

# Order Splitting and Order Aggressiveness in Electronic Trading

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## Abstract

This paper examines the orders of active and passive institutional investors across five (bid) steps of the limit order book and tests recent theories of order aggressiveness in limit order placement decisions. We document that institutional investors break their desired quantities into several limit orders submitted simultaneously at multiple prices. We find that active institutions submit more aggressive orders than passive institutions and increase order aggressiveness through the day, consistent with hypothesized responses to observed changes in execution risk and the cost of non-execution. These findings highlight the importance of limit order information beyond the best quotes.

*Keywords: Limit order book, order aggressiveness, execution risk, picking-off risk*

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## Abstract

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**JEL Classification: G24, G25, G29**

# Order Splitting and Order Aggressiveness in Electronic Trading

## Introduction

Order driven automated trading now predominates on most of the world's exchanges and there is keen interest in understanding how such trading can rely primarily on limit orders as the source of liquidity. This paper shows for the first time that rather than placing a single order on the book at a single price, most institutional investors frequently split their desired quantities into several smaller orders placed on the book simultaneously *at multiple prices*. In addition, we show that active institutional investors are more aggressive in their order placement decisions than passive institutional investors, consistent with hypothesized behavior in response to differences in the cost of non-execution and non-execution risk.

We employ a unique dataset of snapshots of the entire limit order book every twenty minutes for eighteen months during 2000-2001 for all the leading equities in Australia. Our approach differs from previous empirical work in three ways. First, we know the identity of the institutional clients placing the orders and can, therefore, test hypotheses concerning the relative order aggressiveness of types of traders. Second, in addition to orders at the BBO, we are able to study limit orders that are inferior to the best prevailing quotes, as modeled by Goettler, Parlour, and Ranjan (2004). Previous empirical work on institutional trading by Keim and Madhavan (1995) was unable to analyze order placement away from the BBO because the complete limit order book data were not available.

Finally, Handa and Schwartz (1996) assess the profitability of a multi-price trading strategy by placing a "network" of both buy and sell limit orders simultaneously centered on actual market prices, reentering orders as others execute to maintain the network around the most recent price, allowing an extended period for execution, and then closing out accumulated positions at the end of the test period. Using limit orders 1%, 2%, 3% up to 5% away from the BBO, Handa and Schwartz demonstrate statistically and economically significant gains. However, since few if any

equity traders express buying and selling interest simultaneously, a question of the practical significance of these multi-price trading strategies remains open. Using a broad-based sample of the most liquid stocks, we document the frequent use of multi-price multi-order execution strategies by institutions trading on one side of the market only.

In an electronic trading environment, demanders of liquidity place marketable limit orders that can be executed immediately against a limit order already standing in the book. Marketable limit orders are analogous to the market orders for immediate execution at posted prices in a specialist or dealer market such as the New York Stock Exchange. Theoretical works such as Parlour (1998), Foucault (1999), and Handa, Schwartz and Tiwari (2003) focus primarily on this choice between demanding liquidity by placing market orders (or marketable limit orders) and supplying liquidity by submitting limit orders that cannot be immediately executed. Keim and Madhavan (1995) hypothesize that institutional traders with short-lived information and with greater deviations between consensus intrinsic value and their reservation prices prefer market orders over limit orders. They report that institutional traders show a surprisingly strong demand for immediacy attributable either to a belief that their information is short-lived or to their high opportunity cost of failing to execute.

Because we examine the state of the limit order book at a given point in time (i.e., eighteen snapshots per day for eighteen months), we do not address this choice of order type, so prominent in the prior literature, between market and limit orders. In fact, no marketable limit orders can show up in our sample because marketable limit orders execute immediately against depth standing in the electronic limit order book. Instead, our paper focuses directly on graduated order placement either at or away from the BBO, throughout five bid (and ask) price steps of the limit order book.

For the same reason, we do not address any aspect of the *flow* of orders over time such as stealth trading. Barclay and Warner (1993) hypothesize that informed traders break up their trades into medium-sized lots in response to the trade-off between the fleeting value of their information and the price concessions required to execute larger size. Chakravarty (2001) confirms empirically

that information is revealed primarily through medium size orders.<sup>1</sup> While we acknowledge that the size of an order can vary for many reasons including stealth trading, the proposition we test is that irrespective of the size of the order, active institutional orders will be placed systematically closer to the BBO than those of passive institutions. In short, while some questions like stealth trading, the *dynamics* of order placement intraday, ex post confirmation of picking off risk, or the limit order book's refresh rate clearly require continuous order flow information (i.e., a "reconstruction of the book"), others just as clearly do not. Specifically, the present paper employs 12,064 snapshots of the state of the limit order book at a leading institutional brokerage house to examine cross-sectional hypotheses about order aggressiveness by trader type.

This snapshots approach is a research design free of systematic sampling bias. An aggressive trader type with selling interest at or near the touch might pay the spread and hit a bid of sufficient size to clear his selling interest at the ask just before we take a snapshot of the book. Our observation *would* then capture that trader type not close to but well away from the touch.<sup>2</sup> However, there are three reasons to believe such sampling of 12,064 snapshots would not systematically mismeasure the aggressiveness of that trader type. First, the trader type in question would need to behave consistently in this fashion, on the exact timetable we use, to bias our observations in the way suggested. It is just as plausible that notional market orders would be cancelled and replaced with selling interest at the ask just before our snapshot. In short, intervening behavior between the snapshots at points in time unknown to the trader is not a plausible source of *systematic* bias. Second, although one does encounter systematic clustering bias in transactions data (on the price grid and near the open and close), there is no reason to believe that there is any systematic clustering bias around the twenty minute observation windows we employ. Finally, we don't perform the hypothesis tests of the ranked order aggressiveness of our trader types *intraday*. Instead, we test each intraday slice of data across the 497 stock-days of

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<sup>1</sup> In related work, Easley and O'Hara (1992) and Dufour and Engle (2000) find that with the market architecture of the NYSE, rapid trading also conveys information.

<sup>2</sup> Recall we document the first evidence in a broad-based sample of liquid stocks that institutions with selling interest place simultaneous orders at multiple prices up the book.

10:10 snapshots of the limit order book, then we repeat with the 665 stock-days of 10:30 snapshots, followed by a test of the 596 stock-days of 10:50 snapshots, etc.

A few prior authors have addressed the placement of orders across the price steps of the limit order book. Biais, Hillion, and Spatt (1995) focus on the aggressiveness of orders relative to the orders that are standing in the limit order book at the time the order is placed. The least aggressive orders are buy (sell) orders less (greater) than the prevailing best bid (ask), followed by orders at the best bid (ask), then orders inside the BBO, marketable limit orders that cross the spread with depth insufficient to change the BBO, and finally marketable limit orders that improve the best ask (bid). Griffiths, Smith, Turnbull, and White (2000) and Rinaldo (2004) adopt this Biais, Hillion, and Spatt taxonomy to study order aggressiveness. Again, our research design differs from this previous literature on order aggressiveness in that we analyze 1) the placement of multiple simultaneous limit orders at multiple prices, 2) order aggressiveness by investor type, and 3) limit orders at *individual* price steps inferior to the BBO.

The remainder of the paper is organized as follows. Section 2 analyzes the previous theoretical literature on limit order submission strategy. Section 3 develops testable hypotheses about order aggressiveness across trader types and about multi-price limit order submissions. Section 4 describes the data and the methodology for performing ordered hypothesis tests. Section 5 presents our results on order aggressiveness across trader types, accounting for multi-order multi-price submission strategies. An Appendix discusses our descriptive findings about the price of immediacy and order aggressiveness intraday. A conclusion is provided.

## **2. Theoretical Models of Optimal Order Placement**

The earliest studies of order submission strategy focus on the choice between limit orders and market orders. Using their six price step taxonomy of the order flow, Biais, Hillion and Spatt (1995) demonstrate that order aggressiveness is dependent on the state of the limit order book, with traders placing limit orders when the spread is large and the book is thin, and placing market orders when the book is thick. Parlour (1998) distinguishes between each side of the order book

and finds that market orders to sell (buy) are used when the risk of non-execution is high because of a thin book on the bid (ask) side of the market, and limit orders when this risk is low. Handa, Schwartz and Tiwari (2003) show that the larger the order imbalance (e.g., the excess depth of sell size minus buy size at the current quotes), the higher (lower) the execution risk to sellers (buyers), the more likely sellers (buyers) are to use market orders or marketable limit orders rather than place limit orders at the Ask (Bid).

In an asymmetric information environment, Rock (1996), Glosten (1994), and Seppi (1997) pose separate models that provide a common insight -- namely, that investors submitting limit orders are subject to a winner's curse in which the probability of execution is directly related to the probability of incurring a loss. Assuming their private information allows inferences about the direction of the next permanent price move, informed investors incur minimal picking off risk and therefore prefer to maximize the probability of execution by using market orders rather than limit orders. In contrast, Kaniel and Liu (2001) find that informed traders prefer to submit market orders only under certain conditions. In an experimental setting, Bloomfield, O'Hara, and Saar (2003) confirm that informed traders use market orders in a manner directly proportional to their information. That is, informed traders use market orders when their information is at the extremes of their prior distribution of beliefs, and limit orders when their information is consistent with their priors.

