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Order Aggressiveness on the ASX Market

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Abstract

This paper investigates how traders on the Australian Stock Exchange (ASX) market make their joint decision on price aggressiveness and quantity when they submit an order, based on information from limit order book and stock price movement. We use a simultaneous-equation system including an Ordered Probit model to account for the discrete nature of price aggressiveness and an OLS model to fit the continuous quantity. The results suggest a negative trade-off between price aggressiveness and quantity. Factors such as depths at the best quotes, bid-ask spread, volatility and price changes are major determinants of the traders' order submission decision. This paper also provides evidence for a U-shaped intraday pattern of order flows and positive serial correlation in order type.

Keywords: Limit order book, Price aggressiveness, Ordered probit model, Order flow

1. Introduction

Many stock exchanges around the world, such as the Australian Stock Exchange (ASX), have adopted a fully computerized order-driven trading system. In such a market, liquidity is provided by participants who submit orders to buy or sell electronically to Stock Exchange Automated Trading System (SEATS). The electronic limit order market gains its popularity because of the greater transparency offered by this system compared to dealer market setting. One critical part of study on the limit order trading process is how the trader makes the decision to trade. Following the paper of Lo and Sapp (2007), traders are assumed to confront with a simultaneous choice on both price aggressiveness and quantity. Price aggressiveness is defined by the execution priority: markets orders, those to buy or sell a pre-specified quantity at the best available price and thus being executed immediately, is regarded as the most aggressive orders. In contrast, limit orders are orders that buy or sell a pre-specific quantity at a pre-specific price. A trade results only when the incoming bid or ask order matches or overlaps the price of the best opposite quote (the lowest limit sell or highest limit buy), otherwise, the limit order is stored on the limit order book followed strict price and time priority waiting for execution. We suppose that traders collect information from limit order book, for example, depths at best quotes, bid-ask spread, together with information from market price movement to decide an order submission. Therefore, order flow has information content and traders behave strategically using limit orders. This paper is designed to empirically investigate some features of order flow and the determinants for traders to make the joint decision on price aggressiveness and quantity.

In order to test the joint decision on price aggressiveness and quantity based on trader's information set, we set up a simultaneous-equation system, including a price aggressiveness equation estimated via Ordered Probit model and a quantity equation fitted via OLS method. Examining order submission and trading data for five most traded stocks on the ASX market during July and August 2002, the results indicate that: First, there exist a negative trade-off between price aggressiveness and quantity, i.e. traders tend to employ a strategy to combine more aggressive orders with smaller size, aiming to increase the probability of execution and meanwhile reduce transaction costs and minimize potential loss. Second, factors like depths at best quotes, bid-ask spread, volatility and price changes explicitly affect the decision criterion used by market participants. Third, the analysis of order flows on the ASX market supports the "diagonal effect" and shows a positive autocorrelation in order type; orders exhibit a U-shaped pattern during normal trading periods. In most cases, the empirical results we find are consistent with theory and literature for other market structures.

The remainder of this paper is organized as follows. Section 2 reviews relevant theoretical and empirical literatures. Section 3 introduces economic framework and formulates hypotheses. Section 4 explains the econometric model. Section 5 presents a detailed description of the ASX trading system and data set. Section 6 reports and analyzes the empirical findings on limit order submission. Section 7 provides some concluding remarks.

2. Theoretical and Empirical Literature

One stream of the theoretical literature makes restrictive assumptions about the behavior of informed traders, while some ignore such traders completely. When studying the limit order market, they focus on the tradeoff between the immediate execution of placing the market order versus the better price, and uncertain execution, of submitting a limit order. As elaborated by Hasbrouck (2007), a key determinant of order submission choice is the probability that a particular limit order will be executed, while the execution probabilities are determined by the order choice decisions of other agents. An ask order may be executed only when it meets an offering price at the other side, and the latent reservation values may trigger market orders. Therefore, there is an obvious relationship between an agent's own order choice problem and the others' order choice in the past and in the future. A set of traders are assumed to follow the trading strategy by the former traders, and the prerequisite that the solution to order choice problem should be consistent with the assumed price and execution processes is necessary for the market to be in dynamic equilibrium. The early study by Cohen et al. (1981) develops a gravitational pull model to explain the trading decision in limit order markets by a dynamic balance of the relative costs of price improvement and execution risk. They find that the end-of-period wealth of participants who choose to trade via a limit order is an increasing function of the order execution probability. The larger the expected execution probability, the shorter the expected waiting time and thus the smaller the expected adverse selection cost. They further indicate that, as spread narrows, the benefits of the better price available to limit order traders decrease, causing more traders to prefer the certain execution of the market order. Some researchers like Foucault et al. (2005) tend to classify investors as patient and impatient traders, and argue that prices and times-to-execution are jointly determined in equilibrium and there exist intertemporal trade-offs involved with limit orders. Hollifield et al. (2003) build a structural model of a pure limit order market, which captures the trade-off between order price and probability of execution. They estimate their model nonparametrically and derive implications for trader's order submission strategies.

In some theoretical literature on price discovery and limit order book's informativeness, researchers believe that limit orders are not as informative as market orders. Glosten (1994) and Rock (1996) explicitly incorporate informed traders into their models, but assume that they always use market orders instead of limit orders. Their common belief is that with short-lived private information, informed traders will be impatient and prefer market orders because these orders guarantee immediate execution. On the other hand, without private information on the direction of price movements, limit order submitters will face an adverse selection risk, as such orders will be more likely to execute when they generate a loss to the uninformed submitters. For instance, if the informed trader knows that the current market price is too high and the price will decrease in the near future, only a bid limit order with relatively higher price could be executed. Since the submitter purchases at a price over the security's true value, the execution of this submission is a loss for him, and this phenomenon is the winner's curse.

The second stream of the theoretical literature takes market characteristics such as state of limit order book as exogenous variables and examines how both liquidity and informed traders choose between limit and market orders. Angel (1994) derives an analytical expression for the probability of limit order execution, conditional upon an investor's information set. His result indicates that informed traders are less likely to use limit order than liquidity traders, especially when the realized asset value is further away from its expected value and therefore they have the opportunity to capitalize on their private information. Handa and Schwartz (1996) model the effects of liquidity traders and informed traders on the choice between market and limit orders, and find that limit order submitters lose from trading with informed traders but gain from accentuated short-run volatility induced by liquidity trades. Harris (1998) predicts that liquidity traders who need to meet a target will start by using limit orders and then switch to market orders as the end of trading or their deadline approaches. Similarly, the probability of submitting a limit order by the informed traders decreases with time until the end of trading, when their information is revealed. Using an experimental market setting to investigate the evolution of liquidity in an electronic limit order market, Bloomfield et al. (2005) confirm Harris' suggestion that large liquidity traders prefer limit order early in the trading period, but their preferences shifts over time toward using more market orders. Contradicting the theoretical prediction, informed traders start more likely to employ market orders and then shift to trading mostly using limit orders. This may reflect that informed traders search for a source of profit, earning the bid-ask spread via limit order submission. They further conclude that the informed traders' behavior results in a provision of liquidity to market and allows the market to endogenously create liquidity even in the presence of information asymmetry.

The third stream of literature is consistent of dynamic equilibrium models in which key market attributes arise endogenously. A trader's optimal strategy depends on conjectures of other traders' strategies.

Due to Parlour's (1998) equilibrium model, depth on either side of the market has an impact on traders' choice between market and limit orders. The increase in book depth on the bid side decreases the probability that a buyer will submit a limit order; while a depth's increase on the offer side increases the probability that a buyer will submit a limit order. As a consequence of limit order queuing, when adding an order to a book which is already with large depth, i.e. many more orders standing in front of this order, the trader receives a lower probability of execution. Although there is no uncertainty about the asset's cash flows, nor is there price determination in Parlour's model, it illustrates a key equilibrium interaction between a trader's order choice and his beliefs about similar choices made by others in the future.

The Foucault's (1999) equilibrium model provides an analysis of individual order choice, when the opposite side depth is deep, a trader is more likely to use a limit order. If the fundamental risk of a security increases then a given limit order faces a higher pick-off risk, causing limit order trader place less aggressive prices and then the spread widens. Later, market orders become more expensive, leading traders to favor limit orders. Additionally, Foucault (1999) argues that there is a direct relationship between bid-ask spread and volatility, and an inverse relationship between market depth and volatility. The reason might lie on: when the market is volatile, the probability of trading against informed investors increases; therefore, the expected loss for uniformed traders is larger. To protect themselves from trading disadvantage, limit buy (sell) order traders have to post lower (higher) bid (ask) price or reduce their order sizes. Thus, the price volatility determines the trader's decision between market and limit orders through spread and depth.

On the empirical side, numerous studies analyze the order book, order flow and especially examine the intraday variation in bid-ask spread. A U-shaped intraday pattern is widely found in the spreads of NYSE stocks. However, Brock and Kleidon (1992), Chan, Chung and Johnson (1995) attribute this pattern to specialists' market making behavior, while Chung and Van Ness (1999) show this pattern largely reflects the intraday behavior of the spread established by limit order traders. Al-Suhaibani and Kryzanowski (2000) survey the behavior of market participants in a pure order-driven market without market makers, Saudi Stock Market, and find that its intraday patterns are surprisingly similar to those found in other markets with different structures, including the persistent U-shaped patterns in number of shares traded, volume, and bid-ask spread. In their paper, the call market is taken as a contributing factor to the concentration at the opening, whereas the high level of limit orders at the end of every trading session could be a result of limit price adjusting.

Other empirical studies study the question whether and to what extent the state of limit order book influences traders' order submission strategies. Biais et al. (1995) are among the first to study this problem, using data on order flow on the Paris Bourse. They report that investors tend to place limit (market) orders when the spread is wide (narrow) or the depth is low (high). To compete for price and time priority, traders quickly submit limit orders within the quotes when the depth declines or the spread widens. And the unexecuted orders are less competitive orders that at prices away from the quotes. Griffiths et al. (2000) examine the costs and determinants of order aggressiveness through the limit order submissions on the Toronto Stock Exchange during June of 1997, and report that aggressive orders have large price impacts but smaller opportunity costs than passive orders. Additionally, aggressive buy (sell) orders are observed to tend to follow other aggressive buy (sell) orders and occur when bid-ask spreads are narrow and depth on the same (opposite) side of the limit book is large (small), resulting in improved execution probabilities in the more competitive market states. Finally, an analysis of longer-term returns to holding stock subsequent to the order suggests that aggressive buyers are more likely to be motivated by information, whereas aggressive sellers tend to be motivated by liquidity. Applying the similar method proposed by Biais et al. (1995) and Griffiths et al. (2000) to the data of 15 Swiss Stock Exchange issued during March and April 1997, Ronaldo (2004) shows that patient traders become more aggressive when the own (opposite) side book is thicker (thinner), which are consistent with earlier studies. He argues that this result demonstrates that the depth of limit order book is a proxy for the execution probability of an incoming trade and strengthens or weakens trading aggressiveness. Besides, transient volatility and a wider spread are found to encourage limit order placement and discourage market order submission. Similar investigation on NYSE market is conducted by Beber and Caglio (2005), whose results indicate that order aggressiveness depends on the state of the order book and on the asset dynamic, and the most important determinants of order submission strategies are the depth on the same side of the book and a momentum indicator. They further support their conjecture that in the case of information-based trading, orders are less aggressive, by a different response to changes in the investor's information set and by a stronger price impact of less aggressive orders.

According to the empirical studies on the Australian Stock Exchange (ASX) market, Verhoeven et al. (2004) examine factors that affect the decision used by market participants for the stocks CML and BHP, using logit regressions. Their results indicate that the bid-ask spread, depth at the best price, price changes in the last five minutes and order imbalance are major determinants for traders to choose between market and limit orders. Cao et al. (2004) employ a more comprehensive dataset, covering 21 constituent stocks from the ASX-20 index to study the order submission strategies of traders using an Ordered Probit modeling approach. They provide evidence to confirm that traders use the available information on the state of the limit order book, including spread, depths on the same and opposite sides, when developing their order submission strategies. More recently, Hall and Hautsch (2006) conduct a dynamic investigation on five most traded stocks from ASX market using a six-dimensional autoregressive conditional intensity (ACI) model, in order to study the determinants of order aggressiveness and traders' order submission strategy. They find that market depth, the queued volume, bid-ask spread, recent volatility, as well as recent changes in order flow and stock price are important determinants of order aggressiveness, consistent with theoretical predictions.

