The costs and determinants of order aggressiveness[☆]

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Abstract

This paper examines the costs and determinants of order aggressiveness. Aggressive orders have larger price impacts but smaller opportunity costs than passive orders. Price impacts are amplified by large orders, small firms, and volatile stock prices. To minimize the implementation shortfall, the optimal strategy is to enter buy (sell) orders at the bid (ask). Aggressive buy (sell) orders 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). Aggressive buys are more likely than sells to be motivated by information. © 2000 Elsevier Science S.A. All rights reserved.

1. Introduction

This paper analyzes the costs and determinants of order aggressiveness using order flow data. We address the following research questions: (1) How large are the costs of executed orders as measured by their price impact and how do they relate to the decision variables (order aggressiveness and order size) of the trader as well as to certain exogenous variables such as firm size and stock price variability? (2) To what extent do the opportunity costs of unfilled limit orders offset their favorable price impacts? (3) What are the determinants of order aggressiveness? (4) Are aggressive orders information-motivated?

Our findings contribute to the burgeoning body of literature exploring order flow. Previous papers have documented how limit order orders are the sole, or at least a partial, source of liquidity on major stock markets. Biais et al. (1995) analyze the Paris Bourse, Lehman and Modest (1994) examine the Tokyo Stock Exchange, and Harris and Hasbrouck (1996) examine limit orders placed on the New York Stock Exchange (NYSE). Unlike the NYSE, the Paris Bourse and the Tokyo Stock Exchange have no market makers but rely strictly on the limit-order book to provide liquidity. Our study employs data from the Toronto Stock Exchange (TSE), which uses a centralized electronic order-matching system similar to those of the Paris Bourse and Tokyo Stock Exchange and also, like the NYSE, uses market makers. However, the TSE market makers have less ability to disrupt and take precedence over the public limit orders than do specialists on NYSE. Thus, analysis of order flow on the TSE is of interest as it has features of both the idealized open limit-order book discussed in Glosten (1994) and the hybrid/specialist limit-order market modeled in Seppi (1997). Compared to the developed stock markets around the globe, the TSE ranks fourth in terms of market capitalization, eighth based on traded volume, and has the sixth highest number of listed securities.

Our paper extends previous work on limit versus market orders, but more precisely classifies orders in terms of aggressiveness using the classification scheme of Biais et al. (1995) which relates order price and size to the prevailing price and depth of bid and ask quotes. This method of determining order aggressiveness distinguishes this paper from other studies of order costs such as Bessembinder and Kaufman (1997), Chan and Lakonishok (1995), Keim and Madhavan (1997), and Harris and Hasbrouck (1996). Using this classification scheme, we show how the two components of an implementation shortfall (Perold, 1988), execution and opportunity costs, differ across orders ranked by aggressiveness. We find that the higher the order's price and quantity are set relative to those available on the limit-order book, the larger is the price impact but the lower the opportunity costs. Conversely, passive orders have negative price impacts but high opportunity costs. These opportunity costs arise because a large percentage of the passive orders go unfilled and there is an adverse-selection problem associated with unfilled orders. In particular, limit orders

offer free options to other traders and are exposed to the possibility that they will be 'picked off' by better-informed traders. Our findings are also consistent with trader's choice models between market and limit orders (Cohen et al., 1981; Holden and Chakravarty, 1995). We conclude that the lowest implementation shortfall occurs with buy (sell) orders at the bid (ask). Wagner and Edwards (1993) define a third order cost – timing cost – as the price change of the security from the time of the initial submission to the trading desk until the time the order is first exposed to the exchange. Because the order flow data available to us include only information after the order is sent to the exchange, we cannot measure this cost.

We argue that factors found in earlier studies affecting order execution costs (e.g., order size) should be examined in the context of order aggressiveness. In support of this argument, we find that the relation between price impact and order size is positive and significant in the most aggressive category of orders. We also find that the price impact of executed orders is most sensitive to firm size and stock price volatility for orders that are extremely aggressive or passive. The significant costs associated with aggressive orders designed to achieve immediate execution are crucial for interpreting findings of market anomalies, as well as the economic significance of event studies. Knez and Ready (1996) demonstrate that the cost of executing orders would make exploitation of the weekly small-firm effect uneconomical. Similarly, studies of events (e.g., ex-dividend days) need to be reexamined with consideration given to large order execution costs.

Because order flow underlies changes in quote and trade prices, our analysis of the determinants of order aggressiveness has implications for a number of other areas of research. For example, models of bid–ask spreads such as Glosten and Harris (1988) and Huang and Stoll (1997) assume that the fundamental value of a stock is affected by whether the most recent trade is buyer- or seller-initiated, i.e., consummated by an aggressive (information-motivated) buy or sell order. Another example is the model of intraday volatility of Madhavan et al. (1997) which assumes that there is autocorrelation in order flow as large traders who are either information- or liquidity-motivated break up orders. Our analysis of order flow extends Hausman et al. (1992) who estimate the conditional distribution of trade-to-trade price changes using an ordered probit analysis and Biais et al. (1995) who examine the autocorrelation of order types. We find that aggressive buy (sell) orders tend to follow other aggressive buy (sell) orders. Aggressive orders are also more likely with small-firm stocks and when the limit-order book has a wide bid–ask spread and high (low) depth on the opposite (same) side as the order. We also find evidence that aggressive buys are more likely to be motivated by information than aggressive sells.

As this paper examines how factors within the trader's control (order aggressiveness and size) relate to the implementation shortfall of buying and selling shares, the findings are of interest to traders placing orders as well as to sponsors

(in the case of institutional traders). Further, an understanding of which factors lead to different types of orders and the extent to which those who enter aggressive orders are informed can help traders both predict and interpret the behavior of other market participants.

Section 2 of the paper describes the salient aspects of order execution on the TSE. The third, fourth, and fifth sections describe the research methods, results, and conclusions, respectively.

