Price Aggressiveness and Quantity: how are they determined in a limit order market? *

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Abstract:

Dealers in a limit order market must choose both the price aggressiveness and the quantity. We empirically investigate how investors jointly make these decisions using a simultaneous equations model An ordered probit model is implemented to account for the discrete nature of price aggressiveness and a censored regression model is implemented to capture the clustering of orders placed at $1 million. We find evidence of a clear trade-off between price aggressiveness and quantity: more aggressive orders tend to be smaller in size when submitted or cancelled. Depth on the same (opposite) side of the market leads to less (more) aggressive orders in smaller (larger) size. Orders become more (less) aggressive if there were more aggressive orders submitted on the opposite (same) side of the market. Although the impact of the submission and cancellation of off-best orders on the depth of the market are not observable to traders, they impact the price aggressiveness of the orders submitted.

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1. Introduction:

This paper investigates the interdependence of the two most important components of a trader's order submission decision in a limit order market – the aggressiveness of the price and the quantity at which they are willing to transact. Although much of the market microstructure literature focuses on what factors influence how traders determine the aggressiveness of their prices, traders must also specify the quantity they wish to trade when submitting an order. Despite the importance of the quantity aspect of this decision, it has received relatively little attention (a notable exception being Moulton (2003)). In this study we simultaneously investigate how various factors characterizing the state of the market and the order book influence the traders' decisions on the aggressiveness of prices, the associated quantity and how they interact.

To empirically study these relationships, we develop a method which accounts for the fact that traders have to determine the price aggressiveness and quantity simultaneously. The price aggressiveness is defined in terms of how quickly an order is executed. Market orders are the most aggressive because they are executed immediately. Limit orders are less aggressive because their execution is not guaranteed and they follow strict price and time priorities in execution. Those submitted at the most favorable price (the lowest ask or highest bid) are executed first and if quotes are submitted at the same price, the one submitted earlier has execution priority. As documented in the literature, the price aggressiveness decision depends on the tradeoffs between execution risk, adverse selection risk and price risk. Market orders, for example, do not face execution risk but they have price risk. The price risk exists because the price at which they are executed depends on the bid ask spread and market depth. Limit orders specify the price at which to trade but they bear execution risk – the further away a limit order is from the best price, the higher the execution risk. Limit order traders also face adverse selection risk because these orders are most likely to be executed when the value of the asset has changed adversely. More aggressive orders are exposed to more adverse selection risk, since they suffer a larger loss when the underlying value of the asset changes.

The quantity or size of the order also plays an important role in the trade-off of risks for both market and limit orders. The price risk for market orders increases as the quantity increases – the order may have to walk further up the order book to be completely executed. For limit orders, the execution risk increases with

order size because it is less likely to be executed in one lot. Adverse selection risk also increases as the size increases: a trader may suffer a larger total loss when the value of the underlying asset changes. As a consequence, quantity interacts with price aggressiveness when traders evaluate the price risk, execution risk and adverse selection risk of each price-quantity combination.

In our study we formally investigate the inter-relationships between price aggressiveness and quantity for both order submissions and cancellations. We start by assuming the dealer has already decided on which side of the market to focus (i.e. whether they wish to submit an order to buy or sell the asset), our analysis focuses on the decisions pertaining to the aggressiveness of the price and the quantity. Following recent studies in this area such as Griffiths et al. (2000), Cao, Hansch and Wang (2004), and Ranaldo (2004), we use an ordered probit model to investigate what factors influence the level of price aggressiveness. This builds on the discrete nature of prices to capture the most significant differences in the levels of price aggressiveness of orders submitted by traders.[1] Unlike previous studies, however, we model quantity simultaneously with the price aggressiveness. The quantities submitted are modeled using a censored regression framework to accommodate for the fact that the minimum order allowed on the Reuters system is $1 million and orders appear to cluster at $1 million.