Harris (1998) argues that the optimal order placement of informed traders is time-varying, moving from initially stealthy limit orders at the quote to prevent information leakage to subsequent limit orders inside the quote to capture part of the spread and only later to market orders that assure immediate execution. Clearly, such hypotheses address the dynamics of the order submission strategy of informed traders. To test such propositions about informed trading is beyond the scope of the present paper because it requires empirical analysis not of the *state of the limit order book* at particular points in time but rather of the *flow of limit order placements* throughout a continuous window of trading time.

To return then to the topic at hand, Foucault (1999) presents the order submission choice of uninformed, liquidity traders as a trade-off between execution risk and picking off risk. He defines the former as a decrease in the execution probabilities at all price levels and the latter as the probability of being on the wrong side of a trade relative to subsequent price moves. In a dynamic model in which traders arrive sequentially, Foucault finds that execution risk increases through the trading period. Bloomfield, O'Hara and Saar (2003) confirm this role of execution risk amongst experimental liquidity traders who initially submit limit orders before switching to market orders to achieve their targeted volume by the end of the trading period.

Foucault (1999) hypothesizes that volatility (perhaps from shocks to the order imbalance) is a main determinant of order aggressiveness, with higher volatility resulting in a greater picking-off risk and, hence, less aggressive orders by uninformed traders. That is, a mean-preserving spread of the distribution of intrinsic value increases the probability of losing intrinsic value greater than a reservation value equal to the ask. To reduce this probability of seller's remorse requires moving up the book, perhaps to a sell limit order at the best ask +2 price steps. Moving to a sell limit order at the ask +2 will reduce picking off risk at the expense of increased execution risk, but with higher volatility the execution risk for any given price deviation from the BBO has diminished. For uninformed traders, less execution risk at each price point inferior to the BBO and a higher perceived picking off risk implies less aggressive order placement (which we term, the Foucault proposition).

In an empirical study, Rinaldo (2004) confirms that the tradeoff between the execution probability and the risk of adverse selection influences the aggressiveness of the order. In particular, Rinaldo finds that market variables such as order size, spreads, limit order book thickness, and intraday volatility determine the choice of order aggressiveness, a result consistent with the findings of Griffiths, Smith, Turnbull and White (2000). Both these empirical papers analyze the placement of limit orders at or between the bid and the ask but neither examines limit orders inferior to the BBO. In the results reported below, we show the importance of information

beyond the best quotes, especially the intentional placement of multiple simultaneous limit orders at multiple prices.

Ellul, Holden, Jain, and Jennings (2002) also investigate the Foucault proposition with a multinomial logit model of order types on the New York Stock Exchange. Although some confirmation of order aggressiveness theory is obtained, their results on volatility, time of day, and serial correlation of order type are inconclusive. It is unclear whether these negative results arise from the research design (i.e., order type independent of origin of the order), from the measures adopted (i.e., volatility measured as a five-minute prior return squared), or from the data aggregation (i.e., all orders at price steps inferior to the BBO are collapsed into one category). To address these potential problems requires more detailed information such as we offer here about order type and customer identity at numerous price steps up and down the limit order book.

Handa, Schwartz and Tiwari (2003) —hereinafter, HST—generalize Foucault (1999) to allow a reduction in order aggressiveness to follow not only from greater volatility and order imbalance, but also from differences of private value (reservation prices) relative to the consensus intrinsic value. A trader's order submission decision is determined by the execution risk faced at the time of the order (affected in part by the imbalance of buyers and sellers) relative to the cost to that trader of non-execution. In particular, the dollar cost to the trader of seeking immediate execution against known quotes for sufficient depth by using a marketable limit order that allows the counterparty to capture the spread is compared to the trader's dollar cost of non-execution.

Of special relevance to our paper, HST conjecture that the order placement difference between active and passive institutional trading reflects a difference in the acceptable level and perceived cost of non-execution by the two trader types rather than any significant difference in picking off risk. In other words, theory implies order aggressiveness by active institutions whether informed or not.

Goettler, Parlour and Ranjan (2004) extend these implications about the optimal order aggressiveness derived from the tradeoff between picking off and execution risk to limit orders away from the BBO. Consider the case of a trader with selling interest contemplating a limit order

to sell at the ask. If the mean of the distribution of intrinsic value moves against such a trader (if it increases), a less aggressive order placement at perhaps ask +2 ticks would be required to maintain the probability of a seller's remorse no greater than it was previously. This exogenous increase in the mean of the distribution of intrinsic value increases the picking off risk for limit orders to sell but reduces their execution risk.

The equilibrium order placement decision is then characterized by Goettler, Parlour, and Ranjan (2004) as a stochastic sequential game in which traders of various idiosyncratic, private values ( $\beta$ ) holding identical information sets about exogenous shocks to the consensus intrinsic value ( $\Delta_i^v$ ) maximize their expected payoff from placing a limit order at a relative price level difference  $p^i$ . On the ask side, there are five ticks at which an order can be placed:  $p^{-1}$ ,  $p^1$ ,  $p^2$ ,  $p^3$ , and  $p^4$  where  $p^{-1}$  is the best bid and  $p^1$  is the best ask. The difference between  $p^i$  and  $p^{i+1}$  is one tick.<sup>3</sup> Similarly,  $\beta$  and  $\Delta_i^v$  are expressed as relative price level differences. The expected payoff is then  $(p^i - \beta - \Delta_i^v)$  times the probability of execution  $\mu_i^e$ , which depends on the choice of  $p^i$  as well as on the state of the limit order book through a stationary Markov process. In this framework, Goettler, Parlour, and Rajan (2004) derive a positive relationship between order aggressiveness and the trader's private value. In particular, traders with a low (high)  $\beta$  are more likely to better or match the existing ask (bid) rather than place sell (buy) limit orders at higher (lower) prices on the book.

### 3. Development of hypotheses

In this paper, we test several aspects of Foucault (1999), Handa, Schwartz, and Tiwari (2003) and Goettler, Parlour and Ranjan's (2004) theory of order aggressiveness using snapshots of the entire limit order book. We do so indirectly by first identifying trader types who differ

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<sup>3</sup>For convenience in our work, on the ask side we label these simply as ticks -1, +1, +2, +3, +4 and +5. Note that orders to sell at -1 would either receive immediate execution or better the best ask on the book if their order size exceeds the depth at the best bid. Therefore, our snapshots of the limit order book incorporate the effects of these -1 orders.

across a continuum of non-execution costs (i.e., aggressive institutions, passive institutions, and retail traders).

### **3.1. Identification of trader types**

We begin by securing access to the internal records of all institutional transactions from several of the largest brokerage houses in Australia. All incoming institutional orders are classified by the senior traders, in conjunction with the institutional sales desk, as originating from client accounts with either active or passive trading strategies. Aside from trading instructions, a major source of difference between the active and passive accounts is brokerage rates. Active institutional investors pay higher commissions to brokerage houses in return for access to real-time assessments of the state of the limit order book. These account classifications are part of a well-established client management process that permeates the institutional brokerage industry in Sydney. Interviews of senior trading executives in several leading brokerages confirmed that these account classifications are consistent across the brokerage firms.

Examining our dataset, active institutions comprise two groups of clients: 1) proprietary trading desks whose primary objective is to obtain superior risk-adjusted returns, and 2) hedge funds including macro, market-neutral, long-short, arbitrage, event-driven, quantitative, and “stock-picking” funds. Passive institutions comprise 1) mutual funds, 2) insurance companies, and 3) index funds with a mandate to replicate the return on the market portfolio with a commensurate level of risk. Given these differing objectives, active institutional investors are less benchmark-focused than their passive institutional counterparts who emphasize cost control rather than out-performance.

For comparison purposes, we also time-matched our institutional orders to adjacent retail orders using the Australian Stock Exchange (ASX) tapes of retail broker submissions to the limit order book. The ASX has a high level of pre-trade as well as post-trade transparency, including the

ability to identify separately all 76 retail brokers of the 95 brokers operating on the ASX.<sup>4</sup> Unlike the two types of institutional investors, retail investors have a relatively small amount of capital and high fixed costs, preventing them from adopting sophisticated order management strategies. By comparison with institutional investors, we conjecture that retail investors have less access to information about the changing state of the limit order book, both with respect to its timeliness and its quality. Moreover, because their cost of non-execution falls well below either active or passive institutional investors, retail investors do not continuously monitor the market. If it were costless to update frequently one's limit order submission strategy, retail investors would prefer not to be picked off regularly as counterparties to institutional trades that are better informed about the state of the market. However, we wish to emphasize that "lingering" or "stale" retail limit orders are not an artifact of data collection but rather reflect an endogenous consequence of optimal order submission behavior by retail traders.

### **3.2. Order aggressiveness**

By maintained hypothesis, retail traders believe that when they proceed with either a buying or selling interest, there is an increased probability that the mean of the distribution of intrinsic value will move against them. This anticipation of an increased winner's curse or seller's remorse relative to institutional traders is the heightened picking off risk that in part distinguishes this class of traders. By proposition 2 in Goettler, Parlour, and Rajan (2004), higher  $\Delta_i^v$  for retail traders from an information shock imposes a lower payoff for any given execution probability and, therefore, implies a reduction in the execution probability chosen – i.e., less order aggressiveness. In short, the higher perceived picking off risk in the retail trader category immediately implies placing an ask (bid) farther up (down) the book with a concomitant decrease in the probability of execution. But retail traders are also more patient traders because their cost of non-execution is

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<sup>4</sup> Several of the largest broker age houses like ABN AMRO, Macquarie, BNP, Merrill Lynch, Salomon Smith Barney, and UBS maintain separate institutional and retail brokerages, identified as such in the ASX database.

low relative to institutional traders. Therefore, to mitigate further their higher picking off risk, retail investors express reduced demand for immediacy.