2. Order execution on The Toronto Stock Exchange

All orders sent to the TSE originate from one of three sources: public investors who must have orders handled by a TSE member firm or another client's order, member firms who place orders on their own accounts, or a designated market maker who directly submits orders. In handling a public limit order, a TSE member firm is allowed up to 15 minutes to fill the order in the upstairs market. An order filled in this market by being matched with the member firm's or client's order is referred to as a 'cross'. Consistent with the role of the upstairs market in searching for counterparties for institutional orders, crosses constitute the largest trades on the TSE and nearly half of all dollar volume. If an order cannot be filled upstairs, it must be sent to the downstairs market.

The downstairs market operates through the electronic order book of the TSE. Orders entered into the electronic order book follow strict price priority rules, and at a given price may establish priority up to a certain volume if the orders set the market price (i.e., first order at a new price or last remaining order at the market). Once all priority volume at a given price has been satisfied, any remaining order volume is allocated to existing booked orders on an equal basis across TSE member firms. As discussed in Panchapagesan (1998), a portion of an order can be 'hidden' or undisclosed in the electronic order book but it cannot be filled until disclosed. To be disclosed, any unfilled portion of the entire order must be canceled and a new order submitted. Thus, time priority is lost on both portions of the order. A search of the database could not detect any such orders during June 1997. Orders with special terms such as 'fill-or-kill' also lose time priority; such orders represent less than 0.2% of all orders and are excluded from the analysis. The TSE requires that crosses from the upstairs market follow the price priority rules but not the time priority or sharing rules applicable to downstairs trades. In particular, the price of a cross must be at or within the current market best bid and ask prices but the member does not have to fill equally priced limit orders in the book.

On the TSE, a designated market maker is responsible for maintaining the limit-order book and is charged with making an orderly market for certain securities. In this regard, the designated market maker has a role similar to that

of the specialist on the NYSE. On the TSE, however, the designated market maker's main focus is on providing liquidity for small orders; he rarely participates in large orders. Market orders and immediately executable limit orders at or below a security's minimum guaranteed fill (MGF) that cannot be filled from the limit-order book are filled automatically against the designated market maker's inventory at the market quote. Further, the designated market maker cannot halt trading at his own discretion and has only limited ability to take precedence over other traders. In particular, the designated market maker can choose to 'auto-participate' in up to 50% of trades even when immediately executable limit orders exist. Given the limited role of the designated market maker, the TSE operates more like a pure limit-order market (e.g., the Paris Bourse) than like the NYSE.

We use a new TSE database comprising all transactions for June 1997. In particular, the data indicate for each order sent to the downstairs market its direction, price, size, and time of submission to the nearest second, as well as details on related fills, changes, and cancellations. Previous studies had access only to best available quote depth and prices and the size and price of trades. Each order has a unique identifier which permits tracking the disposition across subsequent transactions.

However, as Harris and Hasbrouck (1996) note, because the database does not provide us with any knowledge of the trader's overall objectives and strategies or with his complete information set, we must be guarded in our conclusions. For example, while our study finds that aggressive buy orders carry a large immediate cost, we cannot conclude that the placement of such orders by a particular trader is uneconomic without knowing whether that trader possessed an information advantage and how long the trader intends to hold the shares. In addition, as we do not know whether the order is part of a buying (selling) program, we cannot measure the cost of acquiring (disposing) of securities through multiple orders.

This study examines only orders for shares priced greater than or equal to $5 since these stocks have a constant tick size of $0.05. A varying tick size can bias the measured price effects. While analysis of a longer time period would be preferred, the month of June 1997 was not unusual compared to the other months of 1997 in terms of daily volume of shares traded, returns, or volatility.

We also examine the data for keying errors. Orders that are either accompanied by negative bid and ask spreads or are changed (CFO'd) within one minute of entry and have no fills are eliminated. We also eliminate opening transactions because the TSE opens as a call-auction market which differs from the trading mechanism employed throughout the rest of the day. We also exclude all orders placed prior to the opening and after the close, since it is impossible to ascertain the price impacts of these transactions. Because the database does not contain detailed order-flow information on upstairs trades, we analyze execution costs only for orders handled in the downstairs market.

Consistent with Biais et al. (1995), we divide the orders into six different categories ranked by the level of aggressiveness. Category 1 buy (sell) orders are the most aggressive in that order price is greater (less) than the ask (bid) price and the size of the order exceeds the depth at the ask (bid). Category 2 and 3 buy (sell) orders have order prices equal to the ask (bid) price. However, the size of category 2 orders exceeds the depth at the best quote on the opposite side of the book whereas category 3 orders do not. Category 3 orders should be immediately executed in full and category 2 orders should be immediately executed in part, with the unfilled portion entered as a limit order. Category 1 buy (sell) orders are executed against the volume at the ask (bid) and in part against the depth available higher (lower) in the book up to the order price. The unfilled portion of the order will remain as a limit order.

Category 4 orders have prices that lie between the bid and ask. Category 5 buy (sell) orders have prices that are equal to the bid (ask). The category 6 buy (sell) orders are the most passive in that their prices are less (greater) than the bid (ask). Category 4–6 orders are not immediately executed and are entered entirely into the limit-order book.

From Panel A of Table 1, the most frequent type of buy order is category 3. These orders constitute 41.36% of a total of 267,789 buy orders. The two most aggressive types of orders (categories 1 and 2) constitute only 0.73% and 7.73% of all buy orders, respectively. However, as a percentage of total number of shares, category 2 orders constitute as much of the total volume as do category 3 orders. This results from the average size of the category 2 orders being almost six times that of category 3.

Category 4 and 5 orders represent 14.08% and 25.03% of all buy orders, respectively. The smaller proportion in category 4 than category 5 results from some of the most liquid securities having bid–ask spreads equal to the tick size, i.e., there is no opportunity to better the market. The most passive buy orders (category 6) constitute 10.57% of all orders. The results for the sell orders (Panel B) mirror those of the buy orders.

The fourth column of Table 1 shows the fill rate, or the percentage of the orders filled. As expected, category 3 orders have nearly a 100% fill rate and are filled almost immediately (in an average of 4–8 seconds). The average fill rate for the other categories of orders declines as order aggressiveness decreases. The average fill rate of category 1 buy (sell) orders is 86.76% (92.77%). The fill rate declines more in categories 4 and 5 to approximately two-thirds and 60%, respectively. Thus, even when the buy (sell) order matches the best bid (ask), only about 60% of the order is filled. Finally, in category 6, the fill rate is only 23.09% (20.84%) for buy (sell) orders, indicating that traders face a substantial non-execution risk.