3. Economic framework and test design

3.1 Order submission strategies

When making the decision of buy or sell a stock, the investor's order submission strategy is not just a choice between a market and a limit order. A trader can submit very different limit orders, trading off probabilities of execution with transaction costs. Moreover, the order placement is a joint decision of price and quantity: large orders can be split into smaller ones. Thus, the order aggressiveness of submission is defined as the investor's preference for an immediate and certain execution, coupled with his indifference for the transaction costs and risks. Greater price aggressive orders have a price priority in execution, but suffer from price risk, originating from the bid-ask spread and market depth. On the other hand, limit orders confront with execution risk and also adverse selection risk, because these orders are more likely to be executed when the value of the asset has changed adversely. The simultaneous choice of order size is also important to traders. For limit orders, both the execution risk and adverse selection risk increases with the ordered quantity, since that a large-sized order may not be executed entirely and a large loss may occur when the value of underling stock changes. Lo and Sapp (2007) provide an empirical study of the joint nature of order price and quantity in the limit order market and they find a significantly negative relationship between price aggressiveness and order size through explicitly examining the trade-offs between these two dimensions, conditioning on the state of the limit order book. They offer two explanations why more aggressive orders are smaller: order splitting or order consolidating (Lo and Sapp, 2007, p.14). Since large orders may reveal more information, as suggested by Easley and O'Hara (1992), informed investors split their orders into smaller amounts to trade without information disclose. Besides, breading up large orders may also reduce transaction cost and picking-off loss, because a large, aggressive limit orders make a trader to suffer from a great loss if the value of the security moves against the trader and he cannot cancel the order in time. Consequently, traders prefer to place more aggressive but smaller order, which have priority in execution and in the meantime minimize the pick-off risk. In the case of order consolidation, traders submit small orders to fulfill immediate liquidity needs. Because liquidity-oriented traders require an immediate execution, they usually place aggressive orders to obtain the priority, and then we could also observe a negative relation between price aggressiveness and order size. Accounting for this idea, we assume that:

Trade-off between price aggressiveness and quantity hypothesis: There is a negative relationship between price aggressiveness and quantity.

Previous studies document a conditional order flow pattern called a diagonal effect, which refers to a higher likelihood to observe a given type of order after an event just occurred than it would be unconditionally. When observing order flow pattern, both Biais et al. (1995) from Paris Bourse and Al-Suhaibani and Kryzanowski (2000) from the Saudi Stock Market find that: after the arrival of a limit buy order, an incoming order is most likely to be the same order type. Biais et al. (1995) offer three explanations to account for the correlation of market orders: strategic order splitting, trade imitation, or similar reaction to information. First, traders may strategically split large orders to reduce price impact. Lo and Sapp (2007) test the autocorrelation of market orders and aggressive limit orders, and their findings suggest that dealers split their orders to either hide their information or to decrease the execution costs. Second, if certain market participants can observe the orders of others whom they believe to be informed, then they may imitate their orders. However, Al-Suhaibani and Kryzanowski (2000) employ a dataset which allow them to refer a subset of orders belonging to the same trader, and find that the proportion of the same trader involved in two consecutive orders is 28.94% of all order flow events. Their findings support strategic splitting rather than an imitation. Third, news events may lead various traders to trade in a similar manner, i.e. the diagonal effect may be caused by a similar reaction of market participants to a particular stock, an information event, or the economy as a whole. In line with this interpretation, Wermers (1999) shows that institutional investors buy (sell) more stocks in the US after it experiences extreme positive (negative) returns in the previous quarter.

The diagonal effect of limit orders within the best quotes is explained by the undercutting and overbidding behavior of traders competing to supply liquidity to the market (Biais et al. 1995). When the number of limit orders placed inside the quote increases, the spread narrows and the cost of submitting a market order reduces, so that it is more likely to place more aggressive orders. The succession of less aggressive orders such as cancellations is explained as trading imitation or similar reaction to the same events. The diagonal effect leads to the hypothesis:

Price aggressiveness autocorrelation hypothesis: The higher is the price aggressiveness of the previous orders, the higher is the aggressiveness of the new orders placed.

3.2 Exogenous explanatory variables

In this part, a number of hypotheses are developed to embody the intuitive idea that investors optimally choose their order submission strategy, including price aggressiveness and order size, so as to maximize their expected profits on the basis of their own information sets, which can be distinguished with limit order book-related variables, market movement-related variables and time-related variables.

3.2.1 Limit order book-related variables

According to theoretical work on order choice, Parlour's (1998) finds that depth on either side of the market has an impact on traders' choice between market and limit orders. Harris (1998) and Foucault (1999) predict that market orders become less and limit orders become more attractive as the spread increases. Foucault et al. (2005) further point out that limit order aggressiveness either increases or decreases with the inside spread, depending on whether patient or impatient traders dominate the trading population. The general empirical findings indicate that the rate of limit order submissions increases with the size of the spread, and that depth at the top of both sides of the book affects order choice, consistent with the theoretical literature.

In order to examine whether and to what extent the state of the limit order book influences traders' order submission strategies, order book statistics which proxy for depths on both sides and bid-ask spread will be included as explanatory variables.

Depth

Depth, which usually refers to the total volume (number of shares) of limit orders on one side of the order book, affects the probability of limit order execution because time priority is enforced after price priority by ASX trading rules. As to Parlour (1998), the execution probability depends on the size of the book and on the trader's belief about further order arrivals, i.e. the aggressiveness of orders arriving over the remainder of the trading day. Therefore, the thicker is the buy side of the order book, the more possible that the incoming buyer submits a market order, since the lower the probability of a new limit bid order being executed. Besides the direct competition effect, sellers rationally anticipate a crowding-out effect of buy limit orders and are thus better off submitting less aggressive sell orders (the potential strategic effect). Both of these effects reduce the incentive to submit a buy limit order when the depth is thicker at the bid. This logic can also hold for the seller's submission decision and the crowding-out effect is symmetric. Thus, we hypothesize that:

Hypothesis 1: The greater the depth of the bid (ask) side, the stronger the order aggressiveness of the incoming buyer (seller).

Hypothesis 2: The greater the depth of the ask (bid) side, the weaker the order aggressiveness of the incoming buyer (seller).

According to the potential strategic effect, which is tested through hypothesis 2, we need to take the characteristic of ASX market into consideration. On the ASX market, market orders are allowed to walk up the book without any market intervention. When there is a bid order imbalance, i.e. greater depth on the bid side than on the ask side, investors perceive this security owning a high valuation and thus increase their demand for this security. A larger demand compared with supply makes the security's price more likely to rise. The increasing price leads to a higher risk of non-execution of a new limit bid, causes a more serious competition among all bids and then increases bid prices to approach to the best ask price. Because the gravitational pull effect of the best ask becomes stronger, as stated by Handa et al. (2000), the execution probability of a limit buy order becomes more uncertain and a buy market order becomes more attractive. As such, we hypothesize that:

Hypothesis 3: The larger the depth at the ask side relative to the bid side, the stronger (weaker) the order aggressiveness of an incoming seller (buyer).

Bid-ask spread

In an order driven marketplace, the spread represents the margin that a holder (purchaser) of shares is required to surrender (pay) to a prospective purchaser (seller) away from the equilibrium price to trade immediately (Note 1). The bid-ask spread is confirmed by empirical research as a function of proxies for the cost of liquidity provision and competition. On one side, a limit order placed within the spread gains the highest price priority and thus has the highest probability of execution. On the other side, the cost of submitting a market order, especially paying the spread, increases as the spread widens. In addition, the larger the spread, the lower the gravitational pull effect exerted by the opposing side (Cohen et al., 1981), and the less possible that the price change, which attributes to a loss suffered by limit order submitter due to the winner's curse. This consideration leads to the following hypothesis:

Hypothesis 4: The wider the spread, the weaker the order aggressiveness.

3.2.2 Market movement-related variables

This group of variables focuses on the investor's information set describing stock price evolution, including the factors volatility and price changes. Grammig, Heinen and Rengifo (2004) assert that the market movement-related variables could be used to predict the future order submission process. When it indicates "bad news", the number of aggressive sell limit and market sell orders increase while buyer activity decreases.

Volatility

The literature has identified various effects that volatility may have to influence order submission behaviors. For instance, Cohen et al. (1981) point out that as price uncertainty increases, risk-averse traders reward a premium on a certain outcome regarding the execution of their trades. As a consequence, more aggressive orders like market orders are placed by risk-averse traders since higher volatility increases the dispersion of outcomes for a limit order submission.

On the contrary, Copeland and Galai (1983) suggest that posting an order is more costly when volatility is higher, limit order traders are therefore less aggressive, because of the risk of being picked off by informed traders. Consistent with this conjecture, Handa et al. (1998) assert that limit order traders always lose from trading with informed traders who have superior information, but they gain from trading with liquidity traders who must meet their liquidity need. However, regardless of whether volatility is caused by liquidity traders or a difference of opinions as to the true price of a security, higher price volatility indicates that a trader faces with a greater opportunity of executing his order at a better price. In this sense he could prefer a limit order rather than a market order. Besides, Lo et al. (2002) show that with higher volatility, the probability of the stock price hitting a limit price barrier increases and hence reduce order aggressiveness, assuming that investors prefer an expected immediate execution. As a result, we can formulate the following hypothesis:

Hypothesis 5: The higher the stock price volatility, the weaker the order aggressiveness.

Although the above hypothesis is based on a series of theories, we should notice that it may be challenged when considering an equilibrium setting, such as the model by Foucault (1999), where the actions of some traders affect others' behaviors. If the uncertainty due to an increase in the asymmetry of information across traders rises, and induces a shift to limit order trading, the market order submission in equilibrium decreases and the probability of execution drops. Therefore, trading will shift back to market order and partially offset the initial shift. This logic leads to an ambiguous relationship between volatility and order aggressiveness, which is confirmed by the mixed results of empirical studies by Hasbrouck and Saar (2004) as well as Bae et al. (2003).

Price changes

Information-motivated trades may occur with the arrival of information and the presence of informed traders in the market. Price changes could be used as a proxy for the arrival of information, where a rising price infers that there is good news being assimilated into the market and a falling price implies bad news. Informed traders tend to use market orders which offer them the immediacy to profit from their private informational advantage. Because soon after, uninformed traders will eventually learn about this information either through observing the behavior of informed traders or a public announcement by the firm, and thereby the potential of profitable gain for the informed will disappear. Kaniel and Liu (1998) find that market orders convey more information than limit orders about the value of the underlying security and suggest that informed traders are more likely to employ markets orders instead of limit orders. Therefore, we hypothesize that:

Hypothesis 6: When prices are increasing, the order aggressiveness rises at the bid side, but drops at the ask side.

3.2.3 Time of the day

Hourly dummy variables are used to capture the changing features of the market during the trading day. There are six hourly-dummies running from 10:00 to 16:00, which allow us to capture the opening and closing effects. Bloomfield et al. (2005) point out that during market openings there is a large quantity of new information arriving at the market, and therefore less aggressive orders are submitted at market openings because of the uncertainty. Furthermore, according to the call market, all qualifying orders are executed at a single price at the open and traders benefit from their orders being executed at a price better than their quotes. Thus, limit order traders lose less to informed traders if they trade during the call market, and we expect less aggressive orders during openings and more aggressive orders over the trading day. As the end of the trading session approaches, liquidity traders are likely to place more aggressive orders since they must meet their liquidity need. A high level of limit orders could also be anticipated, resulting from price adjusting: canceling an existing order and submitting a new one. Greater proportions of large orders are executed at the end of session, partially due to liquidity trading and also because small trades at the opening contribute to price discovery and large trades tend to occur after price discovery has already occurred (Biais et al., 1995). Applying the theoretical prediction we can formulate hypothesis as follows:

Hypothesis 7: Traders submit less aggressive order during the earlier hours, but more aggressive orders when the end of the trading day approaches.