Our analysis extends the existing literature in several dimensions. First, we are one of the first to formally study the joint nature of the price aggressiveness and quantity in the limit order market and explicitly examine the trade-offs between these two dimensions. Though many studies have considered the market versus limit order submission decision (e.g. Hasbrouck (1999), Hollifield, Miller, Sandas and Slive (2002)), few have extended the problem to jointly consider the price and quantity aspects of this decision. Studies which have considered both (e.g., Ellul, Holden, Jain and Jennings (2003) and Ronaldo (2004)), however, focus on specific price-quantity combinations. Our simultaneous equation model, on the other hand, allows us to more formally study the potential inter-relationships between the levels of price aggressiveness and quantity. Second, we explicitly study the decision to cancel an order. Most studies only consider submissions and those which consider both submissions and cancellations (e.g. Cao, Hansch and

[1] Prices change in discrete increments. In equity markets prices depend on the tick size and in the foreign exchange market prices increase in increments of 1 pip where for our data 1 pip is DM 0.0001 per US dollar.

Wang (2004)) treat the cancellation of an order as the least aggressive type of order submission. The cancellation of limit orders is, however, conditional upon there having been an earlier submission. Because cancellation is not a choice available to all traders – it is only available to those who submitted an order earlier – treating cancellation as the least aggressive type of order submission is not appropriate. Another important element of the cancellation decision is that limit orders may be cancelled at different levels of price aggressiveness (i.e., at the best price or behind the best price) so all order cancellations are not the same. As a result, we model limit order submissions and cancellations separately[2].

To focus on the impact of changes in the level of price uncertainty and market depth/liquidity on the price-quantity decisions we consider two closely related models. In the first model, we examine how market depth at the best and off-best prices affect the price aggressiveness/quantity decision. The second model looks at how changes in the state of the order book affect the order submission decision. The specific measures we consider are: 1) the execution of market orders which erode the depth of the market, 2) the submission of best limit orders which add depth and improve the best price, 3) the submission of behind best limit orders which add depth behind the best price, 4) the cancellation of best limit orders which erode depth at the best price, and 5) the cancellation of behind best limit orders which erode depth behind the best price during the two minute interval before an order is submitted or cancelled. In both models, we also consider the impact of uncertainty measured by volatility.

The models are estimated using data on firm quotes submitted to the Reuters D-2000-2 system in the Deutsche Mark-U.S. dollar market[3]. Although we have complete information on the state of the order book, traders using the Reuters D-2000-2 system only observe the best price and quantity posted on both sides of the market and the most recent transaction activity. Since we have more information than traders, another important aspect of our analysis is that we are able to determine whether the information from the orders

[2] Our model for order cancellations contains only an ordered probit model because dealers can only remove existing orders. Although how much to remove is not a choice, our model does recognize that the quantity standing in the market for each order is a major factor affecting the cancellation decision for orders at different price levels.

[3] This market allows traders to submit both market and limit orders. Since these are the only ways for trade to occur (i.e., there is no market maker), we see how liquidity develops over the trading day and its impact on the order submission decision. Many of the existing market microstructure studies use markets where traders can only submit one type of order or one has to consider the impact of factors such as the presence of a market maker on liquidity.

behind the best price that is not available to traders appears to affect the price and quantity decisions. If this information does appear relevant, this would be consistent with dealers using other sources (e.g., their private customer base) to obtain relevant information on the state of the market which they use in making their decisions at each point in time.

We find that there is a negative tradeoff between price aggressiveness and quantity. Quantity tends to be smaller when the order is more aggressive. Studying changes in the marginal probability of submitting each order type we find that more aggressive orders (i.e., in order of most aggressive to least aggressive, market orders, marketable limit orders, limit orders improving the best price and limit orders placed at the best price) are less likely when the order size is large. This is because the potential cost of large market orders is higher – it may have to walk further up or down the order book – and large, aggressive limit orders face increasing adverse selection risk if the value of the asset moves against the trader.

Price aggressiveness and quantity drop (traders submit more limit orders with smaller sizes) when market depth increases at the best price on the same side of the market. The opposite holds when market depth increases at the best price on the opposite side of the market: traders submit larger market orders or more aggressive limit orders. The depth at off-best prices has a similar effect, though it is smaller in magnitude. These results are consistent with traders being concerned about the "crowding out" effect of Parlour (1998) and an increase in adverse selection risk if they submit more aggressive orders as depth increases on the same side of the market.

Not surprisingly, price uncertainty has an interesting impact on the price aggressiveness of orders. Orders from both sides of the market become more aggressive as overall volatility increases. There are two possible explanations for this. First, traders want to ensure they transact in a volatile market as suggested in Cohen et al (1981). Second, traders originally plan to submit off-best orders but price movements result in orders being more aggressive by the time they are submitted. Considering the impact of price uncertainty arising from only the bid or the ask side of the market, we find that traders submit less aggressive orders (i.e. more behind best limit orders) when price uncertainty comes from the same side of the market. This reduces

adverse selection risk. However, they submit more aggressive orders (i.e. best limit orders, marketable limit order and market orders) when price uncertainty comes from the opposite side of the market.

