite}{}_{1\text{-}10}$) is the price difference between steps 1 and 10 on the own (or opposite) side of the book. Together, $Q^{imb}{}_{2\text{-}10}$ and $P^{imb}{}_{1\text{-}10}$ characterize the state of the order book beyond step 1. As stated in the introduction, previous research on the order book focuses on the depth of the book. We include both the depth and price in our analysis.

These explanatory variables characterize the state of the order book, right before an order action is taken. Because responses to changes in the order book may not be immediate—especially in a fast-moving market—we add lagged book variables in the model (e.g., *lrspread,* $lQ^{imb}{}_1$, $lQ^{imb}{}_{2\text{-}10}$, and $lP^{imb}{}_{1\text{-}10}$). Ahn, Bae, and Chan (2001) and Hasbrouck and Saar (2002) show that market conditions, such as the stock return and its volatility, can affect traders order behavior in limit order markets. To control for these factors, we include the stock *return* and *volatility* right before an order action. The variable *return* is calculated as the percentage change in the mid-price (*MIDP*) between the two adjacent order actions, and *volatility* is determined by the absolute value of return. *MIDP* is the average of the best bid and ask price.

Adding explanatory variables in the model increases the risk of multicollinearity. Following Ellul et al. (Forthcoming), we check for multicollinearity by adopting the Belsey, Kuh, and Welsch (1980) method and by computing the condition indices. The condition indices are the square roots of the ratio of the largest eigenvalue to each eigenvalue. Belsey, Kuh, and Welsch suggest that when the largest condition index is around 10 (the critical value), weak dependencies may start to affect the regression estimates. We compute the condition indices for our dependent variables and find that they range from 1 to 7.94; thus, our largest condition index is smaller than the critical value.

Regressions

We estimate an ordered probit regression for each order category and an overall regression for all categories combined together. The purpose of the overall regression is to capture the first-stage decision an investor makes with respect to an existing limit order on the book (i.e., the decision to cancel it or to amend it backward, forward, or at the same price). An investor can always stay put and wait for the order to be executed; thus, no action is a choice, as well. Because our snapshots of the order book are updated on event time, and each event is characterized by an

action, a no-action "action" is, by design, impossible to model in our framework. We therefore omit it from our model but acknowledge that this can be an interesting venue for future research.

Ellul et al. (Forthcoming) model no action as a choice into their multinomial logit model and use five-minute time aggregates. If there is no action within a five-minute interval, it is counted as a no-activity event.

Within each order action, the ordered probit model can capture any second-stage decision an investor makes once the first decision is made. For example, if an investor decides to submit (amend) an order, the model can infer which price step he or she will choose next. We use the maximum likelihood method to estimate the model. Each regression is estimated twice: first with explanatory variables that describe step 1 of the book only (*rspread,* $Q^{imb}{}_1$, *lrspread,* and $lQ^{imb}{}_1$); second, with all the explanatory variables that include the rest of the book. We control for *return* and *volatility* in both estimations. The change in the maximum likelihood function indicates how much the book beyond the insides adds to the explanatory power of the regression. We then compare the unconditional probability of each action with its conditional probability, which is estimated based on the model. We also measure the marginal effect of each explanatory variable by its impulse sensitivity. Table 2 provides a summary of the major findings based on the impulse sensitivities.

V. Empirical Results

Ordered Probit Within Order Submissions

Order submission has been the focus of the existing research on investors' trading strategies. We extend previous research by using information of the entire order book with a more detailed categorization of submission choices. Within new order submissions, let R denote the rank of an action. We assign the highest rank $R = 5$ to the most aggressive submission—market orders. Only slightly less aggressive is the submission of a limit order that improves the current best bid or offer, and its rank $R = 4$. Next, we distinguish among three types of limit orders based on the step at which the order enters the book. We assign $R = 3$ to an order that matches the best bid or offer, $R = 2$ to an order submitted beyond step 1 but before step 10, and $R = 1$ to the least aggressive submission—a limit order at or beyond step 10.

The impulse sensitivities reported in Table 3 show that our results are consistent with previous research on the effect of the inside spread on order submissions. A 1 standard deviation shock to *rspread* reduces the likelihood of market orders by 3.9% because trading across a large spread is costly, but the large spread encourages limit orders at or better than the current best price. We also find that $Q^{imb}{}_1$ increases the likelihood of submitting a market order by 2.6%, as the first step on the book is crowded out and new orders need to "jump the queue." This result is consistent with previous findings on book depth.

TABLE 2. Summary of Major Findings.