Table 1 summarizes the abbreviation and description for each exogenous explanatory variable analyzed in this study, and also shows the seven hypotheses tested thereafter and their related empirical studies.

4. Econometric models

The empirical analysis of price aggressiveness is conducted using an Ordered Probit model, a method introduced in the market microstructure literature by Hausman et al. (1992) to study the nature of discrete price changes, and widely employed by empirical investigations such as Ranaldo (2004) and Lo and Sapp (2007). The Ordered Probit model fits the price aggressiveness equation well because the different actions available to traders are inherently ordered in terms of their aggressiveness. A market order with no price limit can be considered as the most aggressive type of order as its submitter prepares to transact at any price. Limit orders are less aggressive and can be ranked in terms of their limit price. Finally, limit order cancellations, by which traders remove liquidity from the order book, are the least aggressive.

The method of categorizing price aggressiveness applied by Cao, Hansch and Wang (2004) is based on the priority in execution and described as follows: (1) market orders (immediately executed at the best available price) or marketable limit orders (limit orders at prices better than the best price standing on the opposite side of the market) which consume liquidity on the opposite side of the market; (2) best limit orders placed at prices better than the existing best price and therefore improve the current best bid or offer (3) best limit orders placed at the existing best price; (4) off-best orders placed within three ticks of the best price; (5) off-best orders placed more than three ticks away from the best price; and (6) the cancellation of a limit order that removes liquidity from the book without a transaction. The descriptive statistics of price aggressiveness on the ASX market are documented in section 5 in detail. The Ordered Probit model links the discrete observable choice of order type Z_t with the latent variable Z_t^*, which is continuous and whose domain is the set of real numbers, that is:

$$Z_t = \begin{cases} 1, & if\ Z_t^* \in (-\infty, \mu_1] \\ 2, & if\ Z_t^* \in (\mu_1, \mu_2] \\ 3, & if\ Z_t^* \in (\mu_2, \mu_3] \\ 4, & if\ Z_t^* \in (\mu_3, \mu_4] \\ 5, & if\ Z_t^* \in (\mu_4, \mu_5] \\ 6, & if\ Z_t^* \in (\mu_5, \infty) \end{cases} \tag{1}$$

where μ_j, $j = 1, 2, ..., 5,$ are additional parameters such that $\mu_1 < \mu_2 < ... < \mu_5$. Thus the range of Z_t^* is partitioned in 6 mutually exclusive and exhaustive intervals and the variable Z_t indicates the interval into which a particular observation falls. The dependent variable Z_t is ordinal and μ_j is treated as parameters to be estimated.

4.1 Estimation of Ordered Probit model

In order to explain how the Ordered Probit model is estimated, we first assume that the order quantity is exogenous, and therefore we have a single equation for price aggressiveness as follows:

$$Z_t^* = \gamma_1 Q_t + \beta' X_{t-1}^Z + \varepsilon_t^Z \tag{2}$$

where Z_t^* is the latent price aggressiveness, Q_t is the exogenous order quantity, X_{t-1}^Z is the lagged values of exogenous explanatory variables, and ε_t^Z is the error term, conditionally normally distributed with mean zero and variance σ_t^2. The conditional probability of observing a particular price aggressiveness category depends on the location of the conditional means of the underlying variables $\beta' X_{t-1}^Z$ and Q_t, relative to the partitions μ_j. With this formulation, the conditional probability of a particular observed price aggressiveness, for $2 \le j \le 5$, is given by:

$$\begin{aligned} \Pr(Z_t = j) &= \Pr(\mu_{j-1} \le Z_t^* \le \mu_j) \\ &= \Pr(\mu_{j-1} - \gamma_1 Q_t - \beta' X_{t-1}^Z \le \varepsilon_t^Z \le \mu_j - \gamma_1 Q_t - \beta' X_{t-1}^Z) \\ &= F(\mu_j - \gamma_1 Q_t - \beta' X_{t-1}^Z) - F(\mu_{j-1} - \gamma_1 Q_t - \beta' X_{t-1}^Z) \end{aligned} \tag{3}$$

where *F* is the cumulative distribution function of ε_t^Z and is assumed to contain no additional unknown parameters, so that, for instance, the variance of ε_t^Z is known. This assumption fixes the scale of the measurement of Z_t^*, but not the origin. In most cases, the identification could be achieved by assuming a zero intercept, i.e. X_{t-1}^Z does not contain a constant term. Therefore, the full set of probabilities of the possible price aggressiveness is:

$$\begin{aligned} &\Pr(Z_t = 1) = F(\mu_1 - \gamma_1 Q_t - \beta' X_{t-1}^Z), \\ &\Pr(Z_t = j) = F(\mu_j - \gamma_1 Q_t - \beta' X_{t-1}^Z) - F(\mu_{j-1} - \gamma_1 Q_t - \beta' X_{t-1}^Z), j = 2,3,4,5, \\ &\Pr(Z_t = 6) = 1 - F(\mu_5 - \gamma_1 Q_t - \beta' X_{t-1}^Z). \end{aligned} \tag{4}$$

By adopting an additional notation that $\mu_0 = -\infty$ and $\mu_6 = +\infty$, we can obtain a compact version as:

$$\Pr(Z_t = j) = F(\mu_j - \gamma_1 Q_t - \beta' X_{t-1}^Z) - F(\mu_{j-1} - \gamma_1 Q_i - \beta' X_{t-1}^Z) \tag{5}$$

for $j \in [1, 6]$. By this definition, the set of cumulative probabilities can be transformed into a linear function that depends on both Q_t and X_{t-1}^Z, and only the intercepts in this function differ across the six categories:

$$F^{-1}[\Pr(Z_t \leq j)] = \mu_j - \gamma_1 Q_t - \beta' X_{t-1}^Z \tag{6}$$

Through the Maximum Likelihood estimation we can obtain a natural estimator for this model. Define: $Z_{tj} = \begin{cases} 1 & if\ Z_t = j \\ 0 & else \end{cases}$, then the log-likelihood for the price aggressiveness is given by:

$$\log L = \sum_{t=1}^{T} \sum_{j=1}^{6} Z_{tj} \log[F(\mu_j - \gamma_1 Q_t - \beta' X_{t-1}^Z) - F(\mu_{j-1} - \gamma_1 Q_t - \beta' X_{t-1}^Z)] \tag{7}$$

The "Likelihood" estimation refers to a probability of prediction, and reflects how likely it is that the observed value of dependent variables is predicted by some analytical function of the observed values of independent variables and parameters. This likelihood is maximized with respect to $(\gamma_1,\ \beta,\ \mu_1,\ldots,\ \mu_5)$, i.e. a vector of M+5 parameters, where M is the number of exogenous explanatory variables. The standard Ordered Probit model takes F to be Normal and assumes that $\varepsilon_t^Z \sim N(0,\sigma^2)$, therefore, by adopting the scale normalization $\sigma = 1$ and imposing a zero intercept for identification, the probabilities are given by:

$$\Pr(Z_t = j) = \Phi(\mu_j - \gamma_1 Q_t - \beta' X_{t-1}^Z) - \Phi(\mu_{j-1} - \gamma_1 Q_t - \beta' X_{t-1}^Z) \tag{8}$$

where Φ is the cumulative distribution function of a standard Normal and the log-likelihood by equation (7) with F is replaced by Φ.

As pointed out by Ranaldo (2004), employing the results obtained from the Ordered Probit model, one can estimate the cumulative probabilities that any of the six events will occur and also the probability that a specific order is likely to be submitted. However, the marginal effects of the regressors Q_t and X_{t-1}^Z on the outcomes' probabilities are not equal to the estimated coefficients $\hat{\gamma}_1$ or $\hat{\beta}$, because of the ambiguous effect on the middle partitions. Therefore, in order to understand in what direction and magnitude a change in the explanatory variables affects, the marginal effects for each outcome are calculated by differentiating the probabilities in equation (8):

$$\begin{aligned}
\frac{\partial \Pr(Z_t = 1)}{\partial X_{t-1}^Z} &= -\phi(\hat{\mu}_1 - \hat{\gamma}_1 E[Q_t] - \hat{\beta}' E[X_{t-1}^Z])\hat{\beta}, \\
\frac{\partial \Pr(Z_t = j)}{\partial X_{t-1}^Z} &= -[\phi(\hat{\mu}_j - \hat{\gamma}_1 E[Q_t] - \hat{\beta}' E[X_{t-1}^Z]) - \phi(\hat{\mu}_{j-i} - \hat{\gamma}_1 E[Q_t] - \hat{\beta}' E[X_{t-1}^Z])]\hat{\beta}, \quad j = 2,3,4,5, \\
\frac{\partial \Pr(Z_t = 6)}{\partial X_{t-1}^Z} &= \phi(\hat{\mu}_5 - \hat{\gamma}_1 E[Q_t] - \hat{\beta}' E[X_{t-1}^Z])\hat{\beta}.
\end{aligned} \tag{9}$$

where ϕ is the normal probability density function, $\hat{\mu}_j$ are the estimated thresholds and $\hat{\gamma}_1$ and $\hat{\beta}$ represent the estimated coefficients resulting from Eqs (1) and (2). The unconditional mean of instruments of quantity and each independent variable over the entire sample is used as the estimate of $E[Q_t]$ and $E[X_{t-1}^Z]$, respectively. Thus, the marginal effect, induced by an incremental variation in one of the order flow components, on the order choice probabilities can be calculated by using equation (9). For instance, we could estimate how the probability of submitting orders at each level of aggressiveness changes marginally when the spread increases by one tick, avoiding difficulties in interpreting the coefficients in the Ordered Probit model.

As criticized by Hall and Hautsch (2006) and Lo and Sapp (2007), the above Ordered Probit model suffers from several disadvantages: First, it is set up based on the assumption that all the observations are independent, however, orders for the same stock might share similarities, in which case the model will be misspecified and the usual standard errors will be incorrect. Second, the Ordered Probit model is set up in a static environment, however, ignoring the dynamics within the individual processes may also induce misspecification and bias. Third, the model treats the cancellation of limit order as the least aggressive type of order submission. Since this behavior happens only conditional upon an earlier submission, but not a choice available to all traders, and moreover, the aggressiveness of cancelled orders is ignored, treating cancellation same as other order submissions is controversial. Finally, the Ordered Probit model ignores the exact time when the order is submitted given the current state of market.