Passive institutional traders, on the other hand, are more impatient. Their liquidity-based motivation for trading to meet redemption demand, complete a sector rebalancing of a portfolio, reduce tracking error, or hedge a position necessitates higher execution probability ( $\mu_i^e$ ) than for retail traders. Such heterogeneous trading is triggered by independent and particular circumstances – e.g., a higher cost of non-execution (Handa, Schwartz and Tiwari 2003, Keim and Madhavan 1995) or exogenous shocks to the immediacy preferences of liquidity traders in the sense of Mendelson and Tunca (2004). Moreover, this class of traders perceives lower  $\Delta_i^v$  from an information shock—i.e., less chance they will be picked off than perceived by retail traders. Consequently, again by proposition 2 in Goettler, Parlour, and Rajan (2004), passive institutional investors are unambiguously more aggressive in their order placement than retail traders.

Active institutional investors glean valuable insights from continuous monitoring of the limit order book and the patterns of trading of participants therein. Such monitoring of the market combined with independent assessments provided by brokerage firm trading desks allows active institutional traders to express selling interest when their  $\beta$  is low and buying interest when their  $\beta$  is high relative to the consensus mean of the distribution of intrinsic value. Any such asymmetric information advantage about the state of the market is not only time-sensitive but even more fleeting than asymmetric information about intrinsic value itself, so active institutional investors perceive the highest cost of non-execution. Consequently, again by Goettler, Parlour and Rajan (2004) proposition 2 as well as Handa, Schwartz and Tiwari (2003), differential private value implies active institutional traders will be more aggressive in both buying and selling than either passive institutional or retail traders not engaged in continuous monitoring. In short, active institutional traders wish to minimize their probability of non-execution because they perceive their cost of non-execution to be great, for any given perceived picking off risk.

Our first hypothesis is therefore as follows:

$H_1$ : The deviation between the best quote on a given side of the market and the volume-weighted average price of the orders placed in the schedule by customers of a particular type will be ordered from highest to lowest as follows: retail investors, passive institutional investors, and active institutional investors.

This reasoning is summarized in Table 1. By maintained hypothesis, both institutional trader types perceive low picking off risk relative to retail investors, and the cost of non-execution varies from highest to lowest from active institutional, to passive institutional, to retail investors. This implies a cross-sectional testable hypothesis  $H_1$  distinguishing order aggressiveness by trader type.

### **3.3. Multi-price order splitting**

We also investigate whether traders frequently follow a strategy of placing limit orders simultaneously at different prices. We believe that this practice is common, has not been previously examined empirically, and needs to be taken into account in models of limit order aggressiveness. Submission of simultaneous orders at multiple prices has advantages over a single order. A large proportion of passive institutional orders are benchmarked against a volume-weighted average price. This benchmark is easier to achieve by the submission of multiple orders, which represent an effective way in which to ensure participation at price points where significant volume trades<sup>5</sup>. In addition, certain stock trading characteristics also support the use of multiple orders. For liquid stocks with a dense limit order book (where there is consistently a large amount of volume at price steps both at and away from the best bid-offer), the submission of multiple orders is essential to capture time priority in the order queue as price moves. For thinly traded stocks, the lack of liquidity at some price points in the limit order book can result in these stocks trading in a discontinuous manner, with prices “gapping-up” or “gapping-down”<sup>6</sup>. When this

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<sup>5</sup> This motivation is equivalent to the “participate-but-do-not-initiate” order on the New York Stock Exchange.

<sup>6</sup> For example, {5.01,5.00,5.01,5.02} represents a continuous price sequence typically associated with a thickly traded stock. Alternatively, {5.01,5.05,5.06,5.02} represents a discontinuous price sequence most likely to occur with a thinly traded stock.

prospect occurs, the submission of multiple orders away from the best bid-offer can take advantage of potentially favorable price movements<sup>7</sup>.

If investors optimally submit multiple simultaneous orders at multiple prices, this behavior needs to be accounted for any hypothesis testing about order aggressiveness in order to allow a better indication of the investors' notional supply/demand schedule and consequent estimation of the execution risk / picking off risk trade-off. Table 2 displays a limit order book for AMP, a top twenty stock by market capitalization. The submission of orders at different prices by both active and passive institutional investors is clearly visible. On the ask side of the book, the client labeled Passive 2 has orders at three disparate prices, and the client labeled Active 2 has orders at two adjacent prices close to the touch.

Table 3 displays the frequency across our eighteen month data set of order splitting by institutional investors across all the leading equities. The multi-price order placement strategy is evident. Only 51.6% of institutions placing orders to buy, place orders solely at the bid; only 51.9% placing orders to sell, place orders solely at the ask. 19.7% (23.7%) of all institutional orders to buy (sell) are by clients placing orders at two prices simultaneously. As many as 13.8% of all orders to buy are placed by institutional clients working orders at five prices simultaneously. And 15% of all orders to sell are placed by institutional clients working orders at four or five prices simultaneously. A similar incidence occurs on the ask side of the market. Clearly, the execution strategy of submitting several orders simultaneously at multiple prices is typical of institutional investors. In the Discussion of Results below, we address further the significance of this finding for defining market liquidity.

Figure 1 further characterizes this multi-price simultaneous order submission behavior averaged across the 18 times of day and the 35 securities in our sample. These histograms display the percentage volume on any given price step associated with all orders to sell or to buy of passive or active institutional traders as a percentage of that trader's total volume on any one

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<sup>7</sup> These motivations associated with multiple order submission arose in interviews with senior traders from Credit Suisse First Boston, ABN Amro NV and Deutsche Bank AG.

snapshot of the limit order book. Three points stand out. First, active institutions offer almost as much volume +1 price step above the ask (32%) as at the ask itself (34%), and similarly almost as much volume -1 price step below the bid (23%) as at the bid (24%). Second, passive institutional traders write twice as many limit orders at the BBO as active institutional traders (i.e., 67% versus 34% at the ask and 45% versus 24% at the bid). And third, except for passive institutional offers to sell, more aggregate depth is offered one to three steps away from the BBO than at the BBO. Specifically, active institutional investors offer to sell 66% of the volume on the book at prices above the best ask. And they offer to buy 76% of the book's volume below the best bid. Even passive institutional investors post offers to buy 55% of the book's volume below the best bid.

Hollifield, Miller, and Sandas (1999) also find more depth away from the BBO in their detailed study of three months of the limit order book for Ericsson, one of the most actively traded stocks on the Stockholm Stock Exchange. Limit order book information beyond the BBO is clearly critical in assessing execution strategy and testing theories of order aggressiveness. We use such information to calculate the volume-weighted average price of the orders to create a point estimate of the notional supply/demand schedule for each client and then for each investor type.

### **3.4 Intraday order submission strategy**

Foster and Viswanathan (1990), Madhavan (1992) and Glosten (1994) argue that information asymmetry is highest at the open and declines during the trading day. Hence, picking off risk declines during the day, and we hypothesize that in their limit order placement strategy, traders especially focused on mitigating high perceived picking off risk (retail investors) will be especially cautious in the morning and more aggressive as the day progresses. According to Foucault (1999) and Parlour (1998), execution risk also increases over the trading day. Therefore, traders especially focused on mitigating execution risk (active institutional traders) will also be more aggressive in their order placement as the day progresses, leading to our second hypothesis:

H<sub>2</sub>: Retail order flow and active institutional order flow exhibit volume-weighted average price deviations from the market best bid or offer that are highest at the open and declining thereafter during the trading day. Passive institutional investors exhibit situation-specific VWAP deviation from the BBO at various times throughout the trading day.

That is, informationally disadvantaged retail investors mitigate their higher information asymmetry about the state of the limit order book in the morning by moving away from the BBO and then converge to the BBO in the afternoon as asymmetric information is resolved. Active institutional investors also move closer to the BBO throughout the day but for a different reason – to mitigate the increased execution risk due to order imbalances from highly correlated passive institutional order flow in the afternoon. Because of their more moderate levels of both non-execution cost and perceived picking off risk, passive institutional investors like mutual and index funds increase the aggressiveness of their limit orders on a more situation-specific basis, for example when particular tracking errors are anticipated.<sup>8</sup> These implications are consistent with the experiment findings of Bloomfield, O’Hara, and Saar (2002) that showed intraday order submission strategy depends on subtle as well as conspicuous differences in investor type.

Our sampling of snapshots of the limit order book is less well suited to testing the intraday hypothesis H<sub>2</sub> than the cross-sectional hypothesis H<sub>1</sub>. Again, there is no systematic bias clustering the order aggressiveness we observe every twenty minutes, eighteen times per day. However, it would be desirable in testing H<sub>2</sub> to secure continuous observations (or accurate reconstructions) of the entire limit order book for many stocks for long periods of time. Obtaining permission to access the intervening nineteen minutes proved not possible in this case because of the extremely sensitive nature of the proprietary data. Consequently, the results on testing H<sub>2</sub> should be interpreted with some caution and seen as indicative, rather than the final word on the subject. For

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<sup>8</sup> To the extent VWAP benchmarking at the close each day triggers such liquidity trades, passive institutional investors will join the other two investor types in moving closer to the BBO near the close.

each of the eighteen data points intraday we provide unbiased estimates of order aggressiveness; continuous data may show other intraday order submissions strategies at work.