The fifth column of Table 1 suggests that partially executed orders form a nontrivial component of executed orders for all but category 3 orders. Category 2 orders have the highest proportion of partially executed orders since,

by definition, they can be only be partly filled immediately by the available depth at the market quote. The two most aggressive order categories also have the largest number of filling trades. For category 1 buy (sell) orders, the average number of filling trades is 3.21 (3.23). In contrast, for categories 3–6 buy (sell) orders, the average number of filling trades varies from 1.39 to 1.56 (1.47 to 1.81).

Excluding categories 3 and 5, the average time to disposition increases as order aggressiveness decreases. Category 1 buy (sell) orders are displayed for an average of 9.54 (8.82) minutes before they are canceled or filled, versus 88.61 (82.84) minutes for category 6 buy (sell) orders. Category 5 orders are displayed on average for a shorter time than category 4 orders. This is likely a consequence of the most liquid securities on the TSE having a bid–ask spread equal to a single tick.

3. Research methods

Huang and Stoll (1996), Lee (1993), and Bessembinder and Kaufman (1997), among others, refer to the comparison of the average trade price to the midpoint of the bid and ask prices as the effective bid–ask spread. These authors use the term price impact to refer exclusively to the information content of a trade. We measure the price impact of an order as the percentage increase from the pre-trade midquote to the average realized price, as in Chan and Lakonishok (1997). The pre-trade midquote is the mean of the best bid and ask prices immediately prior to the order. The average realized price is the weighted average of the prices of the shares filling the order. Since each order can be tracked to its ultimate disposition, orders with multiple fills are reconstructed.

Keim and Madhavan (1998) classify the factors that influence the price impact of an order into trader decision and exogenous variables. In our paper, the decision variables are order direction, order aggressiveness, and order size; the exogenous variables are stock price volatility and firm size. Based on these explanatory variables, we conduct the following cross-sectional regression:

$$O_{i,j} = \sum_{k=1}^{6} (C_k T_{(i,j,k)} + C_{(k+6)} T_{(i,j,k)} \, Buydummy_{i,j}$$

$$+ C_{(k+12)} T_{(i,j,k)} \, OrderSize_{i,j} + C_{(k+18)} T_{(i,j,k)} \, PriceVol_{i,j}$$

$$+ C_{(k+24)} T_{(i,j,k)} \, FirmSize_{i,j}) + e_{i,j}, \tag{1}$$

where

$O_{i,j}$ $= \ln(B_{i,j}/E_{i,j})$,

$B_{i,j}$ = the volume-weighted average of the fill price for stock i for order j,

$E_{i,j}$ = the mean of the best bid–ask prices immediately prior to the order entering the book,

Table 1
Descriptive statistics on order classifications

This table presents general descriptive statistics for all orders for stocks priced at more than $5 on the Toronto Stock Exchange during June 1997. The first column describes six different classifications of orders that are handled in the downstairs market and are ranked according to the degree of aggressiveness as defined in Biais et al. (1995). The second number in each cell represents the percentage of the total for the column. The fill rate equals the average number of shares traded as a percentage of total shares in an order. The figures in the fifth through seventh columns describe the disposition of only executed orders.

Order classification (ranked from most (1) to least (6) aggressive)	Number of orders (% of total)	Average number of shares in order (% of total)	Average fill rate of all orders (%)	Percentage of executed orders that are only partially executed (%)	Average number of filling trades of executed orders	Average time to disposition of executed orders (min)
Panel A: Buy orders						
(1) Order price > ask Order size > depth at ask	1963 (0.73)	4375 (1.72)	86.76	13.61	3.21	9.54
(2) Order price = ask Order size > depth at ask	20,705 (7.73)	5707 (23.39)	85.73	28.86	2.64	25.04
(3) Order price = ask Order size ⩽ depth at ask	110,765 (41.36)	1082 (23.74)	99.85	0.06	1.56	0.07
(4) Bid < order price < ask	37,713 (14.08)	2213 (16.52)	65.85	19.05	1.54	40.07
(5) Order price = bid	67,035 (25.03)	1934 (25.67)	61.66	10.63	1.39	29.06
(6) Order price < bid	29,608 (11.06)	1531 (8.98)	23.09	17.47	1.50	88.61
Totals	267,789 (100.00)	505.0 million (100.00)	n.a.	n.a.	n.a.	n.a.

Panel B: Sell orders

(1) Order price < bid Order size > depth at bid	2216 (0.89)	3835 (1.69)	92.77	10.27	3.23	8.82
(2) Order price = bid Order size > depth at bid	22,194 (9.00)	5746 (25.34)	85.64	27.96	2.90	25.26
(3) Order price = bid Order size ⩽ depth at bid	84,875 (34.38)	1240 (20.90)	99.83	0.09	1.59	0.14
(4) Bid < order price < ask	34,409 (13.93)	2495 (17.04)	68.27	22.68	1.81	41.39
(5) Order price = ask	70,736 (28.65)	1752 (24.62)	61.95	10.45	1.47	25.17
(6) Order price > ask	32,512 (13.16)	1616 (10.44)	20.84	19.45	1.71	82.84
Totals	246,942 (100.00)	503.5 million (100.00)	n.a.	n.a.	n.a.	n.a.

$T_{i,j,k}$ = a dummy variable equal to one if order aggressiveness is type k and zero otherwise (ranges from $k = 1$, most aggressive, to $k = 6$, most passive type of order),

$Buydummy_{i,j}$ = a dummy variable equal to one for a buy order and zero for a sell order,

$OrderSize_{i,j}$ = the order size divided by the average daily volume of shares in the period of March–May 1997, inclusive,

$PriceVol_{i,j}$ = the standard deviation of the daily return of the stock in the period of March–May 1997, inclusive, and

$FirmSize_{i,j}$ = the market capitalization of the firm as at the end of the last trading day of May 1997.