Panel A. Order Submissions			
Regressors	Findings	Consistent with	Inconsistent with
Insides			
rspread	Discourage market orders	Biais, Hillion, and Spatt (1995)	
	Encourage limit orders	Foucault (1999)	
$Q^{imb}{}_1$	Encourage market orders	Parlour (1998)	
	Discourage limit orders	Ranaldo (2004)	
		Griffiths et al. (2000)	
		Beber and Caglio (2005)	
Control variables			
volatility	Minimal effect	Beber and Caglio (2005)	Ahn, Bae, and Chan (2001)
		Hall and Hautsch (2006)	Hasbrouck and Saar (2002)
return	Minimal effect		Hall and Hautsch (2006)
Lagged *insides*[a]			
lrspread	Same sign but smaller effect than *rspread*		
$lQ^{imb}{}_1$	Same sign but smaller effect than $Q^{imb}{}_1$		
Book beyond the insides			
$P^{imb}{}_{1\text{-}10}$[a]	Minimal effect		
$Q^{imb}{}_{2\text{-}10}$	Discourage market orders but encourage limit orders	Hall and Hautsch (2006)	
Lagged book[a]			
$lP^{imb}{}_{1\text{-}10}$	Minimal effect		
$lQ^{imb}{}_{2\text{-}10}$	Minimal effect		

Panel B. Order Cancellations		
Regressors	Findings	Consistent with
Insides		
rspread	Discourage cancellations at step 1	
	Encourage cancellations at other steps	Ranaldo (2004), Ellul et al. (Forthcoming)
$Q^{imb}{}_1$	Discourage cancellations at step 1	Hall and Hautsch (2006)
	Encourage cancellations at other steps	
Control		
volatility	Same sign but smaller effect than *rspread*	Ranaldo (2004), Ellul et al. (Forthcoming)
return	Minimal effect	
Lagged insides[a]		
lrspread	Same sign but smaller effect than *rspread*	
$lQ^{imb}{}_1$	Same sign but smaller effect than $Q^{imb}{}_1$	
Book beyond the insides[a]		
$P^{imb}{}_{1\text{-}10}$	Encourage cancellations at step 1	
	Discourage cancellations at other steps	
$Q^{imb}{}_{2\text{-}10}$	Discourage cancellations at step 1	
	Encourage cancellations at other steps	
Lagged book[a]		
$lP^{imb}{}_{1\text{-}10}$	Same sign but smaller magnitude than $P^{imb}{}_{1\text{-}10}$	
$lQ^{imb}{}_{2\text{-}10}$	Same sign but smaller magnitude than $Q^{imb}{}_{2\text{-}10}$	

(Continued)

TABLE 2. Continued.

Panel C. Amendments Forward	
Regressors	Findings
Insides	
rspread	Discourage amending forward to the opposite side Encourage amending forward at own side
$Q^{imb}{}_1$	Encourage amending forward to the opposite side Discourage amending forward at own side
Control	
volatility	Minimal effect
return	Minimal effect
Lagged insides	
lrspread	Same sign but smaller effect than rspread
$lQ^{imb}{}_1$	Same sign but smaller effect than $Q^{imb}{}_1$
Book beyond the insides	
$P^{imb}{}_{1\text{-}10}$	Minimal effect
$Q^{imb}{}_{2\text{-}10}$	Discouraging amending forward to the opposite side
Lagged book	
$lP^{imb}{}_{1\text{-}10}$	Minimal effect
$lQ^{imb}{}_{2\text{-}10}$	Minimal effect

Note: This table summarizes the major findings of our article. The conclusion is based on the results of ordered probit models and impulse sensitivities. Panels A, B, and C report findings for order submissions, order cancellations, and forward amendments, respectively. The explanatory variables used in the ordered probit models are defined as follows: *rspread* = relative inside spread; $Q^{imb}{}_1$ = the imbalance in depth at the first step; $Q^{imb}{}_{2\text{-}10}$ = the imbalance in the number of shares from steps 2 to 10; $P^{imb}{}_{1\text{-}10}$ = the imbalance in the price gap between steps 1 and 10; *return* = the percentage change in share price between two adjacent order actions; *volatility* = the absolute value of *return*; and *lrspread,* $lQ^{imb}{}_1$, $lQ^{imb}{}_{2\text{-}10}$, and $lP^{imb}{}_{1\text{-}10}$ are lagged variables of *rspread,* $Q^{imb}{}_1$, $Q^{imb}{}_{2\text{-}10}$, and $P^{imb}{}_{1\text{-}10}$, respectively.
[a]Indicates variables that are not used in previous research. All order amendments in Panel C are not used in previous research.

In contrast to previous research, we do not find *volatility* and *return* to have a significant effect on order submission strategies. None of the impulse sensitivities is larger than 0.1% in magnitude though they both have significant coefficients. Other explanatory variables describing the rest of the book do not seem to have a significant effect on order submissions, as the impulse sensitivities are small.

Ordered Probit Within Order Cancellations

Order cancellations are fairly common on the ASX. During our sample period, they account for 7.83% of total order actions (see Table 1). Being the opposite of an order submission, an order cancellation may carry significant information for investors' trading strategies. The same factors that affect order submissions may also explain order cancellations, though possibly in the opposite way. Within order cancellations, we assign $R = 3$ to canceling an order at step 1of the book, $R = 2$ if beyond step 1 but before step 10, and $R = 1$ if canceling an order at or beyond step 10.

TABLE 3. Estimates of Impulse Sensitivities and Coefficients for Order Submissions.