4.2 Joint decision on price aggressiveness and quantity

Explicitly allowing traders to simultaneously select their limit price and order size, we transform equation (2) to a set of simultaneous equations for each stock:

$$Z_t^* = \gamma_1 Q_t + \beta' X_{t-1}^Z + u_t^Z \tag{10a}$$

$$Q_t = a + \gamma_2 Z_t^* + b' X_{t-1}^Q + u_t^Q \tag{10b}$$

where Z_t^* is the latent price aggressiveness, Q_t is the endogenous quantity, X_{t-1}^Z and X_{t-1}^Q consist of a series of predetermined variables in price aggressiveness equation and quantity equation, respectively, while u_t^Z and u_t^Q are disturbance terms. For identification purpose, X_{t-1}^Z contains the variable of price change Δp, which is a predetermined variable that not in the quantity equation, i.e. $X_{t-1}^Z = [X_{t-1}^Q, \Delta p]$ (Note 2). As to the identification of simultaneous equations with Probit model, Nelson and Olson (1978) suggest that the number of independent restrictions on the coefficients of each equation should be not smaller than the number of structural equations minus one. In order to exactly identify each of the tow equations in our model, there must be one independent restriction in equation (10a) and (10b). Intercept equal to zero and $\Delta p = 0$ are the restrictions for each equation respectively, and thus both equations in the simultaneous system are just identified. These two simultaneous equations are estimated adopting a method analogous to the two-stage least squares method of Lo and Sapp (2007) (Note 3). In the first stage, we calculate the reduced-form of price aggressiveness and quantity equations:

$$\begin{aligned} Z_t^* &= \frac{\gamma_1 a}{1-\gamma_1\gamma_2} + \frac{\gamma_1}{1-\gamma_1\gamma_2} b' X_{t-1}^Q + \frac{1}{1-\gamma_1\gamma_2} \beta' X_{t-1}^Z + \frac{\gamma_1}{1-\gamma_1\gamma_2} u_t^Q + \frac{1}{1-\gamma_1\gamma_2} u_t^Z \\ Q_t &= \frac{a}{1-\gamma_1\gamma_2} + \frac{1}{1-\gamma_1\gamma_2} b' X_{t-1}^Q + \frac{\gamma_2}{1-\gamma_1\gamma_2} \beta' X_{t-1}^Z + \frac{1}{1-\gamma_1\gamma_2} u_t^Q + \frac{\gamma_2}{1-\gamma_1\gamma_2} u_t^Z \end{aligned} \tag{11}$$

Equation (11) can be written compactly as:

$$\begin{aligned} Z_t^* &= \pi_1' X_{t-1} + \upsilon_{1t} \\ Q_t &= \pi_2' X_{t-1} + \upsilon_{2t} \end{aligned} \tag{12}$$

where X_{t-1} is a vector of explanatory variables, i.e. $\left(1 \quad X_{t-1}^Q \quad X_{t-1}^Z\right)$. In order to estimate the parameters in the structural forms, we first estimate the coefficients in the reduced form of the simultaneous equations separately. Specifically, π_1 is estimated using an Ordered Probit model and π_2 is estimated using OLS method. With the estimated coefficients, we could form the instruments for price aggressiveness $\hat{Z}_t^* = \hat{\pi}_1' X_{t-1}$ and for quantity $\hat{Q}_t = \hat{\pi}_2' X_{t-1}$, which are at least asymptotically uncorrelated with disturbance terms. In the second stage, $\hat{Z}_t^*$ replaces its counterpart in right hand side of equation (10b). Treating the instrument as fixed regressor and the resulting equation as single equation model, we estimate the structural parameters in equation (10b) via OLS model. Similarly, $\hat{Q}_t$ is substituted for Q_t in equation (10a) and the price aggressiveness is estimated via an Ordered Probit model.

The order submission analyses for the buy and sell sides are performed separately, indicating that for any one stock, the entire time series of the order flow are broken into two sub-samples. Each of these sub-samples contains six order types submitted on one side of the book, their order sizes and dynamic explanatory variables (volatility and price change) at time *t*, which is calculated already based on lagged values, as well as the static explainable variable data (ask depth, bid depth, relative depth and actual spread) immediately before, i.e. at time *t-1*. Therefore, these explanatory variables are predetermined and exogenous.

4.3. Hausman specification test

In order to correctly build the econometric model, it is necessary to judge whether the regressor quantity is endogenous or exogenous. For the liquidity-oriented trading, quantity is predetermined and should be regarded as exogenous, however, for informed traders, they simultaneously decide order price and quantity on the available information, and thus both are endogenous. A disadvantage in recent study is that we cannot distinguish whether an order submission is liquidity- or information- motivated. As respect to the econometric respective, the simultaneity problem arises because some regressors are endogenous and are therefore likely to be correlated with the disturbance. The Hausman specification error test is a test of simultaneity, essentially a test of whether regressor is correlated with the error term. If the simultaneity problem exists, the usual least squares estimator or Probit estimator is inconsistent (Rivers and Vuong, 1984), instead, with the valid instrumental variables, the two-stage estimator is consistent and should be used. In the above setting, the exogeneity condition is stated in terms of the correlation coefficient ρ, which can be interpreted as the correlation between Q_t and u_t^Z for equation (10a) and (10b). When $\rho = 0$, Q_t and u_t^Z are uncorrelated, Q_t is exogenous for equation (10a) and we can directly estimate this equation. On the contrary, $\rho \neq 0$ implies that Q_t is correlated with u_t^Z, and therefore endogenous, in such case we have to use instrumental variables for the estimation. The Hausman test to test whether Q_t is exogenous involves two steps: First, estimate the reduced form of the quantity equation by OLS, as shown in the second line of equation (12), to obtain the residual $\hat{\upsilon}_{2t} = Q_t - \hat{\pi}_2{}' X_{t-1}$. Second, include the residual computed in step 1 as an explanatory variable in the regression:

$$Z_t^* = \gamma_1 \hat{Q}_t + \beta' X_{t-1}^Z + \delta \hat{\upsilon}_{2t} + u_t^Z \tag{13}$$

Estimate the artificial regression, as stated by equation (13), by ML and perform the z-test for the hypothesis of the coefficient δ:

$H_0: \quad \delta = 0$ (Q_i is exogenous)

$H_1: \quad \delta \neq 0$ (Q_i is endogenous)

If the z-test is significant, do not reject the hypothesis of simultaneity; otherwise, reject it.

5. Description of the market and data set

The data used in this paper is provided by the Australian Stock Exchange (ASX), which employs the fully computerized Stock Exchange Automated Trading System (SEATS), modeled on Toronto's Computer Assisted Trading System (CATS). The ASX data is particularly suitable for the purpose of the study, because: First, ASX market relies almost solely on liquidity provision by investors. There are no dealers or designated market makers on the ASX, although brokers may act as informal market makers and facilitate their client's trades by placing opposing orders on their own accounts (Note 4). In contrast, the New York Stock Exchange where the specialist plays an important role in the provision of liquidity and maintenance of market integrity, and the Paris Bourse where exists a number of markets makers assigned to its stocks, confront with a principal-agency problem and higher transaction costs that might influence the test results. Second, ASX has an almost instantaneously updated limit order book, containing detailed information about each order. Third, ASX strictly enforces price before time priority on limit order execution. Finally, it is considered to be a highly transparent market, and only orders with a total value exceeding \$200,000 can be entered with a hidden volume. Therefore, on the ASX market, traders are likely to act strategically, taking into account the beliefs, reactions and order submission strategies of other traders.

5.1 Institutional details of the ASX trading system

Several modes of operations in SEATS may affect the information available to traders and their order submission behavior. The various phases in a typical day on the ASX are illustrated in Table 2. The pre-opening period takes place between 7:30am and 10:00am, during which orders can be entered into the system but they cannot be matched at this time. The ASX opens at 10:00am with a call auction procedure aimed principally at maximizing traded volume at the chosen opening price. After that, the normal trading takes place continuously until 4:00pm. Orders entered during normal trading hours are matched, resulting in trades for market orders, or stored in the order book automatically for limit orders. A 5-minute pre-closing period begins at 4:00pm and then is followed by the official single-price closing auction. The closing phase between 4:05pm and 5:00pm facilitates late trading, during which the system accept new orders but does not match them. Once the order has been matched, the selling broker is responsible to apply manual procedures, which execute orders in the same manner as though SEATS is fully active, reporting and subsequently canceling their order. Afterwards, the after hours adjust phase operates between 5:00pm and 7:00pm, aiming to adjust to take account of capitalization and other changes which come into effect on the following day. After a half-hour period of housekeeping to routinely maintain the system, from 7:30pm to 11:30 pm and again from 3:30am to 7:30am the system is in enquiry mode only providing information regarding the current orders for stock. None can log into the system between 11:30pm to 3:30am when SEATS is off-line.

The order book enforces strict price and time priority, and limit orders are stored in the buy and sell queues. During normal trading, orders can be modified by either changing the limit price or the number of shares or cancellation. While a size reduction does not influence the order's priority, a price change leads an order to be relocated in the queue at the new price level. The minimum tick rules stipulate the minimum distance in cents at which an order can be placed from another at a different price. According to the amendments to the minimum bid rule in 1996, which is outlined in Table 3, a minimum bid would be \$0.001 for equity securities with the market price up to \$0.10, and a minimum bid of \$0.05 for those with market price from \$0.10 to \$0.50. Limit orders for at least \$200,000 can include an undisclosed reserve volume which replenishes the visible order size upon partial execution. However, order book information is sufficiently transparent, and traders can view details of individual buy and sell orders along the book and aggregate depth at multiple prices through SEATS Trading Screen.

5.2 Descriptive statistics

The investigated sample consists of the order book data of five most liquid stocks on the ASX market, specifically, Broken Hill Proprietary Limited (BHP), National Australia Band (NAB), Telstra (TLS), Woolworths (WOW) and Mount Isa Mines (MIM), during the period 1 July to 30 August 2002. The ASX Intra-Day dataset provides historical details on order submission of the five stocks placed on SEATS as well as the resulting trades. Each order and trade record includes information on the price, volume and direction, time-stamped to the nearest one hundredth of a second. In order to focus on the information content of the limit order book and avoid confounding effects from the opening and closing procedures, we restrict our attention within the normal trading period from 10:09am to 4:00pm, and remove data from the opening and closing call auctions as well as all market crossings (Note 5) and off-market trades. The resulting samples consist of 133,059, 102,366, 94,089, 52,493 and 30,559 observations for BHP, NAB, TLS, WOW and MIM, respectively.

Table 4 shows summary statistics of limit order book, including the explanatory variables across the sample period. Depth at the best ask price is larger than the depth on the bid side, however, depth at off-best prices on the ask side seems smaller than that on the opposite side. This suggests that generally the bid side of the market is more liquid, but it is not so liquid to market order buyers. Given that the minimum tick size is 1 cent for all the observed stocks and the actual spread is one or two ticks, the stocks can be regarded quite liquid. These results confirm the work by Aitken et al. (1995), which provides evidence that bid-ask spreads are constant and flat during the day, but contrasts with data from US markets (Note 6), which suggests that spreads follow a U-shaped pattern. The reason may be that Australian market, unlike US market, has a fully competitive market-making system, without specialists or market-makers who may be exercising their monopoly power. Information models (such as Easley and O'Hara, 1987) predict that specialist may keep spread wider enough so that the profits from trading with liquidity traders sufficiently compensate for the losses from trading with informed traders. According to this theory, without these specialists, the intraday pattern of spread could be flat and keep narrow. The relative spread (Note 7) in our sample (0.271%) is lower compared with the results of Angel (1997), in which the relative bid-ask spread median is calculated to equal 0.65% for major market indices of fifteen countries. The mean of volatility for five stocks on the ASX market is 0.747, while the value on Swiss market is 0.482, as surveyed by Ranaldo (2004). Generally, "a market is liquid if traders can buy or sell large number of shares when they want and at low transaction costs. Liquidity is the willingness of some traders to take the opposite side of a trade that is initiated by someone else, at low cost" argues Harris (1990) when defining a liquid market. According to this definition, market liquidity can be measured from four dimensions: width, referring to the spread for a given number of shares; depth, measured by the number of shares that can be traded at given quotes; immediacy, referring to how quickly trades of a given size can be done at a given cost and resiliency, defined as how quickly prices revert to former levels after they change in response to large order flow imbalance initiated by uninformed traders. Because of its relatively narrow spread and high depth, the ASX market is regarded quite liquid. In addition, Vo (2007) proves that the price volatility is negatively related to market liquidity, which measured by both spread and depth. Intuitively, if price is high volatile, the probability that a limit order is executed is higher even though spread is wide. As a result, limit order submitters decrease limit price when they buy or increase limit price when they sell and thus lead to a narrow spread. The coexistence of a high volatility and narrow spread in our sample confirms this suggestion.