It should be noted that rational traders are likely to condition their trades on an understanding or anticipation of the price impact, which is used as a dependent variable. For example, traders are expected to reduce their order size during periods when the price impacts are expected to be large for such orders. Thus, our findings are conditional.[1]

We assume that the more aggressive is the order, the more information is conveyed. Bodurtha and Quinn (1990) find that market orders have larger price impacts than limit orders. Thus, the coefficients C_1–C_6 are expected to be decreasing in value. The buy/sell indicator variables are used to identify asymmetry in the magnitude of the price impact. We include explanatory variables that are multiplied by order aggressiveness dummy variables because the sensitivity of the price impact to order size, price volatility, and firm size is expected to differ across orders of varying aggressiveness. Category 1 buy orders whose price and quantity exceed the ask price and depth at the ask, respectively, are expected to show a more sensitive price–volume relation. The fifth and sixth order categories that result in fully booked limit orders do not seek priority over all other orders in the limit book and thus it is not expected that these orders possess any private information. Therefore, C_{13} is expected to have the highest value and C_{17} and C_{18} are expected to be insignificant.

Another explanatory variable is the stock price variability. Greater stock price volatility makes traders less willing to supply liquidity since greater losses can arise in holding and adjusting inventory positions. Wagner and Edwards (1993) document the extreme variation in investor return when liquidating security holdings under different market conditions for the supply and demand of liquidity. To compensate for these risks, liquidity suppliers are expected to experience favorable price impacts. Thus, for passive buy (sell) orders, C_{22}–C_{24} are expected to be negative (positive). On the other hand, for aggressive buy (sell) orders that demand immediacy of execution, C_{19}–C_{21} are expected to be positive (negative).

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[1] We thank an anonymous reviewer for this insight.

Bessembinder and Kaufman (1997), Keim and Madhavan (1997), and Chan and Lakonishok (1995) show that the highest execution costs are concentrated among the stocks of the smaller, more illiquid firms. Further, smaller firms tend to have a smaller analyst following and there is greater opportunity for information asymmetry between insiders and outside investors. Under these conditions, $C_{25}-C_{30}$ are expected to be of the opposite sign to C_1-C_6, respectively, as the small firm size will magnify any impacts associated with order aggressiveness.

We compute opportunity costs associated with unexecuted limit orders. As noted in Harris and Hasbrouck (1996), the selection of method to measure opportunity costs of unexecuted orders depends on knowledge of the traders' motives. Harris and Hasbrouck assume that the trader is precommitted to transact in the stock so if the limit order is not executed, a market order is assumed to be entered and filled at the end of the trading day at the best available quote. This assumes that order size is within the depth at the best available quote so the impact would be greater for larger orders. We refine this method to account for large unfilled limit orders that might need to be filled subsequently with a category 1 order. For pre-committed large orders, we compute the opportunity cost as the product of the percentage of the order unfilled and the sum of the change in midquote from immediately before entering the limit order until the time it is canceled plus the execution cost of a category 1 order. The change in midquote is included to incorporate the adverse selection problem in that informed traders will not sell (buy) if they possess positive (negative) private information about the security. For precommitted small orders, we calculate opportunity cost likewise but use the execution cost of a category 3 order.

To assess which type of limit order has the lowest overall costs, we compute implementation shortfall. The implementation shortfall, as defined in Perold (1988), is calculated as the opportunity cost plus the execution cost of the portion of the order filled. The execution cost is estimated by multiplying the percentage of the order filled by the price impact shown on Table 2 (for buy orders) for the appropriate category of limit order.

Following Hausman et al. (1992), who analyze changes in stock prices with trade-to-trade data, we analyze the determinants of order aggressiveness using ordered probit analysis. The technique is appropriate as we have partitioned our sample of orders into six levels of aggressiveness, the ranking of which we expect to have a monotonically increasing or decreasing relationship with each of the explanatory variables. In addition, there are large numbers of observations in each of the categories. The explanatory variables include *FirmSize* (as defined earlier) and the four following variables:

LastAggressive = dummy variable with value one if the previous order is, in whole or part, immediately executable, i.e., categories 1–3, and it has the same direction (buy or sell) as the current order,

RelSpread	= bid–ask spread as a proportion of the bid–ask midquote immediately before the order,
DepthSame	= for buy (sell) orders, the depth at the bid (ask) immediately before the order, and
DepthOpp	= for buy (sell) orders, the depth at the ask (bid) immediately before the order.

To profit from a potentially short-lived information advantage, informed traders are expected to place aggressive orders. As information asymmetries are expected to be greater in small firms, we expect proportionately more opportunities in these firms for informed traders to place aggressive orders. Therefore, firm size should be negatively related to the likelihood of an aggressive order.

As in Biais et al. (1995) and Griffiths et al. (1998), we expect order aggressiveness to exhibit positive autocorrelation. Thus, *LastAggressive* should have a positive relation with order aggressiveness. *RelSpread* should have a negative relation with order aggressiveness because a wide bid–ask spread provides traders with an opportunity to place passive orders that take priority over other limit orders. Order priority rules also encourage the placement of aggressive orders when there are competing orders on the same side of the limit-order book. Conversely, more depth of orders on the opposite side of the limit-order book reduces the need to place aggressive orders.

Finally, we conduct a more direct test of the informativeness of aggressive orders. Over the three-month period following order execution, we measure the excess returns on stocks of executed orders according to the level of aggressiveness. The quarterly excess return is calculated as the percentage increase (decrease) from the weighted-average fill price of the order to the closing midquote as at the last day of trading in September 1997 less the return over the same period in the TSE 300 Index. If aggressive buy (sell) orders are motivated by private information, their quarterly excess returns should be highest (lowest). The use of a three-month holding period allows sufficient time for private information to become public through the release of quarterly financial statements.

Given the large number of observations, one must be careful in interpreting levels of significance. As Zellner (1984) discusses, a large sample size drives the standard error of the estimates toward zero and produces large t-statistics. This is a concern when no theoretical magnitude for the coefficient exists and one judges the significance of a variable only by its t-statistic. Since a considerable risk of type I error exists, we follow Griffiths and White (1993) and conduct a posterior odds ratio test as an alternate method of determining a critical t-value.