#### **4. Data and methodology**

##### **4.1. Data collection and characteristics of the sample**

On the Australian Stock Exchange (ASX), the depth at all price points in the limit order book is visible to all market participants through the Stock Exchange Automated Trading System (SEATS). The market is open from 10:00 to 16:05, with an opening call auction from 10:00 to 10:10 and a closing auction from 16:00 to 16:05. Our sample comprises snapshots of the entire limit order book at twenty-minute intervals from 10:10 to 15:50 for the time period 1 January 2001 to 30 June 2002. For the first security, for the first day, for the time of day 10:10, we first ascertain whether there exists at least one outstanding limit order to buy from each investor type – active institutions, passive institutions, and retail clients. If so, we record a snapshot of all five steps of that bid side of the limit order book. We then repeat this snapshot collection process for the other side of the book, for each time of day, and for each security. The final sample consists of 12,064 snapshots of the limit order book for 35 stocks, 33 of which are from the All Ordinaries Index. Table 4 provides descriptive statistics for the sample. Most all these securities trade several million shares across several hundred trades per day. More importantly for our testing of H1 and H2, for each of the eighteen time slots from 10:10 to 15:50 we have several hundred snapshots (i.e., 497 to 750) of the limit order book. Table 5 lists the number of snapshots by security and by time of day.

In addition to the publicly available data, we collected institutional order flow data with attached client I.D. codes from two leading securities dealers. These one-time-only releases of a proprietary dataset provide a representative sample of institutional order flow on any given trading day. According to DFS IRESS, a provider of trading platforms and market data, the securities dealers providing the proprietary data ranked among the top brokers by dollar turnover across the

entire sample period. Retail order flow was obtained directly from ASX limit order book data, using broker identification numbers to identify firms that are known to have only retail clients.

For each security for each limit order book snapshot, we calculate the deviation of each outstanding order from the best ask (or bid) price. To aggregate orders for each investor type, we calculate the volume-weighted price deviation from the BBO. These weighted price deviations are then ranked, where a rank of 1 (3) represents the investor category with the smallest (largest) deviation from the BBO. This set of procedures results in a synchronous, ranked set of simultaneous limit orders at multiple prices for active institutional, passive institutional, and retail investors.

To describe the sample, we calculate the percentage depth available at the most aggressive price of each investor class relative to the total depth of that class in the limit order book, restricting the analysis to the best five bid and best five ask prices. Individual clients in the active institutional category place between 38% and 100% of their order flow volume at the price of their most aggressive order.<sup>9</sup> Corresponding figures range from 15% to 100% for passive institutional investors and from 1% to 47% for retail investors. These findings provide a first indication that active institutional investors are the most aggressive order placers, and retail investors are the least aggressive in their order submission strategy.

We also calculate spreads by time of day and trader type. Figure 2 shows proportional and standardized spreads decline across the trading day, before increasing slightly during the hour before the close. This reverse J-shaped pattern, which is more pronounced for the standardised spread, has been documented previously in Australia (Aitken, Brown and Walter (1995)) and mirrors still earlier findings in the U.S. market (McInish and Wood (1992) and Chan, Chung and Johnson (1995)). The percentage depth at the BBO (available from the authors) follows almost an inverse pattern to that of the spreads, with depth lowest on the open before increasing to its highest point at the close.

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<sup>9</sup> Calculations by time of day and investor type are available from the authors.

A second indication of order aggressiveness came from isolating the spreads on limit orders standing in the book by investor type, as though no other orders were present. The proportional spread is consistently smallest for the active institutional investors reflecting their more aggressive order placement. For example, in the last two hours of trading, active institutional orders are approximately ten basis points more aggressive (0.42% versus 0.53%) than passive institutional orders which are themselves thirteen basis points more aggressive (0.53% versus 0.66%) than retail orders for a round trip transaction.<sup>10</sup>

## 4.2 Statistical methodology

Australian equities have been screen traded in decimal hundredths since October 1987. Spreads on the ASX are very tight, but they remain several multiples of the one-cent minimum tick size in most stocks. In our sample, quoted spreads range from A\$0.05 for CSL to A\$0.01 for IPG. The mean quoted spread for our ASX stocks in 2000-2001 is A\$0.016 or ¼ of 1% of the mean stock price. The median quoted spread is A\$0.02, twice the minimum tick size. Consequently, the price discreteness issue that led U.S. researchers to develop ordered probit microstructure models of price changes (see Campbell, Lo, and MacKinlay 1997, pp. 108-128) is seldom present in our data.

One of our principal interests in this paper is the volume-weighted average price of limit orders as a measure of the order aggressiveness of active and passive institutions and retail traders. We wish to test an ordered hypothesis involving these three investor types in our proprietary data set.<sup>11</sup> We use Page's (1963) *L*-statistic to test the null hypothesis of equal aggressiveness in order submission strategy,

$$H_0: P_{Active} = P_{Passive} = P_{Retail}$$

against its ordered alternative: for buy orders:  $H_1: P_{Active} > P_{Passive} > P_{Retail}$ , and for sell orders:  $H_1: P_{Active} < P_{Passive} < P_{Retail}$ . Page's *L*-statistic for three ordered variables is computed as follows:

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<sup>10</sup>Tables by time of day and investor type are available from the authors.

$$L = \sum_{j=1}^3 \sum_{i=1}^m X_{ij} Y_j$$

where  $m$  is the number of observations at each time period,  $X_{ij}$  the observed rank of the  $i$ 'th observation of order flow category  $j$  and  $Y_j$  the hypothesized rank of category  $j$ . The critical value of  $L$  (for a given level of confidence and three ordered variables) is computed as follows:

$$L_{critical} = 2m \frac{Z_{critical}}{\sqrt{2m}} + 6$$

This testing procedure for ordered hypotheses has been employed previously in both asset pricing (Levhari and Levy 1977) and in financial market microstructure (Wood and McInish, 1984).

## 5. Results

### 5.1 The price of immediacy

At each snapshot of the limit order book, we examine the price of immediacy—i.e., the price deviation of all limit orders from the price available for immediate execution at the BBO. Table 6 provides both absolute and volume-weighted measures every twenty minutes throughout the trading day.<sup>12</sup> We begin with limit orders of active institutional traders. For the 10:10 snapshot on the first day in our sample, for the first firm in our sample, we identify the best bid price, which we assign tick 0. The next best tick is assigned the value 1, and so forth. For the absolute measure, we simply identify the difference in ticks between the best active institutional bid and the best market bid. This difference can range from 0 to 5. For the volume-weighted measure, we calculate the difference in ticks of each price in the limit order book (for this investor type) and weight by the order sizes. We repeat the measure for the 10:10 snapshot for the remaining days in our sample and compute an average for the first firm. We average across all

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<sup>11</sup> This three-category aggregation was the restriction we agreed to in exchange for access to the client order flow data.

<sup>12</sup> Alternatively, many earlier studies have examined the price of immediacy in a less detailed way as the normalized deviation from the closing price.

firms to obtain the first entry in our table. In Table 6, we report the calculations for each investor type, for each time of day, and for both the bid and the ask side of the market.

From Panel A, retail investors on average choose 3.22 volume-weighted price steps on the bid side and 3.53 volume-weighted price steps on the ask side at 10:10 a.m., ten minutes after the opening, and similar deviations (3.13 on the bid and 3.50 on the ask) at 15:50 ten minutes before the close. In contrast, institutional investors choose 3.02 and 3.03, respectively, ten minutes after the open and 2.62 and 2.67 price steps ten minutes before the close. This intraday decline in the volume-weighted price of immediacy for institutional investors is statistically significant. In addition, the larger deviations for immediacy of retail than institutional orders is statistically significant in every twenty minute period throughout the day.

Disaggregating types of institutional investors in Table 6, Panel B, the volume weighted average price of immediacy is much lower for active institutional investors (e.g., 1.05 price steps on the bid and 1.03 price steps on the ask at 10:10) than for passive institutional investors (1.67 price steps on the bid and 1.65 on the ask at 10:10). Wilcoxon tests show these differences are statistically significant in each of eighteen times of day examined. As in the aggregate institutional results in Panel A, the price of immediacy declines from the open to the close for both active (I1) and passive (I2) institutional investors.

Closer examination, especially of the volume-weighted bid in column 3 and the volume-weighted ask in columns 4 and 5, indicates most of the variation in the price of immediacy happens in the first hour of trading. After that, there is almost no change in the price of immediacy intraday. Whether the unusually large price deviations from the BBO in the first hour reflect asymmetric information and picking off risk or instead reflect order imbalance and execution risk is addressed with further tests and interpretations discussed below.

## **5.2 Order aggressiveness by trader type**

Table 7 presents the results of Page's *L*-test under the null hypothesis of equal rankings in order aggressiveness across trader types. This no-difference null hypothesis is rejected in 70% of

the cases (227 out of 324 stock-time-of-day combinations) in favor of the ranked alternative (Alternative Hypothesis I in Table 7) in which active investors submit more aggressive orders than passive investors, who are, in turn, more aggressive than their retail counterparts. The remaining 97 cases are tested to establish whether any alternate ranking is significant. For 40 of the 324 stock-timestamps, or 12% of the total sample, passive institutional investors are found to be more aggressive in their order submission than active institutional investors, with retail investors continuing to be the least aggressive.