5.3 Order aggressiveness on the ASX market

Table 5 breaks down the price aggressiveness of order submissions into six categories in our sample, and shows the frequency of order submissions ranked by price aggressiveness: market orders or marketable limit orders (23.7%--40.8%), best limit orders improving existing best prices (0.1%--3.7%), best limit orders placed at the best prices (30.9%--43.1%), off-best limit orders within 3 ticks of the best prices (8.4%--16.7%), off-best limit orders more than 3 ticks of the best prices (4.8%--10.6%) and cancellations (3.3%--14.6%). These results indicate that the most frequent order types are market or marketable limit orders and limit orders placed at the best prices, consistent with the observations provided by Lo and Sapp (2007) as well as Beber and Caglio(2005). The high number of orders placed at the best quote implies a good average performance for these orders, as suggested by Harris and Hasbrouck (1996). The percentage of best limit orders which improve the present best prices in our sample is quite small, compared with the findings (14%) of Lo and Sapp (2007). One of the main attributes of this small proportion is that the most liquid securities have actual bid-ask spread equal to the tick size, thus giving less opportunities for traders to better the market. The proportion distributions are generally similar for both ask and bid sides of the market, however, for some stocks, there is a slightly higher aggressiveness for buy orders with respect to those for sell orders. This finding may occur because the market is perceived as a rising market, considering that market ask orders confront with a potential lost when stock prices rise, sellers would like to adopt less aggressive orders instead of a market order.

Table 6 shows the likelihood of order arrival conditional on the level of the last price aggressiveness on both ask and bid sides. The columns correspond to an event at time t, and the rows to events at time $t-1$. The diagonal effect in the conditional order arrival can be obviously observed through that most bold numbers, which represent the maximum proportion of order type based on each previous price aggressiveness category, locate along the diagonal of the frequency table. This result indicates an autocorrelation between order sequences, for instance, after a limit order at best price is submitted, the probability that the same limit order type will arrive is higher then other order types, consistent with Biais et al. (1995), who report that an incoming order is likely to be at the same aggressiveness level as the previous order.

Table 7 illustrates the total number of shares submitted and average order sizes according to every price aggressiveness category. A general observation on the order quantity is that order size increases gradually as the price aggressiveness decreases from category 1 to category 3, and the order size for the category of cancellations is largest, except for MIM. This phenomenon results of the joint decision of order price and quantity by investors, who have a negative trade-off between price aggressiveness and size. The possible loss of a price-aggressive order could be reduced by decreasing its quantity. Another interesting finding is that the order sizes are relatively small for limit orders off-best prices. Since high trading volume is considered to be an indication of the advent of informed traders. Uninformed traders are more inclined to submit these small orders, in order to lower their risks from trading with informed traders who usually expropriate their private information by placing aggressive orders with great volumes. For all the stocks, the total bid volume is higher then the ask volume, indicating that there is a higher demanding market during the period of analysis. As to a cross-section analysis, we find that the higher the stock price, the smaller the average quantity for each price aggressiveness classification. The negative relationship between stock price and order size reflects traders' budget constraint and the intention to minimize the potential loss if the stock price walks to the opposite side from their expectation.

6. Empirical findings

This section presents the results from the analysis of the price aggressiveness and the corresponding quantity for the order submission on the ASX market. According to Table 8, which documents the main results from Hausman specification test, all coefficients for error terms are significantly not equal to zero, therefore, we reject the null hypothesis that Q_t is exogenous. The Hausman test confirms that traders simultaneously decide their order price aggressiveness and quantity, and we should adopt a simultaneous system, as shown in equation (10a) and (10b) to model traders' behavior. Table 9 reports coefficient estimates for the sample on demand and supply side events separately. The price aggressiveness equation and quantity equation are estimated using a method analogous to the two-stage OLS approach as introduced in section 4. When interpreting the results, a positive coefficient in the price aggressiveness equation means that the factor increases the price aggressiveness of the order submitted, since the ascending ranking from 1 to 6 reflects increasing price aggressiveness.

6.1 Trade-off between price aggressiveness and quantity

Table 9 shows that the estimated coefficients of quantity on price aggressiveness are negative but not significant on the ask side, whereas the quantity has a slight positive influence on price aggressiveness on the bid side. For the quantity equation, price aggressiveness is found to be significantly positively associated with quantity on both ask and bid sides. These results are not totally consistent with the findings of Lo and Sapp (2007), which document a negative relationship between price aggressiveness and quantity after controlling for the state of the limit order book for both two equations, although their estimated coefficient on quantity in the price aggressiveness equation is also not statistically significant. Our results are also not consistent with the findings of Bessembinder et al. (2006), which indicate a slightly positive effect of order size in the price aggressiveness equation and a negative effect of price aggressiveness in the quantity equation, using two-stage Least Squares estimation that allows for endogeneity. The marginal probability analysis in Table 10 illustrates that, buyers placing orders at more aggressive prices are more likely to submit smaller orders, suggesting that a submission strategy that combines aggressive price with small order size. However, sellers for stocks except NAB behave in an opposite pattern.

In the price aggressiveness equation, quantity is found to be negatively related with price aggressiveness for sellers. This result is quite reasonable if we assume that sellers are dominated by liquidity-motivated traders, who have to first meet their trading target. Under this assumption, the negative correlation between price aggressiveness and quantity implies that larger liquidity traders are propone to place less price-aggressive orders. This result confirms the prediction of Harris (1998) about the behavior of large liquidity traders, that traders needing to meet a target by a certain deadline would start a greater propensity for using limit orders. One might conjecture that large traders would submit aggressive orders to transact early to avoid any possibility of incurring trading penalties. However, the empirical finding suggests that liquidity traders are more concerned with the execution quality of their orders, a result in line with the behavior of traders in a simulated market of Bloomfield et al. (2005). For buyers, if we suppose that they are dominated with informed traders, we can interpret that investors owning private information are incline to use price aggressive orders to guarantee an immediate execution, as well as higher order quantity to increase their profit. Besides, after a transaction, if the transacted price does not reflect a stock's true value and future stock price moves against the trader, the trading generate a real loss for sellers, but only a potential loss for buyers, because stock price may latterly move in favor of them. Therefore, buyers tend to behave more aggressive than sellers, and their behavior may attribute to the positive relationship between price aggressiveness and quantity.

On the other hand, the estimated coefficients on the price aggressiveness in the quantity equation are significantly positive, except for the stock of MIM on the bid side, which is significantly negative. An optimal order size is obtained through investors' consideration on the balance between execution risk and potential profit. By submitting a small order, trader face low execution risk, since his order is more possible to be executed totally. However, a small order directly reduces the trader's profit, especially when he has valuable information on the movement of stock price. Easley and O'Hara (1992) provide a possible reason why more aggressive orders are smaller, i.e. order splitting, and their assumption is latterly supported by Lo and Sapp (2007). This explanation asserts that investors slip their orders to either hide their private information or to reduce the execution costs. Nevertheless, if we consider that this market is mainly consist of informed traders, whose strategies most likely stem from the changing value of their private information associated with the dynamic adjustments of prices, we could understand why there exists a positive relationship between price aggressiveness and quantity. When the market prices differ from the true value, informed traders have an incentive to take liquidity by trading via market orders with large quantity, as long as the investment value is not beyond their budget constrains. After the market price adjustment and the true value's reveal, the informed traders change their strategy. In an asymmetric information setting, the informed traders ultimately have the advantage because while all traders placing limit orders face execution risk, they do not have the potential risk of adverse selection , which confronting the liquidity traders. Thus, informed traders can price the limit orders more aggressively and be at the inside quote to make profit. Without uncertainty and trade-off between different risks but only considering the stock's market price dynamics, informed traders have more possible combinations of decisions on order price and size, and this is perhaps the reason why we observe different correlations between price aggressiveness and quantity among stocks.

6.2 Limit order book-related variables

Depth

The coefficients of depths at the best quote on the same side for sellers of all stocks except NAB and for buyers of stocks TLS, WOW and MIM in the price aggressiveness equation are significantly positive, implying that an increase in the depth at the best prevailing price on the same side of the market encourages aggressive orders. This is consistent with the empirical findings of Ranaldo (2004), beber and Caglio (2005) and the crowding-out hypothesis of Parlour (1998), and therefore basically confirms our hypothesis 1. The crowing-out effect forces a trader to compete for execution, since high market depth on the same submission side indicates a long queue for execution. The increased competition provides newly arriving traders with incentives to place more aggressive orders in order to jump the queue. This effect is similar on both sides of the market. Table 9 shows that the marginal probabilities of market orders and aggressive limit orders being submitted drop, meanwhile, the marginal probabilities of less aggressive limit orders and cancellations increase, when the same side depth rises, for stocks TLS, WOW and MIM. Moreover, depths on the same side are significantly positively correlated with submitted order size for stocks NAB and MIM.

Considering changes in the depth on the opposite side of the market, the results show that the opposite market depth is inversely associated with price aggressiveness for the stocks BHP, TLS and MIM, consistent with Ranaldo (2004) and Verhoeven et al. (2004). A large opposite market depth indicates a higher chance of execution, which shortens the order queue, and thus traders need not to adopt a price-aggressive strategy. However, for the stocks NAB and WOW, the results are not in accordance with theoretical prediction, where orders become more aggressive when the market liquidity supply on the other side of the book is greater. For the quantity equation, the results are more ambiguous. Generally the findings do not provide enough evidence to support hypothesis 2. Table 9 reveals that for changes in the opposite depth, bid and ask sides of the market react symmetrically in terms of price aggressiveness, but not in the case of stock BHP. The asymmetry in buyers and sellers trading attitude may be due to the impatience of sellers compared with buyers. A slow execution when the market moves down leaves the sellers a realized loss, while a slowly execution when price goes up represents only an opportunity cost for buyers. Besides, as sellers are considered more likely to be liquidity-motivated than buyers, a higher market depth on the bid side implies a lower marginal cost of submitting market orders, especially when orders can walk up the order book in the markets. Thus, when opposite depth increases, sellers' marginal probability of placing aggressive orders rises at a greater degree than buyers'.

As *reldep* is defined as shares at the best five ask prices divided by total shares at the best five bid and ask prices, the significantly negative coefficients on the ask side except for BHP implies that the larger the depth at the ask side relative to the bid side, the lower the probability of submitting a more aggressive ask order, contradicting hypothesis 3. On the bid side of the market, price aggressiveness is significantly positively associated with the relative depth for stocks NAB and TLS. A possible explanation provided by Verhoeven et al. (2004) is that a large depth at the off-best ask price indicates to the buyer that the true price is likely to be at this off-best ask, which promotes the buyer to submit a market order to buy at the best ask price to make profits, because the stock is perceived to be under-priced. Due to the same logic, once the sellers find depth further from the market is high, they are less likely to fill in the schedule in front of those off-best prices. Table 10 indicates that the marginal probability to place more aggressive sell orders increases and the marginal probability to submit less aggressive sell orders drops, with an increment in relative depth, for stocks NAB, TLS, WOW and MIM. On the bid side, when relative depth rises, the marginal probability to observe a more aggressive order decreases, and that to observe a less aggressive order increases for stocks NAB, TLS and WOW. The quantity of orders reacts quite differently to a change in relative depth for a cross-section analysis. On the ask side, order sizes of stocks NAB, TLS and WOW rise significantly as the relative depth increases, whereas for BHP and MIM, the submitted quantity drops. On the bid side, relative depth significantly negatively affects order sides of stocks NAB, TLS and MIM, but is found to be positively correlated with quantities for BHP and WOW.

Bid-ask spread

The bid-ask spread is significantly negatively associated with the degree of price aggressiveness for both buyers and sellers, confirming hypothesis 4 and in accordance with Biais et al. (1995), Hollifield et al. (2004) and Ranaldo (2004). However, this result is not in accordance with Lo and Sapp (2007), who find that orders become more aggressive and larger in size when the spread widens. Since a large spread is costly for the market order, and it indicates high asymmetric information, traders may consider it optimal to submit less aggressive orders. On the contrary, when the spread decreases, i.e. the cost of trading by market orders or the price of liquidity reduces, traders reasonably prefer to demand liquidity and place aggressive orders. An analysis of the marginal effects in Table 10 demonstrates that an increase in the bid-ask spread increases the probability of order submission in some aggressive order categories, whereas the likelihood of observing less aggressive orders and cancellations reduces. This is contrary to the intuition that market orders become more expensive as the spread widens. La and Sapp (2007) propose that this phenomenon suggest that investors become more concerned about ensuring their orders are executed in an uncertain market. Furthermore, we could also notice that a change in the bid-ask spread affects buy price aggressiveness slightly more than sell price aggressiveness, similarly with the results of Beber and Caglio (2005). As to the quantity equation, spread is found to be positively related with order size for stocks NAB, TLS and WOW, in line with Lo and Sapp (2007). The positive relationship is probably because that, in an order-driven market, limit order traders are more inclined to supply additional liquidity if the potential profitability increases as the spread widens.