4. Results

Table 2 presents the price impact of executed buy orders. The results indicate that the price impact increases monotonically with order aggressiveness. In particular, the fact that the largest price impact occurs with category 1 orders suggests that investors pay a high price to quickly fill a large order. The impact of category 2 orders is not much greater than that of category 3, but the fill rate is only 85% versus nearly 100%. These results support the conclusions of Knez and Ready (1996) who find that price improvement on the NYSE falls off dramatically as the size of a market order approaches the quoted depth.

Further, the magnitude of the price impact for all order categories decreases with the market capitalization of the stock. Table 2 shows the results for buy orders for five portfolios each comprising 93 TSE-listed firms that are ranked by market capitalization. For the quintile of largest stocks (quintile 1 with an average capitalization of $4.85 billion), the price impacts range from 0.31% for category 1 to -0.54% for category 6. For the smallest stocks (quintile 5 with an average capitalization of $59.8 million), the price impacts of buy orders range from 1.43% for category 1 to -2.52% for category 6. All t-statistics and all but one of the posterior odds ratios of these means indicate significance at the 1% level. The results for category 1 orders are similar to those in Keim and Madhavan (1997) for a set of institutional orders, the great majority of which are market orders executed on the NYSE. They find that for buyer-initiated trades, price impacts range from 0.30% to 1.77% for the largest to smallest firms, respectively. We do not report the results for sell orders as they carry the opposite sign but are of the same magnitude and degree of significance. This result is similar to Harris and Hasbrouck (1996), who find that the price impacts of buy and sell orders are not significantly different.

Table 3 presents the results for the cross-sectional regression for the determinants of the price impact of executed orders. As expected, price impact has a highly significant relation with order aggressiveness. The values of the six intercept coefficients are consistent with Table 2 since the three most aggressive (passive) orders have positive (negative) signs. The results indicate that for the three types of aggressive buy orders, the price impact has a generally significant positive relation with $OrderSize_{i,j}$. In addition, category 1 orders exhibit the greatest sensitivity of order size to price impact given the magnitude of C_{13} relative to C_{14}–C_{18}. As expected, C_{18} is not significantly different from zero indicating that large extremely passive orders have the same price impact as smaller passive orders.

The relation between price volatility and price impact is significant for both aggressive and passive orders but the signs for the types of orders differ. That is, for the three most aggressive types of buy orders, the *PriceVol* coefficient is significantly positive, suggesting that it is more expensive to immediately trade a more volatile stock. Greater volatility is associated with less liquidity and

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Table 2
Price impact of executed buy orders

This table shows the price impact of all executed orders for stocks priced at more than $5 on the Toronto Stock Exchange (TSE) during June 1997. Orders are classified into six different levels of aggressiveness according to the definitions in Biais et al. (1995) and five different levels of firm size. To group by firm size, all stocks on the TSE priced over $5 are ranked by market capitalization as at May 30, 1997. The stocks are then sorted into five quintiles based on this ranking. The first figure in each cell is the arithmetic mean of the logarithm of the ratio of the mean of the volume-weighted average of fill price divided by the mean of the bid and ask prices immediately prior to the order. The means are presented in percentage terms. The second and third figures in each cell of the table are the *t*-statistics of the mean (in brackets) and the number of orders. One and two asterisks indicate significance at the 5% and 1% levels, respectively. A "#" means that the posterior odds ratio indicates that the odds against the null hypothesis of the mean equaling zero is greater than 20 : 1. Results are not shown for the sell orders as they are nearly identical to those presented below for buy orders but are of the opposite sign.

Order classification (ranked from most (1) to least (6) aggressive)	Firm size				
	Quintile 1 (largest)	Quintile 2	Quintile 3	Quintile 4	Quintile 5 (smallest)
(1) Order price > ask	0.31%	0.57%	1.00%	1.29%	1.43%
Order size > depth at ask	(34.10)**#	(31.50)**#	(19.52)**#	(24.99)**#	(17.14)**#
	894	476	223	233	129
(2) Order price = ask	0.14%	0.36%	0.54%	0.72%	0.91%
Order size > depth at ask	(118.54)**#	(53.06)**#	(50.25)**#	(45.11)**#	(31.26)**#
	12,540	4289	1862	1286	649
(3) Order price = ask	0.14%	0.32%	0.46%	0.66%	0.85%
Order size ⩽ depth at ask	(274.99)**#	(164.05)**#	(56.38)**#	(76.42)**#	(52.74)**#
	74,683	20,578	8129	4916	2396
(4) Bid < order price < ask	−0.04%	−0.10%	−0.15%	−0.24%	−0.25%
	(−26.59)**#	(−22.15)**#	(−6.47)**#	(−12.96)**#	(−5.73)**#
	15,897	5697	2549	1710	854
(5) Order price = bid	−0.17%	−0.36%	−0.55%	−0.76%	−0.97%
	(−214.15)**#	(−138.06)**#	(−78.46)**#	(−57.33)**#	(−32.78)**#
	33,527	10,065	3854	1733	738
(6) Order price < bid	−0.54%	−1.07%	−1.63%	−1.87%	−2.52%
	(−85.19)**#	(−54.84)**#	(−30.82)**#	(−27.63)**#	(−15.71)**#
	5398	1295	483	299	128

Table 3
Regression analysis of determinants of price impact of executed orders

This table shows the coefficients (multiplied by 100), t-statistics (in brackets), and adjusted R^2 of regression (1) for executed orders on the Toronto Stock Exchange during June 1997. Orders are classified into six different levels of aggressiveness according to the definitions in Biais et al. (1995). One and two asterisks indicate significance at the 5% and 1% levels, respectively. A "#" means that the posterior odds ratio indicates that the odds against the null hypothesis of the coefficient equaling zero are greater than 20 : 1. The model of price impact for stock i for order j is

$$O_{i,j} = \sum_{k=1}^{6} (C_k T_{(i,j,k)} + C_{(k+6)} T_{(i,j,k)} \, Buydummy_{i,j} + C_{(k+12)} T_{(i,j,k)} \, OrderSize_{i,j}$$