Turning to how changes in the state of the market affect the order submission decision, we find that orders become more aggressive if there were more aggressive orders on the opposite side of the market, especially market orders and marketable limit orders, submitted in the past two minutes. We also find that although the submission and cancellation of off-best orders are not observable to traders, they impact the price aggressiveness of the orders submitted. More off-best orders submitted in the past two minutes to the opposite (same) side of the market leads to more (less) aggressive orders. The opposite holds for the cancellation of off-best limit orders.

The paper develops as follows. In the next section we discuss the data used. Section three presents our empirical model and our hypotheses. The fourth section discusses the results from the basic model. Sections five and six consider how the performance of the market affects the submission and cancellation decisions. The final section concludes.

2. Data

We use data for the Deutsche Mark - US dollar exchange rate from the Reuters D2000-2 system from the evening of the 5th of October to midnight on the 10th of October 1997. D2000-2 is an electronic order book to which foreign exchange traders can submit both market and limit orders. Subscribers see the best bid and best ask quotes, the size supplied at these prices and the most recent transactions. Although we observe all of the orders submitted to the market, traders do not directly observe the complete order book. For example, they can not observe the off-best limit orders posted nor their cancellation. They do, however, observe similar information from other sources such as the Reuters' EFX page as well as their own customer order flow. Due to an unexpected change in interest rates by the Bundesbank on October 9th, 1997 and its unusual impact on the trading activity in the foreign exchange market (for a discussion see Carlson and Lo (2004)), we exclude this day from our sample. Despite the short time span of the dataset, it is the only data available with complete information on the limit order book in the foreign exchange market. Since around

85% of the interdealer trade in major currencies go through the electronic limit order book (Sager and Tayor (2005)), the dataset provides a unique perspective into the workings of the foreign exchange market.

The dataset includes the following information on each order: the price at which the submitter stands ready to buy or sell the currency, the quantity to be traded, the exact time it arrived, whether the quote is a limit order or market order, whether the quote is bid side or ask side initiated, and the entry and exit time of the quote. Although this data only covers the electronic broker market and not the direct-trade interdealer market, the best quote, type of order and quantity submitted are observable by all of the market participants whereas this information is not observable in the interdealer market.[4] In the interdealer market, dealers contact other dealers directly to arrange the transaction price and quantity. Consequently little is known about these interdealer trades (notable exceptions being Lyons (1995), and Evans and Lyons (2002a, b)) so this electronic order book is our best source of information on foreign exchange transactions.

Using the foreign exchange market has several other advantages as well. Because it is the largest financial market in the world with trade occurring twenty-four hours a day, this limits potential problems resulting from illiquid trading, information asymmetries and other errors in the measurement of microstructure characteristics. It also allows us to completely study how the supply and demand for a highly liquid asset develop over the day and influence traders' decisions , because the submission and cancellation of market and limit orders provide a full picture of the changing state of the limit order book (there is no market maker). Further we can see how liquidity increases and decreases with the opening and closing of markets. The complete data set consists of 130,526 quotes. Because we focus on both order submission and cancellation activities during the most active trading period – from 7:00 to 16:00 (GMT) (see Figure 1) – the dataset we use for our empirical analysis consists of 91,086 submitted quotes and 48,455 cancellations.

Table 1 breaks-down the price aggressiveness of order submissions into six categories: market orders (17%), marketable limit orders (11%), best limit orders improving existing best prices (14%), best limit orders placed at the best price (23%), off-best limit orders within 1 pip of the best price (11%) and off-best limit orders more than 1 pip away from the best prices (24%). The proportions are similar for the ask and bid

[4] The relative importance of trading through electronic brokers is also increasing over time. In 1997 about 30 percent of all UK and US trading volume and 37 percent of all Japanese trading volume was conducted using electronic brokers (BIS (1998)) and by 2001 this had increased to over 67%, 54% and 48% respectively (BIS (2002)).