6.3 Market movement-related variables

Volatility

As illustrated in Table 9, an increase in volatility drives more passive orders for buy side but has ambiguous influence on ask side, partially confirming hypothesis 5. A negative relationship between volatility and price aggressiveness is predicated by the model of Foucault (1999) and is also documented in Ranaldo (2004) and Beber and Caglio (2005). Because volatility is considered as a proxy of information-driven trading: when volatility rises, the trader concerns that his order may be picked off by a better-informed trader on the other side of the market during times of greater uncertainty. Therefore, the expected cost of market order trading increases and the submission of less aggressive orders turns out to be the optimal strategy. On the quantity dimension, order sizes of both bid and ask orders increase statistically significantly as volatility rises. This result signifies that when market condition is turbulent, the information is more valuable and it is easier to pick off other traders, and thus informed traders try to expropriate their information by submitting large orders, and earn more profits from trading with uninformed traders.

Price changes

We find that an increment in the proportion of positive price changes makes sellers to submit orders at less aggressive prices, however, the effect on bid orders are still not perceptible. This result partially supports hypothesis 6. Earlier empirical literature on the effect of price also shows different evidence. For instance, Beber and Caglio (2005) find that when the stock price moves up, buy orders become more aggressive and sell orders less aggressive. The reason is, as they point out, that traders perceive that a positive price trend reduces the probability of execution of passive buy orders, but increases the probability of execution of sell limit orders. Nevertheless, Lo and Sapp observe a completely different result, that an increase in the proportion of positive price changes makes ask (bid) orders more (less) aggressive. The analysis of marginal probabilities in Table 10 shows that price change is one of the most important variables in affecting price aggressiveness. For all stocks, we find that with the increasing of the proportion of positive price change, it is more likely to observe more aggressive asks.

6.4 Time of the day

The signs of coefficients of hourly dummies for most stocks in the price aggressiveness equation of Table 9 turn from negative to positive gradually on both ask and bid sides during normal trading period, suggesting that traders submit less aggressive orders after openings and more aggressive orders when the trading end approaches. This result confirms our hypothesis 7 and is consistent with Beber and Caglio (2005), who document a monotonic increment for the time-of-the-day dummy variables and argue that the proportion of market orders increases at day's end. The finding proves the existence of "deadline effect", as suggested by Bloomfield et al. (2005), where liquidity traders who need to buy or sell a large number of shares tend to use more limit orders early on, but they switch to market orders to meet their targets as the end of the trading period approaches. This deadline effect is observed widely in earlier literature, for instance, Roth et al. (1988) conduct experimental test and find many deals occur just before deadlines, indicating that traders become more aggressive as the close of trading approaches. Similar effect is also posited by Harris (1998) and Hollifield et al. (2003). According to the quantity equation, the result indicates that larger orders are more likely being submitted after opening and just before the end, and shows a U-shape pattern in order submission activity over the trading day. The cluster of order submission early in the day confirms a 24-hour pattern in information arrival and disclosure. Greene and Watts (1996) find that two-thirds of sample earnings announcements take place after the stock exchange close. Because it is possible for the traders to accumulate information overnight, larger orders could be placed early in the day. On the other hand, many traders face an end-of-day deadline for either liquidity requirement or exploiting their information, and therefore larger orders are also submitted at the end of the day.

Table 11 summarizes the main findings for price aggressiveness equation and shows that most of our hypotheses are supported by empirical results, as indicated by the matching of the expected and empirical signs of the coefficients in the regressions. Therefore, we can conclude that limit order traders do make their decisions about order submission, with respect to the information on the limit order book as well as market price movement. Furthermore, traders' submission behavior follows some specific time-of-the-day pattern. However, some results such as relative depth do not support our hypothesis, and the reason may lie on that traders believe that limit orders outside the best bid and ask are not so informative and simply ignore them. Other explanations include that monitoring and analyzing the book is costly or traders are overconfident and give little weight to order book information and other traders' strategy, relatively to their own assessment of the stock's true value, as stated by Cao et al. (2004). Besides, there exists a difference of the effects of explanatory variables on a cross-sectional level to some degree, indicating that some economic relations may hold individually.

7. Conclusion

The limit order book promptly updates the accumulation of limit orders after market orders or marketable limit orders matching, and therefore reflects order submission and trading information, liquidity change, as well as traders' expectation. Using data from five most traded stocks on the ASX market during July and August 2002, this study analyzes how the information from limit order book and stock market determines the trader's join choice on price aggressiveness and quantity. The empirical results suggest that quantity is negatively traded off with price aggressiveness, because traders have to balance execution risk, transaction costs and potential loss. Besides, the depths at the best quotes are informative: order placement becomes aggressive during the period of thick market depths on the same side and thin market depths on the opposite side, consistent to the crowding out mechanism. Off-best depths have ambiguous effect on order submission, due to traders' overconfidence or the inconveniency to observe. Additionally, bid-ask spread, a proxy for the cost to place a market order, is found to significantly negatively related with price aggressiveness and positively related with quantity. Furthermore, high volatility encourages less aggressive limit order placement and discourages market order submission. Price change is also proved as am important factor to affect the price aggressiveness decision. Finally, the order sequences exhibit the diagonal effect, in which the probability that the same order type is more likely to occur after this order type has just occurred than it would be unconditionally. And order flows distribute following a U-shape intraday pattern; the intensity of order submission happens just after opening and as the trading end approaches.

This empirical study offers several practical suggestions for market regulators and participants: First, public release of complete and in time information on the evolution of the limit order book is essential for traders to provide liquidity in an order-driven market. Thus, guaranteeing the limit order book market enough transparency could make it more liquid. Second, because the autocorrelation of price aggressiveness on the ASX market reflects that informed traders strategically slip their orders to hide private information, it seems impossible for uninformed traders to identify informed traders and to imitate their submission strategy. Third, the findings support the practical feasibility of sophisticated order submission strategy, that trades off price aggressiveness and quantity, since a large aggressive order reveal more information and generate high transaction costs and potential loss. The specific order submission strategies and their profitability are not investigated directly in this paper, and we could leave this topic in future research.

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Table 1. Definitions of explanatory variables, hypotheses to test and related empirical studies

Abbreviation	Explanatory variables	Measurements
askdep	Depth at the best ask	Number of shares at the best ask divided by 10,000
biddep	Depth at the best bid	Number of shares at the best bid divided by 10,000
reldep	Relative depth	Total number of shares at the best five ask prices divided by total number of shares at the best five bid and ask prices
spread	Bid-ask spread	Difference between the lowest ask and the highest bid quotes
volat	Midquote volatility	Standard deviation of the last 20 midquotes
Δp	Proportion of positive price change	Number of positive price changes within the past two minutes divided by the total number of quotes submitted within the past two minutes
hdumm	Hourly dummy	Hourly dummy variables from 10:00 to 16:00

Hypotheses	Predictions	Related Literature
Hypothesis 1	*biddep* (*askdep*) positively related to order aggressiveness of buyers (sellers)	Parlour (1998) and Ranaldo (2004)
Hypothesis 2	*askdep* (*biddep*) negatively related to order aggressiveness of buyers (sellers)	Parlour (1998) and Ranaldo (2004)
Hypothesis 3	*reldep* positively (negatively) related to order aggressiveness of sellers (buyers)	Verhoeven et al. (2004)
Hypothesis 4	*spread* negatively related to order aggressiveness	Foucault (1999) and Ranaldo (2004)
Hypothesis 5	*volat* negatively related to order aggressiveness	Foucault (1999) and Ranaldo (2004)
Hypothesis 6	Δp positively (negatively) related to order aggressiveness of buyers (sellers)	Verhoeven et al. (2004) and Lo and Sapp (2007)
Hypothesis 7	Less aggressive orders during earlier hours but more aggressive orders during ending	Hollifield et al. (2004) and Bloomfield et al. (2005)

Table 2. Trading phases on SEATS

Time*	SEATS Market Phases
3:30am-11:30pm	Enquiry Only (Saturday)
3:30am-7:30am	Enquiry Only (Monday to Friday)
7:30am-10:00am	Pre-Opening
10:00am-10:09am	Opening
10:00am-4:00pm	Normal Trading
4:00pm	End of Trading
4:00pm-4:04pm	Pre-Close
4:05pm-5:00pm	Closing
5:00pm-7:00pm	After Hours Adjust
Shortly after 7:00pm	Shut Down
7:00pm-7:30pm	End of Day Processing
7:30pm-11:30pm	Enquiry Only
11:30pm-3:30am	System off-line

*all times in Sydney time

Source: Aitken et al. (1997) The microstructure of the Australian stock exchange: An introduction. Chapter 2, Exhibit 3.

Table 3. Minimum ticks for various stock price interval from 8 December, 1996

Market Price	Minimum Bid
Up to $0.10	$0.001
Over $0.10 to $0.50	$0.005
Over $0.50 to $998.99	$0.01
$999.00 or greater	$1.00

Source: Aitken et al. (1997) The microstructure of the Australian stock exchange: An introduction. Chapter 4, Exhibit 6.

Table 4. Descriptive statistics for explanatory variables

Stock	BHP		NAB		TLS		WOW		MIM		Mean
	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	
Bid depth	9.62	9.20	0.82	0.78	47.78	47.30	1.07	1.08	84.32	95.47	29.74
	(22.05)	(21.74)	(2.06)	(1.94)	(36.77)	(37.48)	(1.30)	(1.29)	(75.29)	(71.39)	
Ask depth	11.74	11.28	1.20	1.09	47.22	47.71	1.06	1.09	81.79	93.60	29.78
	(31.00)	(28.95)	(4.30)	(3.90)	(36.79)	(36.84)	(1.15)	(1.21)	(70.53)	(84.65)	
Relative	0.493	0.475	0.516	0.484	0.502	0.488	0.505	0.466	0.534	0.518	0.498
depth	(0.153)	(0.154)	(0.225)	(0.227)	(0.139)	(0.139)	(0.206)	(0.205)	(0.126)	(0.123)	
Midquote	950.3	943.8	3382.6	3365.2	481.9	481.4	1220.4	1217.6	121.5	118.8	1228.4
	(51.74)	(52.13)	(97.42)	(105.8)	(6.08)	(6.13)	(37.44)	(38.48)	(10.18)	(10.05)	
Actual	1.068	1.063	2.176	2.199	1.006	1.006	1.502	1.512	1.005	1.005	1.354
spread	(0.277)	(0.272)	(1.504)	(1.545)	(0.080)	(0.078)	(0.948)	(0.953)	(0.069)	(0.073)	
Relative	0.113	0.113	0.064	0.065	0.209	0.209	0.123	0.124	0.833	0.852	0.271
spread	(0.030)	(0.030)	(0.045)	(0.046)	(0.017)	(0.016)	(0.078)	(0.078)	(0.087)	(0.090)	
Volatility	0.604	0.497	1.711	1.650	0.245	0.238	1.122	1.017	0.211	0.170	0.747
	(0.971)	(0.845)	(1.689)	(1.635)	(0.299)	(0.289)	(1.116)	(1.041)	(0.297)	(0.272)	
Price	0.334	0.346	0.348	0.385	0.342	0.334	0.336	0.373	0.338	0.320	0.346
change	(0.121)	(0.115)	(0.124)	(0.121)	(0.118)	(0.116)	(0.124)	(0.120)	(0.121)	(0.114)	

This table reports the sample statistics of the explanatory variables for each stock defined in section 3 over the sample period, July and August 2002. The mean and standard deviation values are presented. *Bid (ask) depth* is the number of shares available at the highest (lowest) bid (ask) quote (in 10,000). *Relative depth* is the total number of shares at the best five ask prices divided by total number of shares at the best five bid and ask prices. *Midquote* is the mid-price in Australian cents. The *actual spread* is the difference between the prevailing best ask and bid quotes in Australian cents. The *relative spread* is the actual spread divided by the midquote times 100. *Volatility* is the standard deviation of the last 20 midquotes. *Price change* is the percentage of the positive price changes during the last 10 order submissions.