$$+ C_{(k+18)} T_{(i,j,k)} \, PriceVol_{i,j} + C_{(k+24)} T_{(i,j,k)} \, FirmSize_{i,j}) + e_{i,j},$$

where

$O_{i,j}$	$= \ln (B_{i,j}/E_{i,j})$
$B_{i,j}$	= the volume-weighted average of the fill price of stock i for order j
$E_{i,j}$	= the mean of the best bid/ask prices immediately prior to the order entering the book
$T_{i,j,k}$	= dummy variable with value one if order aggressiveness is type k and zero otherwise; ranges from $k = 1$, most aggressive, to $k = 6$, most passive type of order
$Buydummy_{i,j,}$	= dummy variable with value one if buy order and zero if sell order
$OrderSize_{i,j}$	= the order size divided by the average daily volume of shares in the period of March–May 1997, inclusive
$PriceVol_{i,j}$	= the standard deviation of the daily return of the stock in the period of March–May 1997, inclusive.
$FirmSize_{i,j}$	= the market capitalization of the firm as at the end of the last trading day of May 1997

Coefficient	Variable	Coefficient value	t-Statistic
C_1	$T_{i,j,1}$	5.22	70.08**#
C_2	$T_{i,j,2}$	3.09	129.10**#
C_3	$T_{i,j,3}$	2.71	233.40**#
C_4	$T_{i,j,4}$	− 0.8	− 36.99**#
C_5	$T_{i,j,5}$	− 2.84	− 171.94**#
C_6	$T_{i,j,6}$	− 7.52	− 176.93**#
C_7	$T_{i,j,1} \, Buydummy_{i,j}$	− 0.03	− 3.27**#
C_8	$T_{i,j,2} \, Buydummy_{i,j}$	0	− 0.47
C_9	$T_{i,j,3} \, Buydummy_{i,j}$	− 0.01	− 3.79**
C_{10}	$T_{i,j,4} \, Buydummy_{i,j}$	0	− 1.62
C_{11}	$T_{i,j,5} \, Buydummy_{i,j}$	− 0.01	− 6.15**#
C_{12}	$T_{i,j,6} \, Buydummy_{i,j}$	0	− 0.8
C_{13}	$T_{i,j,1} \, OrderSize_{i,j}$	0.24	20.96**#
C_{14}	$T_{i,j,2} \, OrderSize_{i,j}$	0.04	15.01**#
C_{15}	$T_{i,j,3} \, OrderSize_{i,j}$	0.17	26.18**#
C_{16}	$T_{i,j,4} \, OrderSize_{i,j}$	− 0.03	− 13.41**#
C_{17}	$T_{i,j,5} \, OrderSize_{i,j}$	− 0.02	− 9.81**#
C_{18}	$T_{i,j,6} \, OrderSize_{i,j}$	− 0.05	− 2.33**#
C_{19}	$T_{i,j,1} \, PriceVol_{i,j}$	8.19	18.06**#

Table 3 (*continued*)

Coefficient	Variable	Coefficient value	t-Statistic
C_{20}	$T_{i,j,2}\ PriceVol_{i,j}$	2.51	18.74** #
C_{21}	$T_{i,j,3}\ PriceVol_{i,j}$	2.37	41.02** #
C_{22}	$T_{i,j,4}\ PriceVol_{i,j}$	− 1.00	− 7.33** #
C_{23}	$T_{i,j,5}\ PriceVol_{i,j}$	− 2.00	− 27.21** #
C_{24}	$T_{i,j,6}\ PriceVol_{i,j}$	− 5.67	− 32.42** #
C_{25}	$T_{i,j,1}\ FirmSize_{i,j}$	− 0.23	− 66.81** #
C_{26}	$T_{i,j,2}\ FirmSize_{i,j}$	− 0.13	− 122.41** #
C_{27}	$T_{i,j,3}\ FirmSize_{i,j}$	− 0.12	− 218.07** #
C_{28}	$T_{i,j,4}\ FirmSize_{i,j}$	0.03	35.49** #
C_{29}	$T_{i,j,5}\ FirmSize_{i,j}$	0.12	159.84** #
C_{30}	$T_{i,j,6}\ FirmSize_{i,j}$	0.31	163.03** #
Adjusted R^2		0.5	
Number of orders		514,731	

higher execution costs. For the three categories of passive orders, the price volatility has a negative relation with price impact. Thus, investors who enter passive buy orders tend to benefit from greater price volatility. Further, the benefits are amplified for the more passive orders, as C_{24}, the coefficient for the executed category 6 orders, is greater in magnitude than those of C_{19}–C_{23}.

Table 3 also shows that order aggressiveness affects the relation between firm size and price impact. For aggressive (passive) orders, firm size is negatively (positively) related to price impact. Further, the magnitude of the coefficients indicates that the relation is strongest for category 1 and 6 orders. Consistent with Table 2, this implies that smaller firms have much higher (lower) price impacts than larger firms for highly aggressive (passive) orders.

Table 4 demonstrates that there is a considerable opportunity cost to submitting passive buy orders, especially for the stock of a small company. (The results for sell limit orders are approximately symmetric and thus are not shown.) The opportunity cost is a function of a low fill rate combined with the need to ultimately execute the unfilled portion of the order in a more aggressive and costly manner. The cost of executing the unfilled portion of the order is increased in the presence of adverse selection costs which can produce an adverse shift in the midquote. For all three categories of limit orders, the fill rate decreases monotonically as one moves from the largest to the smallest firms. For category 6 orders, the fill rate is 27.02% for buy orders of the largest firms and only 9.39% for the smallest firms. For category 4, the adverse selection costs as measured by the shift in the midquote is greatest for the smallest firms. For categories 5 and 6, the shift in midquote is much smaller, suggesting that the adverse selection problem causes the largest increase in the cost of executing unfilled limit orders when the order price improves upon the orders in the limit

book. The opportunity cost for precommitted small (large) orders is highest for category 4 orders. For orders in this category, the opportunity cost for small (large) orders ranges from 0.08% (0.13%) for quintile 1 firms to 1.12% (1.50%) for quintile 5 firms. Because of lower adverse selection costs, the category 5 and 6 orders have lower opportunity costs.