Panel A. Impulse Sensitivities (in %)

Step	Unconditional Probability	Conditional Probability at Means	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
Step $\geq$ 10	3.80	4.30	1.00	−0.60	0.00	0.00	0.10	−0.20	0.00	0.30	0.00	−0.10
2 $\leq$ Step < 10	14.00	13.90	1.70	−1.10	−0.10	0.00	0.10	−0.40	−0.10	0.50	−0.10	−0.20
Step = 1	22.80	22.90	1.20	−0.90	0.00	0.00	0.10	−0.30	0.00	0.40	−0.10	−0.20
Step = 0	8.40	8.20	0.10	−0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Step = −1	51.00	50.90	−3.90	2.60	0.10	−0.10	−0.20	0.80	0.10	−1.20	0.20	0.50
Change in model fit		3.50										

Panel B. Coefficient Estimates

	Intercept	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
Coefficient	−1.826	20.4155	−0.0535	−0.9099	0.7571	1.1985	−0.0166	−0.0066	0.125	−0.0088	−0.0521
p-value	<.0001	<.0001	<.0001	.0307	.0584	.0381	<.0001	.0052	<.0001	.0002	<.0001

Note: This table presents estimation results of an ordered probit model for new order submissions. Panel A reports the impulse sensitivities and Panel B reports the coefficient estimates and their associated *p*-values. We use the maximum likelihood method to estimate the ordered probit model. The *p*-values are computed based on the χ^2 distribution with 1 degree of freedom. Impulse sensitivity of an action j with regard to a regressor i (∂Prob(Rank = j)/ ∂x_i) is defined as the change in the likelihood in action j when x_i is shocked by its standard deviation while all the other regressors are held at their respective means. The dependent variable takes on five values: Step = −1 refers to market orders, Step = 0 refers to limit orders that improve the current best bid or offer, Step = 1 refers to limit orders that match the best bid or offer, 2 $\leq$ Step < 10 refers to limit orders submitted beyond step 1 but before step 10, and Step $\geq$ 10 refer to limit orders submitted at or beyond step 10. The conditional probability is the conditional likelihood of an action estimated at the means of all regressors. The change in model fit is calculated as the change in the maximum likelihood function (in %) when $Q^{imb}{}_{2\text{-}10}$, $P^{imb}{}_{1\text{-}10}$, $lQ^{imb}{}_{2\text{-}10}$, and $lP^{imb}{}_{1\text{-}10}$ are included in the regression. Definitions of the variables are provided in Table 2.

As shown in Table 4, the inside spread has a significant effect on order cancellations. A 1 standard deviation increase in *rspread* increases the likelihood of canceling an order between steps 1 and 10 by 2.3% and beyond step 10 by 3.9%. This result is consistent with that reported in Ranaldo (2004) and Ellul et al. (Forthcoming). If orders are already at the top of the book, they have a tendency to be left there as *rspread* decreases order cancellations at step 1 by 6.3%. Consistent with Hall and Hautsch (2006), we find that $Q^{imb}{}_1$ decreases order cancellations at step 1(by 6.8%). In contrast, $Q^{imb}{}_1$ increases order cancellations between steps 1 and 10 by 2.5% and beyond step 10 by 4.3%. These results show that investors with orders at the back of the book lose hope of execution when facing a long first step, whereas investors with orders already at the crowded step 1 do not seem to panic.

Other variables including $P^{imb}{}_{1\text{-}10}$, $Q^{imb}{}_{2\text{-}10}$, $lP^{imb}{}_{1\text{-}10}$, and $lQ^{imb}{}_{2\text{-}10}$ also affect order cancellations. A 1 standard deviation shock to $P^{imb}{}_{1\text{-}10}$ increases order cancellations at step 1 by 2.7%, whereas it decreases cancellations at other steps. The increase in $P^{imb}{}_{1\text{-}10}$ indicates a decrease in liquidity supply on the own side compared to the opposite side as the steps on the own side get relatively sparse. This result shows that when liquidity gets thin along the book, investors tend to cancel orders at step 1 and later move them to fill in the gaps created by the increased $P^{imb}{}_{1\text{-}10}$ (as later results from backward amendments suggest). In contrast, a larger order imbalance along the book as represented by a higher $Q^{imb}{}_{2\text{-}10}$ indicates an improved liquidity supply on the own side relative to the opposite side as the steps on the own side get more crowded. $Q^{imb}{}_{2\text{-}10}$ decreases order cancellations at step 1 by 3.8%, whereas it increases cancellations between steps 1 and 10 by 1.50% and beyond step 10 by 2.3%. This result shows that investors cancel more orders at the back of the book when it is overly liquid, whereas investors with orders ahead of the crowded steps stay put and remain hopeful of execution. Once again, the crowding-out effect is at work. $lP^{imb}{}_{1\text{-}10}$ and $lQ^{imb}{}_{2\text{-}10}$ have the same directional effects as $P^{imb}{}_{1\text{-}10}$ and $Q^{imb}{}_{2\text{-}10}$, but with smaller effects.