To check the robustness of the Page L test procedure, we perform three additional sets of cross-sectional tests. First, we retest the null hypothesis of no difference in the VWAP price deviations against the alternative that had characterized 12% (40) of the stock time-stamps,  $H_1: P_{Passive} > P_{Active} > P_{Retail}$  for buy orders and  $H_1: P_{Passive} < P_{Active} < P_{Retail}$  for sell orders (-i.e., Alternative Hypothesis II in Table 7). In the last column, we show that for each of the 18 time stamps, we are *unable* to reject the null hypothesis in favor of this alternative ordering of investor types.

Second, Table 8 presents the results of a Kruskal-Wallis ranked-sum test for each security to address the question whether this order aggressiveness ranking remains the same throughout the day. Without exception, in all thirty-five securities we are unable to reject the null hypothesis that the ranks remain the same across the eighteen times of day, indicating that none of the investor groups change the relative aggressiveness of their order submission strategy intraday. That is, if active institutional investors are the most aggressive investor group at the open, they remain so across the entire trading day.

Third, both market-wide and stock-specific price trends have the potential to change the order submission strategy of all types of investors. A rising (falling) stock market results in increased (decreased) retail participation. A strong stock price trend may also increase or decrease institutional participation as a result of liquidity constraints. That is, a sufficient decline in market capitalization may result in passive institutional investors exiting a stock that no longer meets the portfolio's investment criteria, with a significant rise having the opposite effect. Consequently, we

split the sample to test the robustness of the ordered hypothesis across the year and a half sample period. Using a Wilcoxon sign rank test of the first and second half of the sample period, we find no significant difference in the order aggressiveness by trader type in the before and after periods for any stock.<sup>13</sup> Therefore, based on all three robustness checks, we can conclude that our findings strongly support Alternative Hypothesis I-- that active institutional investors submit more aggressive orders than passive institutional investors who in turn submit more aggressive orders than retail traders.

## **5.2 Intraday order aggressiveness**

In order to test the intraday hypothesis  $H_2$ , the aggressiveness of each investor type's order submission strategy is quantified by computing the percentage deviation of the volume weighted average price (VWAP) of their orders from the market best bid or offer. In aggregate across all three investor types, the percentage deviation is highest at the open before declining through the trading day. Figure 3 depicts the percentage deviation by investor type. Each type is least aggressive in their order submission strategy at the start of the trading day. The relative vertical position of the three lines in Figure 3 is supportive of the results of the ordered hypothesis test of order aggressiveness, with active investors submitting more aggressive orders than passive investors, who are, in turn, more aggressive than retail investors. As the early morning proceeds, the percentage deviation of retail investors declines rapidly from slightly less than 3.1% to slightly less than 2.7%. Similarly, the more aggressive passive and active institutional investors have percentage deviations from VWAP that decline more gradually through the late morning.

We explored this further through a ranking by investor class (on a stock-by-stock basis) of the percentage deviation from the best bid-offer at each timestamp relative to the rest of the trading day. This results in a ranking in which the lowest percentage deviation (or most aggressive) timestamp receives a rank of 1 and the highest deviation timestamp a rank of 18 (with tied ranks

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<sup>13</sup> These Wilcoxon test results are available from the authors.

each receiving the higher rank). Table 9 reports the average rank by investor class across the trading day. Consistent with Figure 3, the first timestamp in table 9 (at 10:10) has the highest average rank across all investor groups, suggesting that all investor types are less aggressive at the commencement of trading. The lowest average rank for all investor groups is at the penultimate snapshot at 15:30, indicating that investors are most aggressive at this point.

We perform a ranked-sum test of  $H_2$  on the data in Table 9 to determine whether each investor type significantly varies their order aggressiveness through the trading day. The null hypothesis is that the percentage deviation ranks in a column (i.e., by investor type) are drawn from the same population. This null of no-difference in order aggressiveness intraday is rejected for active institutional investors (Kruskal-Wallis statistic 32.70 with p-value 0.01) and for retail investors (Kruskal-Wallis statistic 120.18 with p-value 0.01), but not for passive institutional investors (Kruskal-Wallis statistic 19.10 with p-value 0.32). The most aggressive order placers (the active institutions) and the least aggressive order placers (the retail traders) significantly vary this aspect of their order submission strategy over the course of the trading day. Passive institutions, on the other hand, have more highly variable percentage deviation of their VWAP from the BBO throughout the trading day, as particular circumstances arise (as can be seen in Figure 3).<sup>14</sup>

## 6. Discussion of results

The results presented are consistent with our order aggressiveness hypothesis reflecting Foucault (1999), Handa, Schwartz, and Tiwari (2003), and Goettler, Parlour, and Rajan's (2004) trade-off between the expected costs of non-execution and of picking-off risk. Active institutional investors have the highest opportunity cost of non-execution and low picking off risk, causing them to submit the most aggressive orders. The reverse is true for retail investors, with a relatively

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<sup>14</sup> This finding is consistent with the interpretation of passive institutions as liquidity suppliers except when their demand for immediacy is driven by idiosyncratic preferences (Mendelson and Tunca, 2004).

high picking off risk and a lowest cost of non-execution, resulting in their submitting the least aggressive orders. Passive institutional investors are intermediate in their order aggressiveness in most stocks most of the time.

In about 12% of the stock time-stamps, passive institutions are more aggressive than their active counterparts, which we interpret as an unusually high expected cost of non-execution. For example, passive institutional investors are often benchmarked to the market index with an externally-imposed tracking error constraint. When they approach their maximum allowable tracking error, the cost of non-execution for the passive institution increases substantially, causing them to submit more aggressive orders. This behavior leads to our conjecture that the picking off risk-execution probability trade-off is both time-varying and stock-specific for passive institutional order flow.

The results are also supportive of our second, intraday hypothesis, with the decline in both information asymmetry (Foster and Viswanathan, 1990, Madhavan, 1992 Glosten, 1994) and increase in execution risk (Foucault, 1999, Parlour, 1998 and Bloomfield, O'Hara and Saar, 2003) over the trading day leading to increased order aggressiveness. For active investors, the increased order aggressiveness is caused by a rising execution risk, whereas for retail investors, the increased aggressiveness is caused by the decline in picking-off risk. The results for passive institutional investors are inconclusive, confirming that their trade-off between execution probability and picking off risk is more situation-specific, as hypothesized.

Interestingly, all three types of limit orders are at their most aggressive on the next to last snapshot, despite our presumption that the risk of non-execution continues to rise until the close. We interpret this to mean that many investors prefer to use marketable limit orders to minimize the probability of non-execution immediately prior to the close.

Finally, our results highlight for the first time the importance of measuring market liquidity at more price points than the BBO alone. Competing models of liquidity supply motivated by hedging (Spiegel and Subrahmanyam 1992) versus idiosyncratic immediacy preferences (Mendelson and Tunca 2004) provide opposite implications for market liquidity as

volatility increases. Such competing implications cannot be tested effectively, we find, without examining multiple price steps on the limit order book since evidence presented herein shows clearly that institutional traders place simultaneous limit orders at multiple price points. We have offered several reasons why order splitting reflects optimizing decisions, not simply stale prices or inattentive trading.

## **7. Summary and Conclusion**

We examine empirically the order aggressiveness of institutional and retail investors across the trading day, explicitly acknowledging their ability to submit simultaneous orders at multiple prices in the limit order book. The results show that investors with different information levels about the state of the market and different non-execution costs submit orders consistent with their expected trade-off between picking-off risk and the probability of non-execution. Active institutional investors submit the most aggressive orders. Passive institutional investors submit more aggressive orders than retail investors. In addition, we find evidence of the hypothesized intraday variation in the execution risk-picking-off risk trade-off. A decline in picking-off risk and rise in the probability of non-execution intraday causes both retail and active investors to submit more aggressive orders through the day. Order aggressiveness by passive institutions is more situation-specific.

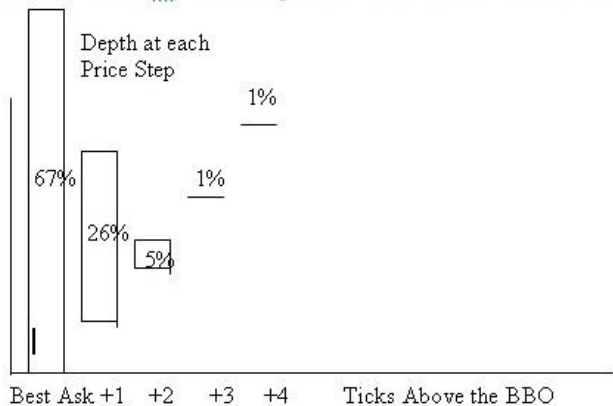
In documenting order splitting and order aggressiveness by trader type across the five bid and five ask steps of the limit order book for all the leading Australian equities over eighteen months, our findings support the recent theoretical models of order aggressiveness (Handa, Schwartz and Tiwari, 2003 and Goettler, Parlour, and Rajan, 2004). On the one hand, these findings underline the importance of the state of the limit order book beyond the best quotes. In addition, this study highlights the need to account for simultaneous multiple order submissions at different prices on the limit order book to improve further our understanding of informed and liquidity trading behavior.