The opportunity costs of the unfilled portion of limit orders generally offset the negative price impact of the filled portion so that the implementation shortfall is positive. For category 4 orders, the implementation shortfall is not much lower than the order execution costs for categories 1 and 3 orders, indicating that there is not much advantage in placing this type of limit order. However, categories 5 and 6 orders have implementation shortfalls that are much lower than the order execution costs of aggressive orders in categories 1 and 3. This is especially true of category 5 orders. Traders who want to minimize overall acquisition costs might initially want to enter a buy limit order at the bid.

Table 5 shows the results of the ordered probit analysis. The coefficients are significant and in the expected direction. Since the ascending ranking from 1 to 6 reflects declining order aggressiveness, a negative sign for the coefficient *LastAggressive* means that aggressive buy (sell) orders are more likely following other aggressive buy (sell) orders, consistent with Biais et al. (1995). The positive sign for *FirmSize* implies that orders for stocks of large firms are much less likely to be aggressive.

The shape of the order book immediately before the order has a significant impact on its aggressiveness. The results indicate that if the bid–ask spread is wide, passive orders are more likely. Further, competing orders as reflected in depth on the same side of the order book encourage traders to be more aggressive. Conversely, passive orders are more likely given depth on the other side of the order book.

The argument that traders who place large aggressive orders are more informed suggests that the large price impacts accompanying their execution are offset by a subsequent rise in the value of the stock as the private information becomes known to other traders. As shown in Table 6, category 1 aggressive buy orders have significantly higher market-adjusted returns over the period from the date of purchase to September 30, 1997 than do all other categories of orders for quintiles 1 and 2 and for most other types of orders in quintile 3. Thus, the immediate price impacts are more than offset by a subsequent rise in the value of the stock, suggesting that traders who place aggressive buy orders are informed. However, category 1 sell orders in quintiles 1–3 also show significantly higher subsequent quarterly excess returns than most other types of orders. Thus, the immediate price impact of a very aggressive sell order is not offset by lower forgone profits. This implies that large aggressive sellers are liquidity motivated. These findings are consistent with the argument of Burdett and O'Hara (1987) that large buyers are more likely to be motivated by information than are large

Table 4
Analysis of opportunity costs and implementation shortfall of limit orders

This table breaks down the implementation shortfall of limit orders of stocks priced at more than $5 on the Toronto Stock Exchange (TSE) during June 1997. Orders are classified into three different levels of aggressiveness of fully booked limit orders according to the definitions in Biais et al. (1995) and five different levels of firm size. To group by firm size, all stocks on the TSE priced over $5 are ranked by market capitalization as at May 30, 1997. The stocks are then sorted into five quintiles based on this ranking. The change in the midquote for unfilled orders is the logarithm of the ratio of the mean of the bid and ask prices five seconds after the order is canceled divided by the mean of the bid and ask prices immediately prior to the order. Opportunity cost for precommitted small (large) orders is calculated by multiplying the percentage of orders unfilled by the sum of the change in midquote for unfilled orders and the price impact shown on Table 2 for category 3 (1) orders. The implementation shortfall as defined in Perold (1988) is calculated as the opportunity cost plus the execution cost of the portion of the order filled. The execution cost is estimated by multiplying the percentage of the order filled by the price impact shown on Table 2 (for buy orders) of a limit order for the categories defined below.

Firm size	Quintile 1 (%) (largest)	Quintile 2 (%)	Quintile 3 (%)	Quintile 4 (%)	Quintile 5 (%) (smallest)
Panel A: Buy limit orders (bid < order price < ask)					
Percentage of orders unfilled	28.71	37.69	49.53	55.99	65.06
Change in midquote for unfilled orders	0.14	0.30	0.48	0.54	0.87
Opportunity cost: precommitted small (large) order	0.08 (0.13)	0.23 (0.33)	0.46 (0.73)	0.67 (1.02)	1.12 (1.50)
Implementation shortfall: precommitted small (large) order	0.05 (0.10)	0.21 (0.30)	0.39 (0.66)	0.56 (0.92)	1.03 (1.41)
Panel B: Buy limit orders (order price = bid)					
Percentage of order unfilled	29.93	30.68	37.97	46.35	54.92
Change in midquote for unfilled orders	0.00	0.00	0.01	0.01	0.00
Opportunity cost: precommitted small (large) order	0.04 (0.09)	0.10 (0.18)	0.18 (0.38)	0.31 (0.60)	0.47 (0.79)
Implementation shortfall: precommitted small (large) order	−0.08 (−0.03)	−0.15 (−0.07)	−0.16 (0.04)	−0.10 (0.19)	0.03 (0.35)

Panel C: Buy limit orders (order price < bid)

Percentage of order unfilled	72.98	80.61	84.19	86.74	90.61
Change in midquote for unfilled order	0.00	− 0.01	− 0.04	− 0.05	− 0.06
Opportunity cost: precommitted small (large) order	0.10 (0.22)	0.25 (0.45)	0.35 (0.81)	0.53 (1.07)	0.72 (1.24)
Implementation shortfall: precommitted small (large) order	− 0.05 (0.08)	0.04 (0.24)	0.10 (0.55)	0.28 (0.83)	0.48 (1.01)

Table 5

Ordered probit analysis of determinants of order aggressiveness

This table shows the ordered probit analysis of orders of stocks priced at more than $5 on the Toronto Stock Exchange during June 1997. Orders are classified into six different levels of aggressiveness of orders according to the definitions in Biais et al. (1995). For the z-statistics, one and two asterisks indicate significance at the 5% and 1% levels, respectively. A "#" means that the posterior odds ratio indicates that the odds against the null hypothesis of the mean equaling zero are greater than 20 : 1.

Parameters

Partition boundaries	Limit points	z-Statistic
α_1	-2.086	$-81.29^{**}\#$
α_2	-1.012	$-40.15^{**}\#$
α_3	0.256	$10.17^{**}\#$
α_4	0.611	$24.25^{**}\#$
α_5	1.500	$59.45^{**}\#$

Independent variable	Coefficient value	z-Statistic
LastAggressive	-0.104	$-29.54^{**}\#$
FirmSize	0.014	$12.61^{**}\#$
RelSpread	5.503	$37.22^{**}\#$
DepthSame	-0.072	$-13.40^{**}\#$
DepthOpp	0.071	$12.63^{**}\#$

sellers since there are relatively few liquidity reasons for a large purchase in a specific stock.