Ordered Probit Within Forward Order Amendments

Existing limit orders can be moved more aggressively to price steps ahead of them. Table 1 shows that most forward amendments end up at step 1 or even to the other side of the market (a market order). We categorize forward amendments the same way as we categorize new order submissions. That is, five ordinal ranks for five new locations of the amendments.

Table 5 presents estimation results for forward amendments. Comparing results in Table 3 and Table 5, we find a similarity between forward amendments and new order submissions. A 1 standard deviation shock to *rspread* reduces the likelihood of amending an order from limit to market by 7.5%, whereas $Q^{imb}{}_1$ increases the same likelihood by 3.1%. The crowding-out and jumping-the-queue effects are evident as investors amend their orders more aggressively when there

TABLE 4. Estimates of Impulse Sensitivities and Coefficients for Order Cancellations.

Panel A. Impulse Sensitivities (in %)

Step	Unconditional Probability	Conditional Probability at Means	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
Step $\geq$ 10	13.20	13.90	3.90	4.30	0.50	−0.20	1.30	1.80	−1.50	2.30	−0.30	0.40
2 $\leq$ Step < 10	42.60	43.00	2.30	2.50	0.40	−0.10	0.90	1.20	−1.20	1.50	−0.20	0.30
Step = 1	44.30	43.10	−6.30	−6.80	−0.90	0.30	−2.20	−3.10	2.70	−3.80	0.50	−0.70
Change in model fit	4.60											

Panel B. Coefficient Estimates

	Intercept	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
Coefficient	−1.2688	34.3044	0.1353	2.4545	−0.721	11.8968	0.0602	−0.1258	0.401	−0.024	0.0687
p-value	<.0001	<.0001	<.0001	<.0001	.1748	<.0001	<.0001	<.0001	<.0001	.001	.0034

Note: This table presents estimation results of an ordered probit model for order cancellations. The dependent variable takes on three values for the following three cancellations: canceling an order at step 1, between step 1 and step 10, and at or beyond step 10. Definitions of the variables are provided in Table 2. The calculations of the estimates are explained in Table 3.

TABLE 5. Estimates of Impulse Sensitivities and Coefficients for Forward Order Amendments.

Panel A. Impulse Sensitivities (in %)

Step	Unconditional Probability	Conditional Probability at Means	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
Step $\geq$ 10	2.00	2.30	1.30	−0.40	−0.10	0.00	−0.40	0.00	−0.10	0.30	0.00	−0.10
2 $\leq$ Step $<$ 10	15.00	14.80	4.00	−1.50	−0.20	−0.10	−1.30	−0.10	−0.30	1.00	0.00	−0.40
Step = 1	24.40	24.50	2.30	−1.10	−0.20	0.00	−1.00	−0.10	−0.20	0.60	0.00	−0.30
Step = 0	10.60	10.40	0.00	−0.10	0.00	0.00	−0.10	0.00	0.00	0.00	0.00	0.00
Step = −1	48.00	47.90	−7.50	3.10	0.50	0.10	2.80	0.20	0.50	−1.90	0.10	0.80
Change in model fit	4.20											

Panel B. Coefficient Estimates

	Intercept	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
Coefficient	−2.1136	40.4242	−0.0651	−1.6822	−0.3559	−14.6151	−0.0046	−0.0241	0.2059	−0.0039	−0.0868
p-value	<.0001	<.0001	<.0001	.0052	.5086	<.0001	.1938	<.0001	<.0001	.5012	<.0001

Note: This table presents estimation results of an ordered probit model for forward amendments. The dependent variable takes on five values: Step = −1 refers to market orders, Step = 0 refers to limit orders that improve the current best bid or offer, Step = 1 refers to limit orders that match the best bid or offer, 2 $\leq$ Step $<$ 10 refers to limit orders submitted beyond step 1 but before step 10, and Step $\geq$ 10 refers to limit orders submitted at or beyond step 10. Definitions of the variables are provided in Table 2. The calculations of the estimates are explained in Table 3.

are relatively more orders on step 1 of the own side than on the opposite side. By jumping the queue, impatient investors can get ahead of other investors and have their orders executed sooner. The rest of the results for forward amendments are similar to those of order submissions.

Ordered Probit Within Order Amendments at the Same Price Step

For amendments that only change the number of shares of an order, we separate them into two groups according to order size: those with an increase and those with a decrease. We then divide each group into three subcategories based on which step an order is located, resulting in six ranks. We assign $R = 6$ to increasing the size of an order at step 1, $R = 5$ to steps between 1 and 10, and $R = 4$ to steps beyond 10. We then assign $R = 3$ to decreasing the size of an order at step 1, $R = 2$ to steps between 1 and 10, and $R = 1$ to steps beyond 10.

We report the estimation results in Table 6. According to the impulse sensitivities, $Q^{imb}{}_1$ reduces the order-size increase at step 1 by 6.1%, whereas it increases the order-size reduction at the same step by 2.0%. This result shows that when step 1 is crowded, there is no need to add more shares. Therefore, the same crowding-out effect that we document for order submissions and forward amendments is prevalent here. $Q^{imb}{}_1$ encourages order reductions between steps 1 and 10 by 3.4% because investors do not have a chance to execute a large order if it stays behind the already-crowded step 1.