## References

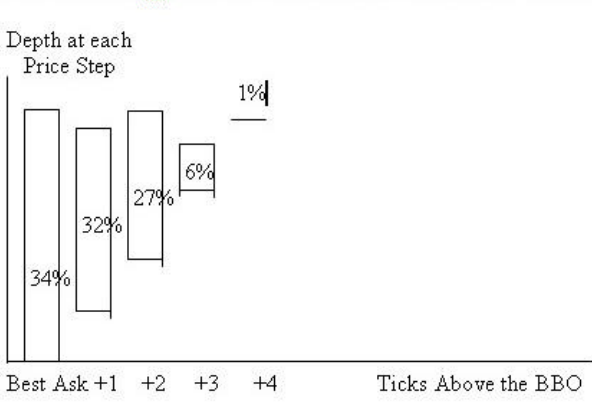
- Aitken, Michael, Philip Brown, and Terry Walter, 1995, The intraday behavior of the bid/ask schedule under an automated trading regime. Working paper, the University of Western Australia, WA 6009.
- Barclay, Michael J. and Jerold B. Warner, 1993, Stealth trading and volatility: Which trades move prices? *Journal of Financial Economics*, 34, 281-305.
- Biais, B., Hillion, P. and Spatt, C., 1995. An empirical analysis of the limit order book and the order flow in the Paris Bourse. *Journal of Finance* 50, 1655-1689.
- Bloomfield, R., O'Hara, M. and Saar, G., 2003, The "make or take" decision in an electronic market: Evidence on the evolution of liquidity. Working paper, Cornell University.
- Chakravarty, Sugato, 2001, Stealth-trading: Which traders' trades move stock prices? *Journal of Financial Economics* 61, 289-307.
- Chan, Kalok, Y. Peter Chung, and Herb Johnson, The intraday behavior of bid-ask spreads for NYSE stocks and CBOE options. *Journal of Financial Analysis* 30, 329-346.
- Dufour, Alfonso, and Robert F. Engle, 2000, Time and the price impact of a trade. *Journal of Finance* 55, 2467-2498.
- Easley, David, and Maureen O'Hara, 1992, Time and the process of security price adjustments, *Journal of Finance* 47, 577-605.
- Ellul, A, Holden C., Jain, P., and Jennings, R., 2002, Determinates of order choice on the New York Stock Exchange. Working paper, Indiana University, Bloomington.
- Foster, F. and Viswanathan, S., 1990, A theory of intraday variations in volume, variance and trading costs in securities markets. *Review of Financial Studies* 3, 593-624.
- Foucault, T., 1999, Order flow composition and trading costs in a dynamic limit order market. *Journal of Financial Markets* 2, 99-134.
- Goettler, R., Parlour, C, and U. Ranjan, 2004, Equilibrium in a dynamic limit order market. *Journal of Finance*, forthcoming.
- Glosten, L., 1994, Is the electronic limit order book inevitable? *Journal of Finance* 49 1127-1160.
- Griffiths, M., Smith, B., Turnbull, A. and White, R., 2000, The costs and determinants of order aggressiveness. *Journal of Financial Economics* 56, 65-88.
- Handa, P., and Schwartz, R., 1996, Limit order trading. *Journal of Finance*, 51, 1835-1861.
- Handa, P., Schwartz, R. and Tiwari, A., 2003, Quote setting and price formation in an order driven market. *Journal of Financial Markets* 6, 461-489.
- Hollifield, B., Miller, R. and Sandas, P., 1999, An empirical analysis of limit order markets. *Review of Economic Studies* 71, 1027-1063.

- Kaniel, R. and Liu, H., 2001, So what orders do informed traders use? Working Paper, University of Texas, Austin.
- Keim, D. and Madhavan, A., 1995, Anatomy of the trading process: Empirical evidence on the behavior of institutional traders. *Journal of Financial Economics*, 37, 371-398.
- Levhari, D. and Levy, H., 1977, The capital asset pricing model and the investment horizon. *Review of Economics and Statistics*, 59, 92-104.
- Madhavan, A., 1992, Trading mechanisms in securities markets. *Journal of Finance* 47, 607-642.
- McInish, T. and Wood, R., 1992, An analysis of intraday patterns in bid/ask spreads for NYSE stocks. *Journal of Finance* 47, 753-763
- Mendelson, H. and Tunca, T., 2004, Strategic trading, liquidity, and information acquisition. *Review of Financial Studies*, 17, 295-338.
- Page, E., 1965, Ordered hypotheses for multiple treatments: A significance test for linear ranks. *Journal of the American Statistical Association* 58, 216-230.
- Parlour, C., 1998, Price dynamics in limit order markets. *Review of Financial Studies* 11, 789-816.
- Ranaldo, A., 2004, Order aggressiveness in limit order book markets. *Journal of Financial Markets* 7, 53-74.
- Rock, K., 1996, The specialist's order book and price anomalies. *Review of Financial Studies*, forthcoming.
- Spiegel, M. and Subrahmanyam, A., 1992, Informed speculation and hedging in a noncompetitive securities market. *Review of Financial Studies*, 5, 307-329.
- Seppi, D., 1997, Liquidity provision with limit orders and a strategic specialist. *Review of Financial Studies* 10, 103-150.
- Wood, R. and McInish, T. H., 1984, Bias from nonsynchronous trading. *Review of Economics and Statistics*, 67, 346-351.

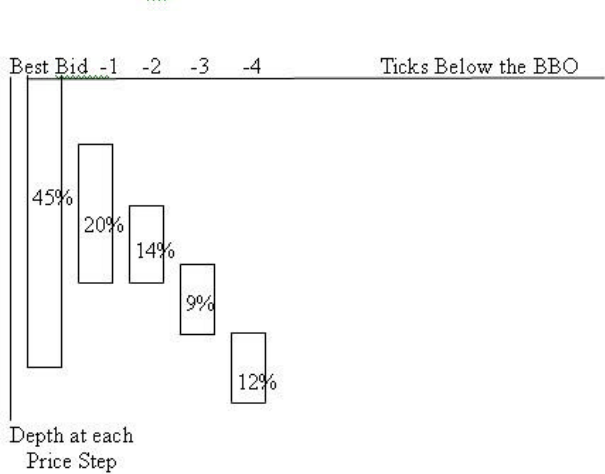
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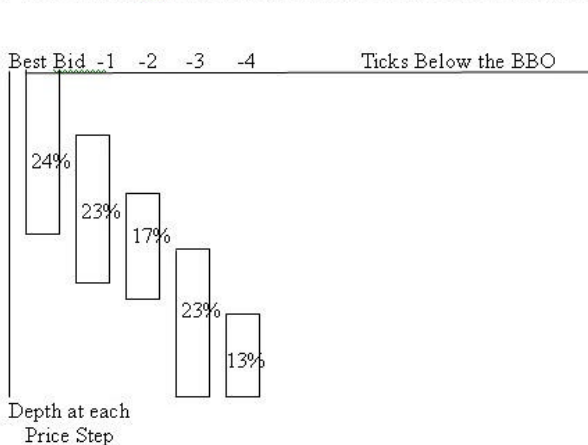
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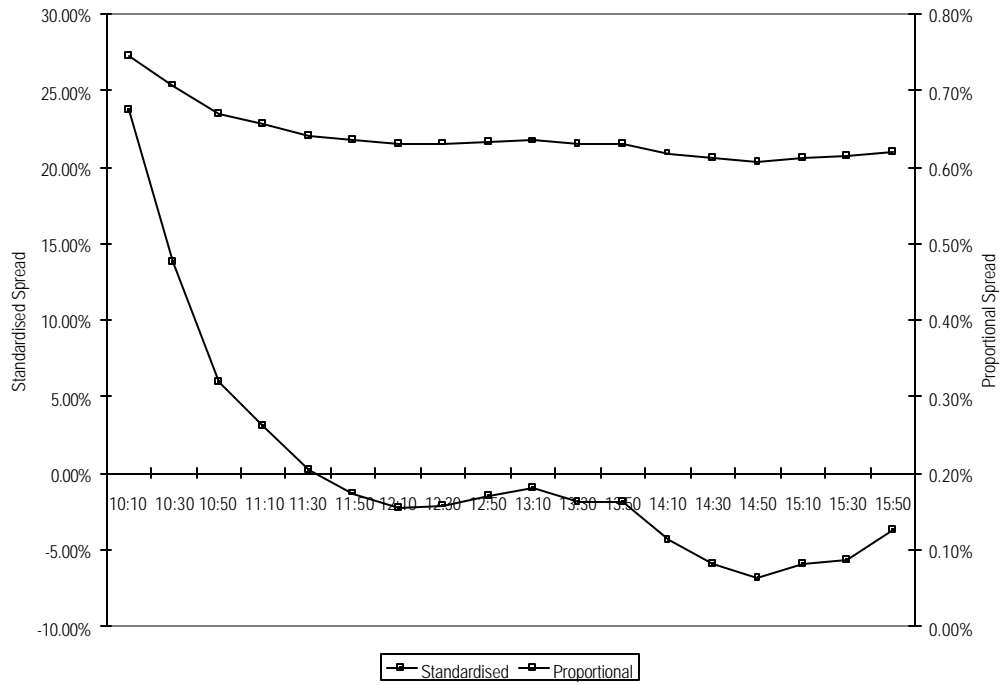
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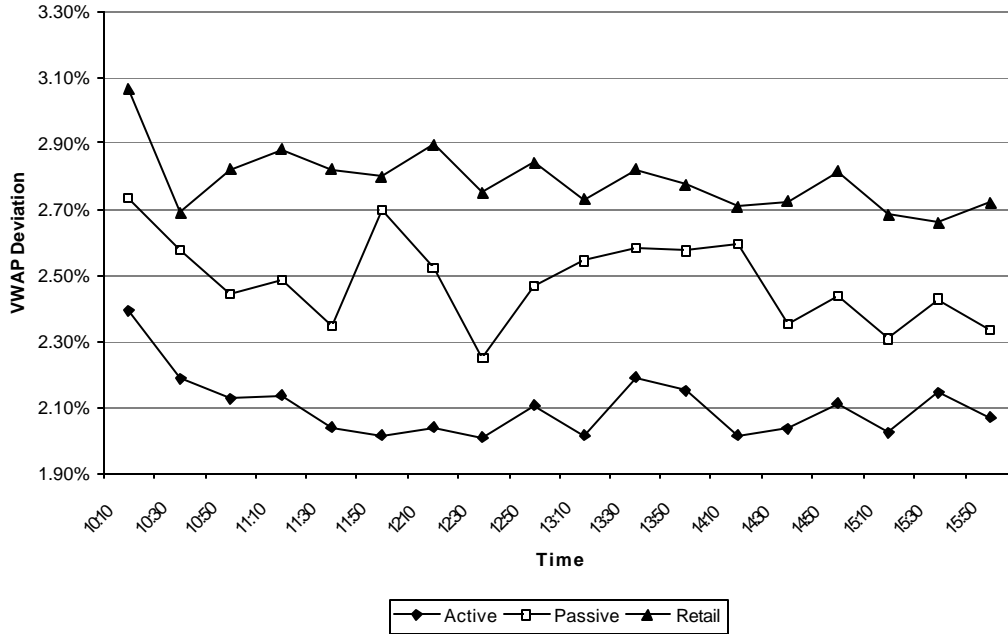
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**Figure 1. Profile of institutional limit orders outstanding.** These histograms display the order flow volume at each price step of the limit order book for a passive (active) institutional client as a percentage of the total order flow volume by that client on any one snapshot of the limit order book, averaged over all 18 times of the day, all 35 securities, and all institutional clients.