sides of the market. Table 1 also shows the proportion of different order sizes in each order aggressiveness category. A general observation on the order size is that orders cluster at $1 million in each category (Note: this is the minimum quantity allowed to be submitted to the limit order book on the Reuters 2000-2 system). The percentages of $1 million orders ranges from 34% for marketable limit orders to 64% for off-best limit orders placed at more than 1 pip from the best price. Because of this clustering at the minimum quantity, we use a censored regression model for quantity in the empirical analysis. The proportion of different order sizes are similar for the ask and the bid sides of the market. For order cancellations, since market and marketable limit orders cannot be cancelled, we only break order aggressiveness into three categories: limit orders cancelled at the best price (36%), limit orders cancelled within 2 pips of the best price (30%) and limit orders cancelled at 2 pips away from the best price (34%).

Table 2 illustrates how the price aggressiveness and quantity of orders change over the trading day. We find relatively more market orders in the morning and less at the end of the trading day. This is consistent with Bloomfield, O'Hara and Saar (2004) who suggest that market orders are used more often at the opening of the market when there is a greater asymmetry of information. There are relatively more best limit orders, especially best orders improving the existing best price in the latter half of the trading day. This suggests that as the asymmetry of information narrows over the trading day, the adverse selection risk decreases so traders are increasingly willing to place limit orders. This is again consistent with Bloomfield, O'Hara and Saar (2004). Quite interestingly, cancellation activities mirror those of submissions. There are relatively more best limit orders cancelled in the morning while more limit orders are cancelled at prices more than 2 pips away from the best price at the end of the trading day. This could be the result of the adverse selection risk being larger in the morning when the asymmetry of information is wider, so traders are most concerned about their best limit orders. In a similar fashion, the execution risk of off-best limit orders is higher at the end of the day, so there are relatively more off-best orders cancelled and replaced by best orders at this time.

Turning to the quantities, we find that the proportion of $1 million orders submitted and cancelled declines while the proportion of larger orders increases over the trading day. This pattern suggests, not surprisingly, that the size of orders is influenced by changes in the asymmetry of information as the trading

day progresses. Our simultaneous equation framework provides us with a unique way to examine how this information asymmetry affects the quantity placed, which is not possible in the existing research which considers only certain price aggressiveness-quantity combinations.

Summary statistics for our explanatory variables are presented in Table 3. An interesting observation from the table is that the depth on the bid side of the market is larger than on the ask side. This is true for the depth at both the best and off-best prices. Not only is the bid side of the market deeper, the difference between the best and the worst prices is also smaller for the bid side of the market. This suggests that the bid side of the market is more liquid, both in terms of depth and the slope of the price schedule.

3. Basic Model:

3.1 Order submission – Simultaneous Ordered Probit and Quantity Regressions

To investigate the order submission process, we jointly model the price aggressiveness and quantity decisions. For our analysis we define the price aggressiveness based on their priority in execution. Dealers choose between submitting 1) market orders (for immediate execution at the best available price), 2) marketable limit orders (limit orders at prices better than the best price standing on the opposite side of the market), 3) best limit orders placed at prices better than the existing best price, 4) best limit orders placed at the existing best price, 5) off-best orders placed within one pip of the best price, or 6) off-best orders placed more than one pip away from the best price. Formally, the discrete choice of order type, I_s, depends on the latent price aggressiveness variable, I_s^*, which is assumed to be continuous. The latent order aggressiveness I_s^* is related to the choice of order type as follows

I_s = 1 if $-\infty < I_s^* \le m_1$ (off-best limit order placed more than 1 pip away from the best quote)

= 2 if $m_1 < I_s^* \le m_2$ (off-best limit order placed within 1 pip away from the best quote

= 3 if $m_2 < I_s^* \le m_3$ (best order placed at the existing best quote)

=4 if $m_3 < I_s^* \le m_4$ (best order bettered existing best quote)

=5 if $m_4 < I_s^* \le m_5$ (marketable limit order)

=6 if $m_5 < I_s^* \leq \infty$ (market order)

where $m_i, i = 1, 2, \ldots, 5$, are the thresholds to be estimated.