Turning to the variables beyond step 1, we find that investors with orders ahead of a large price gap tend to become more aggressive, whereas those with orders inside the gap stay put. This can be shown as $P^{imb}{}_{1\text{-}10}$ encourages order-size increase at step 1 by 4.5% but discourages all other actions, especially reducing the size of an order between steps 1 and 10.

Ordered Probit Within Backward Order Amendments

In addition to amendments discussed previously, other amendments are actions that amend an existing order to a step away from the top of the book. That is, for an investor's buy order, it is amended at a lower price, or for a sell order, it is amended at a higher price. We assign $R = 2$ to amendments between steps 2 and 10, and $R = 1$ to amendments beyond step 10. There are no backward amendments to step 1 because those orders would have already been executed before they could be amended.

The estimation results presented in Table 7 suggest that, judged by impulse sensitivity, $P^{imb}{}_{1\text{-}10}$ has the largest effect on backward order amendments among all variables. It increases the likelihood of amending an order back to between steps 1 and 10 by 6.3%, as some investors would take advantage of the large price gap between steps 1 and 10 even though it means amending their existing orders away from the more advantageous steps. This result is consistent with the effect

TABLE 6. Estimates of Impulse Sensitivities and Coefficients for Order Amendments at the Same Price Step.

Panel A. Impulse Sensitivities (in %)

Step	Unconditional Probability	Conditional Probability at Means	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
Quantity decreases												
Step $\geq$ 10	1.50	1.70	0.10	0.80	0.40	0.00	0.40	0.10	−0.40	0.10	−0.10	0.10
2 $\leq$ Step $<$ 10	15.10	15.10	0.50	3.40	1.90	−0.10	1.70	0.50	−2.30	0.30	−0.40	0.40
Step = 1	24.60	25.00	0.30	2.00	1.10	−0.10	1.10	0.40	−1.70	0.20	−0.30	0.30
Quantity increases												
Step $\geq$ 10	0.40	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 $\leq$ Step $<$ 10	12.90	13.20	0.00	−0.10	0.00	0.00	0.00	0.00	−0.10	0.00	0.00	0.00
Step = 1	45.60	44.40	−1.00	−6.10	−3.40	0.30	−3.10	−1.00	4.50	−0.60	0.80	−0.70
Change in model fit	4.90											

Panel B. Coefficient Estimates

	Intercept	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
Coefficient	−2.242	5.3889	0.1282	5.6886	−0.4291	16.9719	0.0214	−0.2077	0.0578	−0.0358	0.0749
p-value	<.0001	.0444	<.0001	<.0001	.5563	<.0001	.015	<.0001	.1827	.0112	.0872

Note: This table presents estimation results of an ordered probit model for order amendments at the same price step. The dependent variable takes on six values for the following actions: increasing the size of an order at step 1, increasing the size of an order at a step between 1 and 10, increasing the size of an order at step 10 or beyond, decreasing the size of an order at step 1, decreasing the size of an order at a step between 1 and 10, and decreasing the size of an order at step 10 or beyond. Definitions of the variables are provided in Table 2. The calculations of the estimates are explained in Table 3.

TABLE 7. Estimates of Impulse Sensitivities and Coefficients for Backward Order Amendments.

Panel A. Impulse Sensitivities (in %)

Step	Unconditional Probability	Conditional Probability at Means	*rspread*	$Q^{imb}{}_{1}$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_{1}$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
Step $\geq$ 10	18.40	20.20	1.00	−1.50	−0.70	1.00	1.50	−0.40	−6.30	−1.60	−0.60	−0.40
2 $\leq$ Step < 10	81.60	79.80	−1.00	1.50	0.70	−1.00	−1.50	0.40	6.30	1.60	0.60	0.40
Change in model fit	5.20											

Panel B. Coefficient Estimates

	Intercept	*rspread*	$Q^{imb}{}_{1}$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_{1}$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
Coefficient	−0.8941	6.9845	−0.0452	−1.0467	1.4113	10.417	−0.0105	−0.4706	−0.2552	−0.0387	−0.057
p-value	<.0001	0.0577	0.0045	0.1567	0.0391	0.0037	0.5101	<.0001	0.004	0.1355	0.5194

Note: This table presents estimation results of an ordered probit model for backward order amendments. The dependent variable takes on two values: amendments back to steps between 2 and 10, and amendments back to steps behind step 10. Definitions of the variables are provided in Table 2. The calculations of the estimates are explained in Table 3.

of $P^{imb}{}_{1\text{-}10}$ on discouraging order-size reduction for orders in the price gap. $Q^{imb}{}_{1}$ and $Q^{imb}{}_{2\text{-}10}$ have similar, though smaller, effects (1.5% and 1.6%) on backward amendments. The results from this section show that the investors seem to prefer moving their orders back to fill a large price gap rather than to be crowded at the top steps with other orders.