**Figure 2. Intraday proportional and standardised spreads.** Average standardised and proportional spread by time of day.



**Figure 3. VWAP percentage deviation by investor type.** We display the average percentage deviation of the VWAP of orders in the limit order book relative to the market best bid-offer for active institutional, passive institutional, and retail investors.

**Table 1. Summary of Cross-sectional Hypothesis on Order Aggressiveness.** The first column lists the investor types involved in our study. The next two columns list, for each investor type, the relative cost of non-execution and the relative perceived picking off risk emergent from our interviews with senior traders as a maintained hypothesis for that investor type. The last column displays the implication for the relative order aggressiveness by investor type.

	<b>Perceived Cost of Non-Execution</b>	<b>Perceived Picking Off Risk</b>	<b>Implication for Order Aggressiveness</b>
Retail Investor	Lower	High	Farthest Away from BBO (Least Aggressive)
Passive Institutional Investor	Higher	Low	Moderately Aggressive Order Placement
Active Institutional Investor	Highest	Low	Closest to BBO (Most Aggressive)

**Table 2. AMP limit order book** We present the limit order book for AMP with additional proprietary details obtained from the executing broker for four institutional clients: ACTIVE1, ACTIVE2, PASSIVE1, and PASSIVE2. The bid side is shown in columns 1-3. Column 1 shows the client identification code for any buy orders placed in the limit order book by the executing broker for these four clients. Column 2 gives the volume available at the price step shown in column 3. Size for each of the four clients is indicated on a separate line. For each price, the line without a client ID indicates the additional size at that price. Comparable information for the ask side is presented in columns 4-6.

Bid Side			Ask Side		
Client ID	Volume	Price	Price	Volume	Client ID
			578	50,000	PASSIVE2
			577	22,000	
			575	31,000	
			574	96,51	
			573	42,703	PASSIVE2
			573	33,100	
			572	64,279	
			571	30,931	PASSIVE2
			571	56,788	
			570	189,581	
			569	800	
			569	1,000	ACTIVE 2
			569	47,000	
			568	22,515	
			568	10,000	ACTIVE2
			568	33,238	
	15,934	567			
ACTIVE1	83,614	567			
	4,500	567			
	40,572	566			
PASSIVE1	94,169	566			
	1,000	566			
	37,646	565			
	6,600	564			
	26,000	563			
	8,680	562			
	9,000	561			
	59,742	560			
	3,000	559			
	11,040	558			

**Table 3. Simultaneous occurrence of institutional orders at multiple prices.** We capture the limit order book every twenty minutes for five days for 35 securities. For each institutional client with one or more orders outstanding in the limit order book at a given time, we sort based on whether that client's orders are at one price, two prices, three prices, and so forth. We consider the bid and ask side of the market separately.

Number of Prices in Order Submission Strategy	Bid-side		Ask-side	
	Number of Clients	%	Number of Clients	%
1	486	51.6	493	51.9
2	185	19.7	225	23.7
3	80	8.5	89	0.4
4	60	6.4	67	7.1
5	130	13.8	75	7.9
Total	941	100%	949	100%

**Table 4. Descriptive statistics for sample.** For each firm in our sample, we present the average daily volume and average daily number of trades over our sample period, the market capitalization in AUD as of 30/6/2002, and the industry.

<b>Symbol</b>	<b>Volume</b>	<b>Number of Trades</b>	<b>Market Cap</b>	<b>Industry</b>
ALL	937,580	206	\$2,352,250,991	Hotels Restaurants & Leisure
AMC	1,745,671	378	\$7,239,374,270	Materials
AMP	1,826,190	887	\$15,904,321,926	Insurance
ANZ	3,189,261	919	\$28,471,851,903	Banks
AXA	1,238,841	182	\$4,564,703,778	Insurance
BHP	8,319,169	1,702	\$34,429,978,064	Materials
BIL	2,383,074	681	\$6,729,202,189	Commercial Services & Supplies
BPC	1,943,174	103	\$513,775,574	Food Beverage & Tobacco
CCL	1,542,702	254	\$4,468,494,449	Food Beverage & Tobacco
CML	2,353,500	698	\$7,000,867,103	Food & Staples Retailing
CSL	264,869	320	\$3,603,226,956	Pharmaceuticals & Biotechnology
CSR	2,239,586	336	\$6,160,042,762	Materials
FGL	3,663,749	489	\$10,134,642,533	Food Beverage & Tobacco
GAN	1,460,056	59	\$1,669,709,782	Real Estate
IOF	1,063,097	69	\$937,786,495	Real Estate
IPG	724,027	45	\$1,464,344,031	Real Estate
JHX	539,308	98	\$3,081,485,329	Materials
LLC	1,154,443	648	\$4,718,976,285	Real Estate
MAY	2,961,846	699	\$3,004,306,090	Health Care Equipment & Services
NAB	2,940,740	1,265	\$54,056,008,486	Banks
NCP	4,777,945	1,303	\$20,148,311,117	Media
NCPDP	2,830,865	502	\$26,153,515,339	Media
ORI	829,575	315	\$2,631,800,208	Materials
OSH	3,421,414	240	\$914,280,416	Energy
OST	1,162,799	211	\$878,108,131	Materials
PPX	672,944	238	\$1,831,849,181	Materials
QAN	5,758,646	765	\$6,521,291,017	Transportation
RIO	1,191,498	547	\$16,695,376,474	Materials
SRP	1,545,816	349	\$4,169,582,560	Food Beverage & Tobacco
SSX	811,155	110	\$1,045,061,502	Materials
WBC	3,294,435	778	\$26,639,643,318	Banks
WFT	3,017,098	147	\$6,583,184,735	Real Estate
WMC	3,468,225	722	\$8,509,933,769	Materials
WOW	2,278,379	632	\$12,534,232,063	Food & Staples Retailing
WPL	1,723,316	478	\$8,686,666,671	Energy

**Table 5. Sample observations by security and time of day.** For each security in our sample, we examine the limit order book on each side of the market at 20-minute intervals (18 times per day) for the period 1 January 2001 to 30 June 2002. For the first security, for the first day, for the time of day 10:10, we first ascertain whether there exists at least one outstanding limit order to buy from each investor type – active institutions, passive institutions, and retail clients. If so, we record a snapshot of all five steps of that bid side of the limit order book. We then repeat this snapshot collection process for the other side of the book, for each time of day, and for each security. Column 2 displays the number of snapshots for selected securities and column 4 displays the number of snapshots by time of day.

<b>Selected Securities</b>	<b>Snapshots of the limit order book</b>	<b>Times of days</b>	<b>Snapshots of the limit order book</b>
ALL	168	10:10	497
AMC	749	10:30	665
AMP	664	10:50	596
AXA	868	11:10	713
BHP	489	11:30	742
BIL	792	11:50	741
BPC	1,804	12:10	740
CCL	251	12:30	742
GAN	670	12:50	677
IOF	598	13:10	721
LLC	228	13:30	609
OST	1,182	13:50	674
PPX	689	14:10	724
RIO	416	14:30	750
SRP	348	14:50	586
SSX	358	15:10	614
WBC	364	15:30	642
WFT	258	15:50	631
All 35 Securities	12,064		12,064

**Table 6: The price of immediacy.** We calculate the average absolute price of immediacy (in price steps) for each investor class relative to the market best bid and offer across the trading day. For a given security for a given snapshot, let  $B_j$  be the number of price steps from the market best bid to the best bid price by this investor class in price ticks. If the best bid price for this investor class equals the best market bid,  $B_j = 0$ . Otherwise,  $B_j = 1, 2, 3$ , and so forth. Next, we repeat the procedure for the same time on each day in our sample and then calculate the mean for this sample. We then repeat for each stock and average across stocks. The entire procedure is repeated for each investor class, for each snapshot, and for the ask side of the market.