Table 5. The frequency of price aggressiveness

Price aggressiveness	BHP		NAB		TLS		WOW		MIM	
	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid
1.Market/marketable	15950	28884	11695	13285	18329	19933	6747	8852	3918	5462
limit order	(0.288)	(0.372)	(0.237)	(0.250)	(0.408)	(0.405)	(0.282)	(0.310)	(0.299)	(0.313)
2.Limit order with	555	515	1841	1752	71	60	539	618	9	10
improved price	(0.010)	(0.007)	(0.037)	(0.033)	(0.002)	(0.001)	(0.023)	(0.022)	(0.001)	(0.001)
3.Limit order at best	21836	25263	21233	22509	14431	15199	10268	10943	4599	6210
price	(0.394)	(0.326)	(0.431)	(0.424)	(0.321)	(0.309)	(0.430)	(0.383)	(0.351)	(0.356)
4.Limit order within 3	6510	9196	4282	4843	6032	5587	1999	2890	2194	2383
ticks from best price	(0.117)	(0.119)	(0.087)	(0.091)	(0.134)	(0.114)	(0.084)	(0.101)	(0.167)	(0.137)
5.Limit order more 3	5208	7649	5228	5332	4564	3715	2401	2823	921	839
ticks from best price	(0.094)	(0.099)	(0.106)	(0.100)	(0.102)	(0.076)	(0.100)	(0.099)	(0.070)	(0.048)
6.Cancellation	5409	6084	4974	5392	1487	4681	1948	2465	1475	2539
	(0.098)	(0.078)	(0.101)	(0.102)	(0.033)	(0.095)	(0.081)	(0.086)	(0.112)	(0.146)
Total	55468	77591	49253	53113	44914	49175	23902	28591	13116	17443

This table shows the price aggressiveness frequency of the stocks BHP, NAB, TLS, WOW and MIM traded on the ASX market during July and August 2002, including the number of orders in the individual categories as well as their corresponding percentages with respect to the sub-sample of sell and buy markets for each individual stock. The price aggressiveness categories are defined in section 4.

Table 6. Conditional probability of price aggressiveness

BHP	Ask						Bid					
t-1 \ t	1.	2.	3.	4.	5.	6.	1.	2.	3.	4.	5.	6.
1.	**36.68**	30.27	27.98	20.43	25.04	21.96	**44.18**	35.73	34.33	29.57	35.18	30.51
2.	0.82	**4.68**	1.32	0.55	0.83	0.59	0.37	**2.52**	1.06	0.52	0.61	0.49
3.	34.87	35.32	**43.57**	41.27	33.83	39.12	27.60	31.46	**37.85**	33.75	30.42	35.12
4.	10.28	7.39	10.98	**15.61**	12.90	13.75	10.88	11.46	11.02	**16.18**	12.01	13.17
5.	8.65	13.33	7.80	10.65	**16.61**	9.10	10.07	11.46	8.69	10.19	**13.35**	8.65
6.	8.71	9.01	8.35	11.49	10.79	**15.47**	6.89	7.38	7.04	9.79	8.42	**12.06**

Table 6. Conditional probability of price aggressiveness (continued)

NAB	Ask						Bid					
t-1 \ t	1.	2.	3.	4.	5.	6.	1.	2.	3.	4.	5.	6.
1.	**30.67**	21.84	23.10	19.36	20.73	17.85	**32.91**	23.12	23.35	20.51	22.36	19.79
2.	2.90	**9.89**	4.44	2.34	2.54	2.92	2.61	**8.56**	3.87	2.07	2.51	2.76
3.	38.88	40.25	45.97	**46.64**	39.42	42.74	36.53	40.53	45.23	**45.99**	39.95	44.64
4.	8.83	8.53	8.18	**12.75**	8.24	7.60	8.78	8.73	8.72	**12.70**	8.74	8.88
5.	9.71	9.34	9.33	9.69	**17.08**	12.67	10.33	9.36	8.86	9.56	**16.86**	8.12
6.	9.00	10.16	8.98	9.22	11.97	**16.22**	8.83	9.70	9.96	9.17	9.58	**15.80**

Table 6. Conditional probability of price aggressiveness (continued)

TLS	Ask						Bid					
t-1 \ t	1.	2.	3.	4.	5.	6.	1.	2.	3.	4.	5.	6.
1.	**47.45**	42.25	36.64	34.04	37.69	36.38	**47.54**	46.67	35.75	33.55	39.27	35.51
2.	0.11	0.00	0.25	0.12	0.07	**0.27**	0.04	0.00	**0.27**	0.14	0.03	0.06
3.	27.32	26.76	**38.10**	34.38	30.06	30.93	25.94	30.00	**37.16**	33.19	29.64	30.04
4.	12.29	16.90	12.94	**18.30**	14.22	9.89	10.07	8.33	11.05	**16.47**	12.62	10.83
5.	9.83	11.27	8.93	10.69	**15.21**	8.54	7.90	8.33	6.79	7.55	**9.93**	6.67
6.	3.00	2.82	3.13	2.47	2.76	**13.99**	8.51	6.67	8.99	9.09	8.51	**16.90**

Table 6. Conditional probability of price aggressiveness (continued)

WOW	Ask						Bid					
t-1 \ t	1.	2.	3.	4.	5.	6.	1.	2.	3.	4.	5.	6.
1.	**35.78**	25.60	26.16	22.11	25.07	23.82	**38.26**	27.51	27.78	27.27	30.07	25.11
2.	1.51	**8.72**	2.66	1.85	1.50	2.26	1.21	**7.61**	2.70	1.66	1.88	2.72
3.	38.34	39.89	**46.03**	45.92	40.61	43.48	33.00	39.00	42.45	39.13	33.23	**43.25**
4.	7.75	8.16	7.94	**12.71**	8.95	7.60	9.55	11.49	9.38	**14.26**	11.16	8.97
5.	9.41	9.65	9.34	10.26	**15.58**	9.03	10.38	7.77	8.56	9.65	**15.87**	7.79
6.	7.20	7.98	7.87	7.15	8.29	**13.81**	7.60	6.63	9.13	8.03	7.79	**12.17**

Table 6. Conditional probability of price aggressiveness (continued)

MIM	Ask						Bid					
t-1 \ t	1.	2.	3.	4.	5.	6.	1.	2.	3.	4.	5.	6.
1.	40.20	**44.44**	27.59	22.44	26.60	22.58	**40.39**	40.00	28.63	24.60	27.41	25.88
2.	0.08	0.00	**0.13**	0.00	0.00	0.00	0.02	0.00	**0.13**	0.04	0.00	0.00
3.	29.76	22.22	**39.60**	35.07	31.38	37.36	30.67	30.00	38.89	36.57	30.63	**38.95**
4.	14.27	11.11	15.55	**24.21**	19.98	13.83	11.74	10.00	13.29	**19.82**	18.12	11.50
5.	6.28	11.11	6.83	7.66	**11.94**	5.56	4.06	0.00	4.44	5.16	**12.63**	4.41
6.	9.42	11.11	10.31	10.62	10.10	**20.68**	13.13	**20.00**	14.62	13.81	11.20	19.26

This table shows the frequency of each order category at time t conditional on the degree of the last price aggressiveness, on the ask side and the bid side separately, for stocks BHP, NAB, TLS, WOW and MIM. Orders range in a sequence of price aggressiveness, i.e. category 1 is the most aggressive order, market/marketable limit order and category 6 is cancellation. Each row and column represents the order flow event at time t-1 and t respectively. Each column is an analogous probability vector and adds up to 100%. The maximum proportion in each row is in bold.

Table 7. Order Size for each order aggressiveness category

Order aggressiveness	BHP Ask	BHP Bid	NAB Ask	NAB Bid	TLS Ask	TLS Bid	WOW Ask	WOW Bid	MIM Ask	MIM Bid
1.Market/marketable	144,449	164,024	35,696	42,790	341,197	381,855	30,578	34,549	179,929	210,823
limit order	(9056)	(5679)	(3052)	(3221)	(18615)	(19157)	(4532)	(3903)	(45924)	(38598)
2.Limit order with	6,934	6,044	9,019	8,878	3,912	2,880	3,144	3,913	982	1,074
improved price	(12601)	(11737)	(4899)	(5068)	(55098)	(47994)	(5832)	(6332)	(109091)	(107421)
3.Limit order at best	319,292	297,337	115,736	115,715	807,444	781,504	77,797	77,773	335,590	389,001
price	(14622)	(11770)	(5451)	(5141)	(55952)	(51418)	(7577)	(7107)	(72970)	(62641)
4.Limit order within 3	71,410	71,674	16,561	17,263	311,446	264,190	11,003	12,012	93,275	88,235
ticks from best price	(10969)	(7794)	(3868)	(3564)	(51632)	(47287)	(5504)	(4156)	(42513)	(37027)
5.Limit order more 3	29,051	24,123	15,766	15,374	46,614	22,615	7,900	6,922	12,560	12,730
ticks from best price	(5578)	(3154)	(3016)	(2883)	(10213)	(6088)	(3290)	(2452)	(13638)	(15173)
6.Cancellation	73,359	76,718	25,682	26,787	116,815	310,510	13,803	16,898	73,731	143,431
	(13562)	(12610)	(5163)	(4968)	(78557)	(66334)	(7086)	(6855)	(49987)	(56491)
Total	644,555	639,921	218,461	226,807	1,627,427	1,763,554	144,225	152,068	696,066	845,293
	(11620)	(8247)	(4435)	(4270)	(36234)	(35863)	(6034)	(5319)	(53070)	(48460)

The table shows the total number of shares (in 1,000) submitted and the average number of shares of each order (in brackets) during the sample period, according to every price aggressiveness category.

Table 8. Hausman specification test

	BHP		NAB		TLS		WOW		MIM	
	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid
residual	-0.0022**	-0.0007**	-0.0111**	-0.0037**	-0.0018**	-0.0024**	-0.0061**	-0.0057**	0.0002**	-0.0001**

This table shows the estimated coefficients of residuals in the following equation of Hausman specification test:

$$Z_t^* = \gamma_1 \hat{Q}_t + \beta' X_{t-1}^Z + \delta \hat{\upsilon}_{2t} + u_t^Z$$

This equation is estimated by ML and a z-test is performed for the coefficient δ . If the z-test is significant, we do not reject the hypothesis of simultaneity; otherwise, we reject it. The estimated coefficients of other explanatory variables are not reported here, for brevity.