Overall Ordered Probit Regression for Previously Placed Orders

We now examine what investors can do if they already have an order on the book. The choice toward a previously placed order includes canceling it, amending it forward, amending only its quantity, or amending it backward. We estimate an overall ordered probit regression by combining order cancellations, forward amendments, same-price amendments, and backward amendments. The four alternatives are mutually exclusive. We assign $R = 1$ to order cancellations, $R = 2$ to backward amendments, $R = 3$ to same-price amendments, and $R = 4$ to forward amendments. The assignment of the ordinal ranking follows the latent aggressiveness of each action, as a cancellation is the least aggressive action and a forward amendment is the most aggressive. The same set of explanatory variables used in previous subsections is on the right side of the regression. This overall regression represents the first decision, which an investor can make toward a previously placed order. Once investors have made the first decision—for example, a forward amendment—they must then decide where to amend the order. The group-by-group ordered probit results, discussed earlier, examine this second-stage decision, and the overall regression examines the first-stage decision.

Table 8 reports impulse sensitivities. The imbalance between step 1 of the two sides of the book increases the likelihood of forward amendments by 3.0%. This result is consistent with the crowding-out and jumping-the-queue effect. Similar effects are found for $Q^{imb}{}_{2\text{-}10}$. The imbalance in the price gap between steps 1 and 10 has the opposite effect, as $P^{imb}{}_{1\text{-}10}$ increases the likelihood of order cancellations by 2.6% but decreases forward amendments by 2.9%. In summary, the overall regression results suggest that investors become more aggressive by amending their orders forward, which they do to be ahead of a long queue, but they are also less aggressive when there is a large price gap in the book.

Discussion of Other Results

In addition to impulse sensitivities, we report the overall model fit, the conditional and unconditional likelihood of each action, and the coefficient estimates and their associated p-values in Tables 3−8. First, the estimated likelihood for each activity at the mean of each explanatory variable is close to its unconditional probability. For example, for market order submissions, Table 3 shows that the two probabilities are 50.9% and 51.0%, respectively. This close match indicates that the ordered probit

TABLE 8. Estimates of the Overall Ordered Probit Model for Previously Placed Orders.

Panel A. Impulse Sensitivities (in %)

Step	Unconditional Probability	Conditional Probability at Means	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
Cancellation backward	31.80	31.70	−0.40	−2.60	−1.00	0.40	−0.90	−0.70	2.60	−0.90	0.30	−0.30
Amendments	4.50	4.60	0.00	−0.20	−0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.00
Amendments at the same price	11.50	11.50	0.00	−0.20	−0.10	0.00	−0.10	−0.10	0.10	−0.10	0.00	0.00
Forward amendments	52.20	52.20	0.50	3.00	1.10	−0.40	1.00	0.80	−2.90	1.00	−0.40	0.30
Change in model fit	4.40											

Panel B. Coefficient Estimates

	Intercept	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
Coefficient	−0.4322	−2.4164	−0.0601	−5.31	1.9484	−5.1508	−0.0168	0.1338	−0.1062	0.0178	−0.0333
p-value	<.0001	.0089	<.0001	<.0001	.0005	<.0001	<.0001	<.0001	<.0001	<.0001	.0187

Note: This table presents estimation results of an overall ordered probit model for previously placed orders. The dependent variable takes on four values for the following order action groups: forward amendments, amendments at the same price, backward amendments, and order cancellations. Definitions of the variables are provided in Table 2. The calculations of the estimates are explained in Table 3.

TABLE 9. Robustness Check.