We also calculate a volume-weighted price of immediacy in the same way except that we use each price at which an investor class has an order in the limit order book, weighted by the proportion of shares at each price that the investor class has standing in the limit order book.

Panel A presents the results for institutional (*I*) and retail (*R*) investors. Panel B presents the results for active institutional (*II*) and passive institutional (*I2*) investors.

**Panel A: Institutional and Retail Investors**

Time	Volume-Weighted Price of Immediacy				Absolute Price of Immediacy			
	<i>I</i> Bid	<i>R</i> Bid	<i>I</i> Ask	<i>R</i> Ask	<i>I</i> Bid	<i>R</i> Bid	<i>I</i> Ask	<i>R</i> Ask
10:10	3.02	3.22	3.03	3.53	0.41	0.49	0.33	0.36
10:30	2.82	3.21	2.86	3.52	0.34	0.42	0.33	0.37
10:50	2.77	3.18	2.80	3.50	0.32	0.41	0.33	0.36
11:10	2.75	3.16	2.78	3.49	0.32	0.40	0.32	0.36
11:30	2.72	3.15	2.74	3.49	0.31	0.40	0.31	0.36
11:50	2.70	3.14	2.72	3.48	0.30	0.39	0.31	0.36
12:10	2.69	3.13	2.71	3.48	0.31	0.38	0.31	0.36
12:30	2.66	3.12	2.70	3.47	0.30	0.39	0.31	0.35
12:50	2.65	3.12	2.68	3.47	0.30	0.39	0.30	0.34
13:10	2.65	3.11	2.69	3.46	0.31	0.39	0.30	0.34
13:30	2.65	3.10	2.68	3.45	0.31	0.39	0.29	0.33
13:50	2.65	3.09	2.68	3.45	0.30	0.39	0.29	0.33
14:10	2.62	3.09	2.65	3.45	0.29	0.37	0.30	0.34
14:30	2.61	3.09	2.65	3.46	0.28	0.37	0.31	0.36
14:50	2.59	3.09	2.65	3.47	0.28	0.37	0.32	0.36
15:10	2.60	3.10	2.65	3.47	0.28	0.37	0.32	0.37
15:30	2.61	3.11	2.65	3.48	0.29	0.38	0.33	0.38
15:50	2.61	3.13	2.67	3.50	0.30	0.39	0.35	0.40

**Table 6 (Continued)****Panel B: Active (I1) and Passive (I2) Institutional Investors**

Time	Volume-Weighted Price of Immediacy				Absolute Price of Immediacy			
	<i>I1</i> Bid	<i>I2</i> Bid	<i>I1</i> Ask	<i>I2</i> Ask	<i>I1</i> Bid	<i>I2</i> Bid	<i>I1</i> Ask	<i>I2</i> Ask
10:10	1.05	1.67	1.03	1.65	0.85	0.89	0.43	1.43
10:30	0.77	1.40	0.82	1.44	0.55	0.71	0.32	1.23
10:50	0.85	1.31	0.86	1.38	0.60	0.75	0.32	1.16
11:10	0.84	1.30	0.82	1.31	0.54	0.72	0.26	1.09
11:30	0.87	1.28	0.84	1.30	0.48	0.73	0.28	1.09
11:50	0.83	1.27	0.79	1.28	0.41	0.69	0.26	1.08
12:10	0.87	1.26	0.81	1.26	0.40	0.72	0.25	1.05
12:30	0.79	1.23	0.81	1.27	0.38	0.72	0.27	1.05
12:50	0.83	1.25	0.83	1.29	0.52	0.73	0.27	1.07
13:10	0.81	1.27	0.86	1.30	0.53	0.76	0.28	1.09
13:30	0.87	1.29	0.86	1.32	0.57	0.76	0.28	1.10
13:50	0.84	1.31	0.86	1.33	0.54	0.76	0.29	1.11
14:10	0.77	1.26	0.80	1.26	0.42	0.70	0.28	1.05
14:30	0.81	1.28	0.81	1.28	0.38	0.71	0.29	1.07
14:50	0.83	1.27	0.82	1.27	0.52	0.72	0.27	1.05
15:10	0.76	1.25	0.79	1.27	0.41	0.69	0.26	1.06
15:30	0.80	1.25	0.80	1.27	0.55	0.70	0.23	1.06
15:50	0.81	1.29	0.80	1.29	0.53	0.70	0.27	1.08

**Table 7. Page's (1963)  $L$ -statistic of order aggressiveness.** Page's  $L$ -statistic is used to accept/reject the null hypothesis of equal order aggressiveness across active institutional, passive institutional, and retail investors vis-à-vis its ordered alternate ( $P_{Active} > P_{Passive} > P_{Retail}$  for buy orders and  $P_{Active} < P_{Passive} < P_{Retail}$  for sell orders). The  $L$ -statistic for three ordered variables is computed as follows:

$$L = \sum_{j=1}^3 \left( Y_j \sum_{i=1}^m X_{ij} \right)$$

where  $m$  is the number of observations at each time period,  $X_{ij}$  the observed rank of the  $i$ 'th observation of order flow category  $j$  and  $Y_j$  the hypothesized rank of category  $j$ . The critical value for  $L$  at the 10% level of significance is computed as follows:

$$L_{10\%} = 2m \left[ \frac{1.645}{\sqrt{2m}} + 6 \right]$$

For each of the 18 timestamps, column 2 presents the number of stocks for which the null hypothesis is rejected at the 10% level of significance (before the “/”) and the total number of stocks in that timestamp (after the “/”). Column 3 reports the same test against a second alternative hypothesis that ordered the passive institutional orders as most aggressive, the active institutional orders as less aggressive, and the retail orders as least aggressive.

Time of day	Cases where $L$ -statistic rejects null /total cases	
	Alternative Hypothesis I: $P_{Active} > P_{Passive} > P_{Retail}$ for buy orders and $P_{Active} < P_{Passive} < P_{Retail}$ for sell orders	Alternative Hypothesis II: $P_{Passive} > P_{Active} > P_{Retail}$ for buy orders and $P_{Passive} < P_{Active} < P_{Retail}$ for sell orders
10:10	11/14	0/14
10:30	12/20	5/20
10:50	12/16	2/16
11:10	16/21	3/21
11:30	14/22	4/22
11:50	16/22	3/22
12:10	15/20	1/20
12:30	13/19	2/19
12:50	12/18	2/18
13:10	14/20	1/20
13:30	12/16	2/16
13:50	14/18	2/18
14:10	14/19	3/19
14:30	14/20	1/20
14:50	13/15	2/15
15:10	12/16	1/16
15:30	11/17	4/17
15:50	12/17	2/17

**Table 8 Intraday variation in order aggressiveness.** For each security, we test for intraday variation in the order aggressiveness rankings using a Kruskal-Wallis test across the eighteen times of day. Column 2 presents the calculated value of the Kruskal-Wallis statistic and column 3 gives the corresponding p-value.

<b>Stock</b>	<b>Kruskal-Wallis Statistic</b>	<b>p-Value</b>
ALL	0.94	0.63
AMC	0.35	0.84
AMP	1.27	0.53
ANZ	2.37	0.30
AXA	0.34	0.85
BHP	0.73	0.69
BIL	1.06	0.59
BPC	0.62	0.73
CCL	0.43	0.81
CML	0.96	0.62
CSL	1.19	0.55
CSR	2.09	0.35
FGL	1.23	0.54
GAN	1.13	0.57
IOF	0.42	0.81
IPG	0.44	0.80
JHX	0.69	0.71
LLC	0.58	0.75
MAY	0.49	0.78
NAB	1.81	0.41
NCP	0.38	0.83
NCPDP	0.56	0.76
ORI	1.39	0.50
OSH	0.55	0.76
OST	0.42	0.81
PPX	0.85	0.65
QAN	0.43	0.81
RIO	2.81	0.25
SRP	0.66	0.72
SSX	0.61	0.74
WBC	1.18	0.55
WFT	1.23	0.54
WMC	0.88	0.64
WOW	1.13	0.57
WPL	0.84	0.66

**Table 9 Intraday ranking of order aggressiveness.** We rank the percentage deviation of the VWAP of orders submitted by each investor class across the trading day, such that the time of day with the lowest (highest) percentage deviation from the market best bid-offer receives a rank of 1(18). That is, the more aggressive the order, the higher the score within an investor class. Column 2 presents the average rank for each time of day for active institutional investors. Columns 3 and 4 present the corresponding data for passive institutional investors and retail investors, respectively.

<b>Time</b>	<b>Institutional</b>		
	<b>Active</b>	<b>Passive</b>	<b>Retail</b>
10:10	11.08	11.02	12.88
10:30	10.07	9.55	11.00
10:50	10.01	10.00	12.03
11:10	9.85	9.81	11.59
11:30	9.89	9.80	11.69
11:50	10.03	9.99	11.98
12:10	10.25	10.09	11.88
12:30	9.98	9.84	11.96
12:50	10.52	10.33	12.36
13:10	10.17	10.20	11.50
13:30	10.65	10.26	12.33
13:50	10.65	10.01	11.89
14:10	10.03	9.70	11.15
14:30	10.56	10.00	11.27
14:50	10.23	10.32	12.47
15:10	10.08	10.10	11.22
15:30	9.71	9.34	10.45
15:50	9.96	9.47	10.50

Note: Tied ranks are assigned the highest rank so that if three times of day are tied and rank between 2 and 6 each is assigned the rank of 5.