In interpreting the results from Table 6, we note that in the absence of particular knowledge about the 'shelf-life' of any information advantage possessed by aggressive traders and the investment horizon of these traders, our use of quarterly returns is somewhat arbitrary. It is also interesting that with the exception of categories 2–5 in quintile 1 and categories 5 and 6 in quintile 3, sellers lose money (average holding returns are positive). The underperformance among sellers of smaller stocks is consistent with the relatively strong performance of smaller capitalized firms over this period rather than being attributable to any trading strategy. Over the period June–September 1997, the TSE 200 Index which is composed of small- to mid-cap firms, outperformed the larger-cap TSE 100 Index (18.09% versus 8.45%).

5. Conclusions

We analyze costs and determinants of order aggressiveness on the Toronto Stock Exchange. We find that aggressive orders require a significant premium

Table 6
Quarterly excess returns of executed orders ranked by aggressiveness

This table shows the quarterly excess returns of orders of stocks priced at more than $5 on the Toronto Stock Exchange (TSE) during June 1997. Orders are grouped into five quintiles by firm size based on market capitalization as at May 30, 1997. Quarterly excess return equals the percentage increase (decrease) from the weighted average fill price of the order to the closing midquote as at the last day of trading in September 1997 less the return over the same period in the TSE 300 Index. The first and second figures in each cell are the arithmetic mean of the quarterly excess returns and the number of orders, respectively. The asterisks in order types (k) where $k = 2, 6$ indicate significance at the 5% and 1% levels, respectively, in the t-test of whether the mean for order type (1) is equal to the mean for order type (k). A "#" means that the posterior odds ratio indicates that the odds against the null hypothesis of the mean equaling zero are greater than 20 : 1.

| | Firm size | | | | |
	Quintile 1 (largest)	Quintile 2	Quintile 3	Quintile 4	Quintile 5 (smallest)
Panel A: Buy orders Ranked from most (1) to least (6) aggressive					
(1) Order price > ask Order size > depth at ask	2.70%. 894	10.28% 463	−4.96% 220	7.23% 225	12.92% 121
(2) Order price = ask Order size > depth at ask	−1.12%***# 12,540	4.36%***# 4133	4.78% 1779	8.32% 1240	13.88% 600
(3) Order price = ask Order size ⩽ depth at ask	−1.66%***# 74,683	5.97%*** 19,986	1.25%* 7858	4.77% 4753	9.90% 2285
(4) Bid < order price < ask	−1.52%***# 15,897	4.12%***# 5539	1.60% 2484	5.40% 1683	13.33% 811
(5) Order price = bid	−1.19%***# 33,527	4.00%***# 9435	−2.51%***# 3576	6.10% 1650	12.10% 712
(6) Order price < bid	−1.16%***# 5398	2.66%***# 1258	−3.10%***# 472	4.66% 291	17.32% 124
F-test of equality of means (1)–(6)	16.55**	13.95**	21.48**	2.91*	5.09**

Table 6 (*continued*)

	Firm size				
	Quintile 1 (largest)	Quintile 2	Quintile 3	Quintile 4	Quintile 5 (smallest)
Panel B: Sell orders ranked from most (1) to least (6) aggressive					
(1) Order price < bid Order size > depth at bid	0.37% 1032	7.82% 499	4.78% 277	3.62% 261	14.61% 119
(2) Order price = bid Order size > depth at bid	− 2.03%**# 13,808	3.18%# 4440	2.53% 1691	6.71%** 1199	11.83% 664
(3) Order price = bid Order size ⩽ depth at bid	− 0.85%**# 52,680	4.91%** 16,682	1.56%***# 7169	7.20%***# 4257	11.44% 2025
(4) Bid < order price < ask	− 1.50%***# 15,425	5.36%***# 5212	2.54% 2278	7.00%***# 1680	11.67% 773
(5) Order price = ask	− 1.21%***# 38,456	6.41% 10,343	− 2.01%***# 3820	5.83% 1616	12.30% 724
(6) Order price < ask	0.72% 5400	7.52% 1191	− 0.39%***# 487	6.26% 292	11.84% 100
F-test of equality of means (1)–(6)	27.94**	12.03**	13.07**	1.01	0.41

for immediacy of execution while more passive orders have a negative price impact. The price impact of aggressive orders is positively related to order size and price volatility and negatively related to firm size. In contrast, the relation between the price impact of passive orders and each of these variables is either neutral or carries the opposite sign. Thus, large passive orders do not have a higher price impact than smaller passive orders. Additionally, stock price volatility is expensive for the aggressive trader but beneficial to the trader with passive executed orders.

The favorable price impacts received on the filled portion of passive orders is offset by high opportunity costs associated with the unfilled portion. The opportunity costs, which are a function of low fill rates and adverse shifts in the midquote during the time an unfilled order remains on the limit-order book, are highest for small firms. For example, a buy order for the smallest quintile of firms with a price lower than the bid has a 9.39% fill rate. After estimating the implementation shortfall, which incorporates both the opportunity cost of unfilled orders and the execution cost of filled orders, the optimal strategy to minimize overall costs in filling an order is to buy (sell) at the bid (ask). Given this finding, we explore reasons why traders place aggressive orders and whether such traders are more informed than others.

An ordered probit analysis indicates that aggressive buy (sell) orders tend to follow other aggressive buy (sell) orders. Aggressive orders are also more likely with stocks of small firms when the limit-order book immediately prior to the order has a narrow bid–ask spread, large depth on the same side as the order, and small depth on the opposite side. These findings suggest that real-time information on previous orders as well as the limit-order book is highly valuable to traders, and systems that limit this information to a subset of traders, are creating potential information asymmetries among market participants.

Finally, an analysis of longer-term returns to holding stock subsequent to the order suggests that aggressive buyers and sellers of stock have different motives. Aggressive buyers tend to be more informed on average than other buyers, whereas aggressive sellers tend to be motivated by liquidity.

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