Submission	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
First subsample										
Step ≥ 10	1.00	−0.50	0.00	0.00	0.00	−0.20	0.00	0.30	0.00	−0.10
$2 \leq$ Step < 10	1.80	−1.10	−0.10	0.10	0.00	−0.40	0.10	0.50	−0.10	−0.30
Step $= 1$	1.20	−0.80	0.00	0.10	0.00	−0.30	0.00	0.30	0.00	−0.20
Step $= 0$	0.10	−0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Step $= -1$	−3.90	2.60	0.10	−0.20	0.00	0.90	−0.10	−1.10	0.10	0.60
Second subsample										
Step ≥ 10	1.00	−0.60	0.00	0.00	0.10	−0.20	−0.10	0.30	−0.10	−0.10
$2 \leq$ Step < 10	1.70	−1.10	−0.10	0.00	0.20	−0.30	−0.20	0.60	−0.10	−0.10
Step $= 1$	1.20	−0.90	−0.10	0.00	0.20	−0.20	−0.20	0.40	−0.10	−0.10
Step $= 0$	0.10	−0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Step $= -1$	−3.90	2.70	0.20	−0.10	−0.50	0.70	0.50	−1.30	0.30	0.30
Cancellation	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
First subsample										
Step ≥ 10	3.90	4.10	0.40	−0.20	0.90	1.80	−1.50	2.40	−0.20	0.50
$2 \leq$ Step < 10	2.30	2.40	0.30	−0.10	0.70	1.20	−1.20	1.60	−0.20	0.40
Step $= 1$	−6.10	−6.50	−0.80	0.30	−1.50	−3.00	2.70	−4.00	0.40	−0.90
Second subsample										
Step ≥ 10	4.00	4.50	0.50	−0.20	1.70	1.80	−1.50	2.10	−0.40	0.20
$2 \leq$ Step < 10	2.40	2.60	0.40	−0.10	1.20	1.20	−1.20	1.40	−0.30	0.10
Step $= 1$	−6.50	−7.00	−0.90	0.30	−2.90	−3.10	2.70	−3.60	0.70	−0.30
Forward	*rspread*	$Q^{imb}{}_1$	*volatility*	*return*	*lrspread*	$lQ^{imb}{}_1$	$P^{imb}{}_{1\text{-}10}$	$Q^{imb}{}_{2\text{-}10}$	$lP^{imb}{}_{1\text{-}10}$	$lQ^{imb}{}_{2\text{-}10}$
First subsample										
Step ≥ 10	1.20	−0.40	0.00	−0.10	−0.30	0.00	0.00	0.30	0.00	−0.10
$2 \leq$ Step < 10	4.10	−1.60	0.00	−0.20	−1.40	−0.10	−0.20	1.00	0.00	−0.20
Step $= 1$	2.40	−1.20	0.00	−0.10	−1.10	−0.10	−0.10	0.70	0.00	−0.20
Step $= 0$	0.00	−0.10	0.00	0.00	−0.10	0.00	0.00	0.00	0.00	0.00
Step $= -1$	−7.60	3.30	0.00	0.40	3.00	0.20	0.40	−1.90	0.10	0.50
Second subsample										
Step ≥ 10	1.30	−0.40	−0.10	0.00	−0.40	0.00	−0.10	0.30	0.00	−0.20
$2 \leq$ Step < 10	4.00	−1.50	−0.40	0.10	−1.20	−0.20	−0.30	1.00	0.10	−0.60
Step $= 1$	2.10	−1.00	−0.30	0.10	−0.80	−0.10	−0.20	0.60	0.00	−0.40
Step $= 0$	0.00	−0.10	0.00	0.00	−0.10	0.00	0.00	0.00	0.00	0.00
Step $= -1$	−7.30	3.00	0.80	−0.20	2.50	0.30	0.70	−1.90	−0.10	1.20

Note: We partition our full sample into two equal-length subsamples and reestimate the ordered probit models discussed in Tables 3 to 5. This table reports the impulse sensitivities (in %) for the first and second subsample. Definitions of the variables are provided in Table 2.

model is a good fit for the data used. Second, the overall model fit, as measured by the change in the maximum likelihood function, improves by 3.5% to 5.2% when including variables characterizing the order book from steps 2 to 10. Third, most of the order book variables are significant, with *p*-values less than .01. The two control variables, *return* and *volatility,* are less significant or insignificant for some order actions. The impulse sensitivities of *return* and *volatility* are much smaller than those of the book variables. This finding is in contrast to findings reported in Ahn, Bae, and Chan (2001) and Ranaldo (2004). Finally, the lagged variables,

especially the lagged book variables beyond the inside, do not have a significant effect on order choices in most cases.

For a robustness check, we split our sample into two equal-length subsamples and reestimated the ordered probit models. Table 9 provides the results for the three most frequent order actions: submissions, cancellations, and forward amendments. The resulting impulse sensitivities for the two subsamples are similar to those for the full sample. For example, for order cancellations, a 1 standard deviation increase in $Q^{imb}{}_{2\text{-}10}$ decreases the likelihood of canceling an order at step 1 by 3.8% in the full sample, whereas the estimated impulse sensitivities are 4.0% and 3.6%, respectively, for the two subsamples.

VI. Conclusion

We investigate whether investors use the order book information—not only the best bid and offer but also what is behind the best bid and offer—when they formulate their order strategies. In addition to the depth of the book, we consider the price. We differentiate not only between market and limit orders but also between limit orders according to their positions in the book. We extend previous research by including order amendments and order cancellations in the analysis.

Using limit order book data from the ASX, we find that the top of the book affects an investor's order submission decision. Furthermore, we find that the rest of the book (e.g., the book information beyond step 1) affects an investor's order choice and the effect is persistent after controlling for stock return and volatility. Because an order book represents a complete picture of the aggregate supply and demand, our results provide supporting evidence that investors use the order book information beyond step 1 to formulate their order placement strategies.

The order book information beyond the insides has a significant effect on order cancellations and amendments. This result is robust regardless of whether we examine it action by action or with all the order actions combined. Both the price and the depth of the book play an important role, and the imbalance between demand and supply is the key in these effects. When investors believe that their orders will be crowded out by other orders on the same side of the book, they jump the queue to get price priority or to cancel the order. The crowding-out, hence jumping-the-queue, effect is documented in previous research on how the top step affects order submissions. We show that the same effect persists over (1) other order activities (including order amendments and cancellations) and (2) the rest of the order book. Finally, we find that investors tend to fill large price gaps on the book behind them. In contrast, they are unlikely to move orders forward to large price gaps ahead of them.