Table 9. Order submission regressions

Order submission: Price aggressiveness

	BHP		NAB		TLS		WOW		MIM	
	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid
volume	-0.0122	0.0335	0.0078	0.1789*	-0.0048*	0.0026	-0.0496	0.0579	-0.0052	0.0033
askdep	0.0006	0.0419	-0.0221**	0.0251**	0.0030**	-0.0020**	0.0765*	0.0086	0.0016**	-0.0010**
biddep	-0.0027**	-0.0617	0.0545**	-0.0600**	-0.0016**	0.0039**	0.0422	0.0081	-0.0017**	0.0017**
reldep	0.1237**	-0.4562	-0.0851*	0.1347**	-0.1643**	0.2726**	-0.1032*	-0.0291	-0.3356*	0.0918
spread	-0.0704**	-0.1184**	-0.0408**	-0.0410**	-0.1118	-0.2675**	-0.0702**	-0.1058**	-0.0479	-0.2299
volat	-0.0049	-0.0240	0.0007	-0.0207**	-0.0766	-0.1371**	0.0074	-0.0291	-0.0408	-0.1173
Δp	-0.3965**	0.0243	-0.2679**	-0.0767	-0.2826**	-0.0173	-0.2099*	-0.1321	-0.5429**	0.3426**
h10	-0.0230	-0.0276	-0.0469	-0.0343	-0.1122	-0.0460	-0.0929	-0.0968	0.0590	0.2163
h11	-0.0184	-0.0059	-0.0502	-0.0137	-0.0537	-0.0030	-0.0401	-0.0237	0.0444	0.1696
h12	-0.1014	-0.0110	-0.0460	-0.0214	0.0095	-0.0225	-0.0005	-0.0245	0.1222	0.1194
h13	0.0031	0.0262	0.0074	0.0483	0.0283	-0.0092	0.0177	-0.0265	0.1409	0.1231
h14	0.0057	-0.0223	0.0019	-0.0104	0.0483	0.0074	0.0536	0.0451	0.1212	0.1976
h15	0.0742	0.0440	0.1006	0.0459	0.1134	0.0657	0.0788	0.0905	0.2791	0.3302

Table 9. Order submission regressions (continued)

Order Submission: Quantity										
	BHP		NAB		TLS		WOW		MIM	
	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid
intercept	14.1520**	-0.2397	4.5304**	4.7215**	31.1207**	39.4181**	5.6098**	4.7513**	50.9637**	55.9695**
aggre	17.6050**	38.2906	8.0472**	4.3889**	333.6641**	419.6289**	47.9554**	9.8143**	102.1842**	-204.5744**
askdep	-0.0061	-1.2376**	0.0934**	-0.1179**	-1.0206**	0.8382**	-1.0313**	0.1081	0.0205*	-0.2700**
biddep	0.0607**	1.8380**	-0.2250**	0.2975**	0.6260**	-1.6355**	-0.2867	0.1499	0.1862**	0.4335**
reldep	-2.1205**	13.2597**	1.5729**	-0.6885**	83.0317**	-113.5445**	2.7016**	0.2201	-10.3149	-61.7074**
spread	-0.0364	4.7110	0.2635**	0.1643*	44.2413**	112.2703**	3.1927**	1.0278**	26.4232*	-9.0178
volat	0.2006**	0.7760**	0.0847**	0.1175**	63.7451**	54.0213**	0.3754**	0.4586**	34.7240**	7.2812
h10	11.2522**	7.7268**	4.5452**	4.4253**	39.2476**	36.4712**	5.7327**	5.5103**	54.5288**	50.0137**
h11	11.2270**	7.5708**	4.0912**	4.0238**	37.6526**	34.9134**	5.6518**	5.0448**	51.4126**	42.3759**
h12	10.1150**	8.5449**	3.9438**	3.6178**	26.5998**	30.0016**	5.2446**	4.3570**	44.8105**	39.7190**
h13	7.8262**	4.5211**	2.9002**	2.7239**	20.9048**	21.3192**	3.9821**	3.0749**	37.4060**	25.4867**
h14	12.5039**	8.7159**	4.4627**	4.4794**	42.8137**	40.3389**	6.5143**	5.3291**	59.3629**	55.3145**
h15	13.4288**	9.9956**	5.2076**	4.8147**	38.4823**	42.1040**	7.1975**	6.4840**	58.5360**	59.5938**

This table shows the results from estimations of

$Z_t^* = \gamma_1 Q_t + \beta' X_{t-1}^Z + u_t^Z$ for price aggressiveness using Ordered Probit model, and

$Q_t = a + \gamma_2 Z_t^* + b' X_{t-1}^Q + u_t^Q$ for quantity by two-stage OLS model.

Where Z_t^* is the latent price aggressiveness, Q_t is the quantity, X_{t-1}^Z and X_{t-1}^Q consist of explanatory variables for price aggressiveness and quantity equations. The hourly dummies in price aggressiveness equation are analyzed in a separate regression. Both equations are estimated for the order submission on ask and bid sides of market separately, using data of five stocks on the ASX market during July and August, 2002. ** and * denote statistical significance at 1 and 5 percent levels based on the z-statistics for price aggressiveness equation and **t**-statistics for quantity equation, respectively.

Table 10. Marginal probability

Marginal probability: BHP (%)

	1.Market/ marketable limit order		2.Limit order with improved price		3.Limit order at best price		4.Limit order within 3 ticks from best price		5.Limit order more 3 ticks from best price		6.Cancellation	
	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid
volume	0.210	-0.489	0.543	-1.357	0.096	0.048	-0.009	0.059	-0.007	0.007	-0.417	1.266
askdep	-0.010	-0.613	-0.025	-1.699	-0.004	0.061	0.000	0.074	0.000	0.009	0.019	1.584
biddep	0.046	0.903	0.118	2.504	0.021	-0.089	-0.002	-0.109	-0.001	-0.013	-0.091	-2.335
reldep	-2.121	6.673	-5.484	18.51	-0.969	-0.661	0.087	-0.806	0.068	-0.096	4.212	-17.26
spread	1.207	1.732	3.120	4.802	0.552	-0.172	-0.049	-0.209	-0.039	-0.025	-2.397	-4.478
volat	0.084	0.351	0.216	0.972	0.038	-0.035	-0.003	-0.042	-0.003	-0.005	-0.166	-0.907
Δp	6.801	-0.356	17.58	-0.986	3.108	0.035	-0.277	0.043	-0.217	0.005	-13.51	0.920

Table 10. Marginal probability (continued)

Marginal probability: NAB (%)

	1.Market/ marketable limit order		2.Limit order with improved price		3.Limit order at best price		4.Limit order within 3 ticks from best price		5.Limit order more 3 ticks from best price		6.Cancellation	
	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid
volume	-0.137	-3.156	-0.358	-8.178	-0.050	-1.005	0.004	0.183	0.019	0.372	0.239	5.676
askdep	0.389	-0.443	1.020	-1.148	0.144	-0.141	-0.012	0.026	-0.055	0.052	-0.683	0.797
biddep	-0.959	1.058	-2.513	2.742	-0.355	0.337	0.030	-0.062	0.135	-0.125	1.682	-1.903
reldep	1.498	-2.377	3.925	-6.160	0.554	-0.757	-0.047	0.138	-0.211	0.280	-2.626	4.275
spread	0.718	0.723	1.880	1.873	0.265	0.230	-0.023	-0.042	-0.101	-0.085	-1.258	-1.300
volat	-0.012	0.365	-0.032	0.947	-0.005	0.116	0.000	-0.021	0.002	-0.043	0.022	-0.657
Δp	4.715	1.354	12.355	3.507	1.744	0.431	-0.149	-0.079	-0.663	-0.160	-8.267	-2.434

Table 10. Marginal probability (continued)

Marginal probability: TLS (%)

	1.Market/ marketable limit order		2.Limit order with improved price		3.Limit order at best price		4.Limit order within 3 ticks from best price		5.Limit order more 3 ticks from best price		6.Cancellation	
	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid
volume	0.035	-0.044	0.138	-0.110	0.038	-0.029	0.016	-0.019	0.000	0.000	-0.186	0.102
askdep	-0.022	0.033	-0.088	0.084	-0.024	0.022	-0.010	0.014	0.000	0.000	0.118	-0.078
biddep	0.012	-0.065	0.046	-0.162	0.013	-0.042	0.005	-0.028	0.000	0.000	-0.062	0.150
reldep	1.198	-4.544	4.725	-11.38	1.296	-2.974	0.548	-1.935	-0.006	0.008	-6.382	10.57
spread	0.815	4.460	3.215	11.17	0.882	2.919	0.373	1.900	-0.004	-0.008	-4.343	-10.37
volat	0.559	2.285	2.202	5.722	0.604	1.496	0.255	0.973	-0.003	-0.004	-2.975	-5.315
Δp	2.060	0.288	8.125	0.722	2.229	0.189	0.942	0.123	-0.010	-0.001	-10.97	-0.671

Table 10. Marginal probability (continued)

Marginal probability: WOW (%)

	1.Market/ marketable limit order		2.Limit order with improved price		3.Limit order at best price		4.Limit order within 3 ticks from best price		5.Limit order more 3 ticks from best price		6.Cancellation	
	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid
volume	0.744	-0.901	2.050	-2.435	0.221	-0.413	0.033	-0.127	-0.061	0.060	-1.674	2.038
askdep	-1.148	-0.133	-3.162	-0.360	-0.341	-0.061	-0.051	-0.019	0.095	0.009	2.583	0.301
biddep	-0.633	-0.126	-1.743	-0.341	-0.188	-0.058	-0.028	-0.018	0.052	0.008	1.424	0.286
reldep	1.548	0.454	4.265	1.226	0.460	0.208	0.069	0.064	-0.128	-0.030	-3.484	-1.026
spread	1.052	1.647	2.900	4.451	0.313	0.755	0.047	0.232	-0.087	-0.109	-2.369	-3.726
volat	-0.112	0.453	-0.308	1.225	-0.033	0.208	-0.005	0.064	0.009	-0.030	0.251	-1.025
Δp	3.149	2.055	8.675	5.555	0.936	0.943	0.141	0.290	-0.259	-0.136	-7.086	-4.650

Table 10. Marginal probability (continued)

Marginal probability: MIM (%)

	1.Market/ marketable limit order		2.Limit order with improved price		3.Limit order at best price		4.Limit order within 3 ticks from best price		5.Limit order more 3 ticks from best price		6.Cancellation	
	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid
volume	0.099	-0.075	0.236	-0.164	0.039	-0.036	-0.020	-0.003	0.000	0.000	-0.181	0.116
askdep	-0.031	0.022	-0.074	0.048	-0.012	0.011	0.006	0.001	0.000	0.000	0.057	-0.034
biddep	0.033	-0.039	0.078	-0.086	0.013	-0.019	-0.007	-0.002	0.000	0.000	-0.060	0.061
reldep	6.350	-2.084	15.18	-4.590	2.514	-1.009	-1.311	-0.082	-0.012	0.003	-11.63	3.250
spread	0.907	5.216	2.169	11.49	0.359	2.527	-0.187	0.206	-0.002	-0.007	-1.661	-8.135
volat	0.771	2.661	1.844	5.862	0.305	1.289	-0.159	0.105	-0.002	-0.003	-1.412	-4.151
Δp	10.27	-7.775	24.56	-17.13	4.068	-3.766	-2.121	-0.306	-0.020	0.010	-18.81	12.13

This table shows the marginal reactions of price aggressiveness in each category to a change in the explanatory variables. Orders are divided into six price aggressiveness category as discussed in section 4. The values are obtained using equation (9). In order to calculate the marginal probability, the estimated coefficients resulting from the Ordered Probit regressions, together with the unconditional mean of quantity and explanatory variables are used. The marginal probability of hourly dummies is not reported, for simplicity.

Table 11. Comparison between predicted and empirical signs of regression coefficients

Hypothesis	Variable	Ask orders		Bid orders	
		Predicted	Empirical	Predicted	Empirical
Trade-off	*volume*	−	−	−	+
H1	*askdep*	+	+*	−	?
H2	*biddep*	−	?	+	?
H3	*reldep*	+	−*	−	?
H4	*spread*	−	−**	−	−**
H5	*volat*	−	?	−	−
H6	Δp	−	−**	+	?
H7	*hourdummies*	− → +	− → +	− → +	− → +

This table summarizes the empirical findings, compared with tested hypotheses through matching the expected and empirical signs of the coefficients in the price aggressiveness regressions for stocks BHP, NAB, TLS, WOW and MIM. Empirical signs are given when as least the results for four stocks keep the same, otherwise, a symbol (?) is marked, representing ambiguous results. The signs of predicted and empirical coefficients for hourly dummies change from negative to positive.