Our research is particularly relevant considering the substantial changes that U.S. financial markets have experienced in the recent past. Facing stronger

competition from ECNs, both the NYSE and the NASDAQ have incorporated open limit order books into their trading framework. The NYSE Openbook (or the NASDAQ Supermontage) is the first step, followed by the recent consolidations between NYSE and the Archipelago ECN (or the NASDAQ and the Inet ECN). Limit order books are at the center of the changes in the landscape of trading. How investors can benefit from a trading environment that uses limit order books is important for the future development of market microstructure research.

References

Ahn, H., K. Bae, and K. Chan, 2001, Limit orders, depth, and volatility, *Journal of Finance* 56, 767–88.

Barclay, M., T. Hendershott, and T. McCormick, 2003, Competition among trading venues: Information and trading on electronic communications networks, *Journal of Finance* 58, 2637–66.

Beber, A. and C. Caglio, 2005, Order submission strategies and information: Empirical evidence from the NYSE, Working paper, University of Lausanne and the Securities and Exchange Commission.

Belsey, A., E. Kuh, and R. Welsch, 1980, *Regression Diagnostics* (Wiley, New York).

Biais, B., P. Hillion, and C. Spatt, 1995, An empirical analysis of the limit order book and the order flow in the Paris Bourse, *Journal of Finance* 50, 1655–89.

Bloomfield, R., M. O'Hara, and G. Saar, 2005, The "make or take" decision in an electronic market: Evidence on the evolution of liquidity, *Journal of Financial Economics* 75, 165–99.

Bortoli, L., A. Frino, E. Jarnecic, and D. Johnstone, 2006, Limit order book transparency, execution risk and market liquidity, Working paper, University of Sydney.

Cao, C., O. Hansch, and X. Wang, 2008, The informational content of an open limit order book, Journal of Futures Markets, forthcoming.

Chakrabarty, B., 2007, Do dealers infer information from order flow? *Journal of Financial Research* 30, 181–200.

Chakravarty, S. and C. Holden, 1995, An integrated model of market and limit orders, *Journal of Financial Intermediation* 4, 213–41.

Cohen, K., S. Maier, R. Schwartz, and D. Whitcomb, 1981, Transaction costs, order placement strategy, and existence of the bid-ask spread. *Journal of Political Economy* 89, 287–305.

Ellul, A., C. Holden, P. Jain, and R. Jennings, Forthcoming, Determinants of order choice on the New York Stock Exchange, *Journal of Finance*.

Foucault, T., 1999, Order flow composition and trading costs in a dynamic limit order market, *Journal of Financial Markets* 2, 99–134.

Foucault, T., O. Kadan, and E. Kandel, 2005, Limit order book as a market for liquidity, *Review of Financial Studies* 18, 1171–1217.

Glosten, L., 1994, Is the electronic open limit order book inevitable? *Journal of Finance* 49, 1127–61.

Griffiths, M., B. Smith, A. Turnbull, and R. White, 2000, The costs and determinants of order Aggressiveness, *Journal of Financial Economics* 56, 65–88.

Hall, A. D. and N. Hautsch, 2004, A continuous-time measurement of the buy-sell pressure in a limit order book market, Working paper, University of Technology–Sydney and University of Copenhagen.

Hall, A. D. and N. Hautsch, 2006, Order aggressiveness and order book dynamics, *Empirical Economics* 30, 973–1005.

Harris, L., 1998, Optimal dynamic order submission strategies in some stylized trading problems, *Financial Markets, Institutions and Instruments* 7, 1–76.

Harris, L. and J. Hasbrouck, 1996, Market vs. limit orders: The SuperDOT evidence on order submission strategy, *Journal of Financial and Quantitative Analysis* 31, 213–31.

Hasbrouck, J. and G. Saar, 2002, Limit orders and volatility in a hybrid market: The Island ECN, Working paper, New York University.

Hollifield, B., R. Miller, and P. Sandas, 2004, Empirical analysis of limit order markets, *Review of Economic Studies* 71, 1027–63.

Kaniel, R. and H. Liu, 2006, So what orders do informed traders use? *Journal of Business* 79, 1867–1913.
Michayluk, D. and G. Sanger, 2006, Day-end effect on the Paris Bourse, *Journal of Financial Research* 29, 131–46.
Mizrach, B., 2006, The next tick on Nasdaq, Working paper, Rutgers University.
Parlour, C., 1998, Price dynamics in limit order markets, *Review of Financial Studies* 11, 789–816.
Pascual, R. and D. Veredas, 2004, What pieces of limit order book information are informative? Working paper, Universidad de las Islas Baleares and Tilburg University.
Ranaldo, A., 2004, Order aggressiveness in limit order book markets, *Journal of Financial Markets* 7, 53–74.
Rock, K., 1996, The specialist's order book and price anomalies, Working paper, Harvard University.
Sandas P., 2001, Adverse selection and competitive market making: Empirical evidence from a limit order market, *Review of Financial Studies* 14, 705–34.
Seppi, D., 1997, Liquidity provision with limit orders and a strategic specialist, *Review of Financial Studies* 10, 103–50.