For the quantity, we recognize that the minimum quantity one can place in the limit order book is \$1 million and about half of all orders cluster at this quantity. Therefore we adopt a censored regression framework where the observable quantity, qn, depends on the latent quantity, qn^*, such that

$$qn = 1 \text{ if } qn^* \leq 1$$
$$qn = qn^* \text{ if } qn^* > 1$$

We estimate the latent price aggressiveness and the latent quantity with a simultaneous equation framework. The latent price aggressiveness variable, I^*, depends on the latent quantity, qn^*, and factors related to market depth and liquidity. The latent regression model is therefore given by:

$$I_s^* = g_1 qn^*_s + b^{I_s^*\prime} x_s^{I_s^*} + e^{I_s^*} \quad (1)$$

where qn^* is the quantity submitted and $x_s^{I^*} = [x_s \quad z_x^{I^*}]$ consists of a set of predetermined variables, x_s, and a set of predetermined variables not in the quantity equation, $z_x^{I^*}$. The latent price aggressiveness is estimated within an ordered probit framework. Turning to the specification of quantity, the latent quantity equation is specified as:

$$qn^*_s = a + g_2 I_s^* + b^{qn\prime} x_s^{qn} + e^{qn} \quad (2)$$

where $x_s^{qn} = [x_s \quad z_x^{qn}]$ is the predetermined variables as for equation (1) and the predetermined variables not in the latent price regression z_x^{qn}. Equation (2) is estimated using a censored probit model.

The two equations are estimated using a method analogous to the two-stage least squares method of Nelson and Olson (1978). In the first stage, we start by estimating the reduced-form equations to obtain the instruments for the price aggressiveness $\hat{I}_s^* = \hat{f}_{I^*}' x_s^{I_s^*}$ using an ordered probit model and for the quantity $\hat{qn}_s = \hat{f}' x_x^{qn}$ using OLS. In the second stage, $\hat{I}_s^*$ replaces its counterpart in the quantity equation and the model is estimated via OLS. Similarly, $\hat{qn}_s$ is substituted for qn in the latent variable equation for price aggressiveness and the model is estimated via a censored regression model.

3.2 Order Cancellation

To examine the cancellation decision, we only need to model the latent variable for price aggressiveness because quantity is not a choice variable. As a consequence we examine how size affects the latent variable for cancellation, I_c^*, using an ordered probit model as in the order submission decision Just as in the order submission case, the cancellation choice is related to the variable for price aggressiveness defined as

I_c = 1 if $-\infty < I_c^* \le \tilde{m}_1$ (limit orders cancelled more than 2 pips from the best quote)

= 2 if $\tilde{m}_1 < I_c^* \le \tilde{m}_2$ (limit orders cancelled between (0,2] pips from the best quote)

= 3 if $\tilde{m}_1 < I_c^* \le \infty$ (limit orders cancelled at the best order)

Though quantity is not a choice variable in the order cancellation decision, it could affect which order is ultimately cancelled. We examine how size affects the cancellation decision using the latent variable for cancellation, I_c^*, determined using an order probit model as in the order submission decision:

$$I_c^* = g_3 qn_c + b^{I_c^*\prime} x_s + e^{I_c^*} \qquad (1')$$

where the explanatory variables used in the cancellation equation are the same as those used in the model for the submission of orders – the main difference is the use of the actual quantity and not the latent quantity in equation (1').

3.3 Explanatory Variables and Hypothesis

In studying the trade-off between price aggressiveness and quantity, we investigate the impact of volatility, market depth and changes in the state of the order book on the price and quantity decisions. Because of the different ways in which the levels and changes in these factors can impact the price-quantity decisions, we estimate two models. In the first model, we examine how market depth—depth at the best price and off-best price on both the bid side and the ask side—affect the order submission decision. We call this model the "depth model". In the second model, we examine how changes in the state of the limit order book, namely the execution of market orders and the submission and cancellation of best and off-best limit orders, affect the order submission decision. We call the second model the "change-in-state" model.

The following are the explanatory variables we use in both the order aggressiveness and quantity equations in the depth model:

1. ***Volatility:*** The conventional definition of volatility is the centered second moment of the asset's price. Since there are two prices for our currency (the bid price and the ask price) and different market conditions may induce movements in one or both of these prices, we define volatility in three dimensions

   a. Common volatility: the volatility of the mid-quote: $v_{common} = \sqrt{\frac{\sum_{j=1}^{n} (p^{mid-quote} - \overline{p^{mid-quote}})^2}{(n-1)}}$.

   b. Residual volatility: this is the volatility associated with only the ask or the bid side of the market. It is obtained as the residual of the regression of volatility from one side of the market on both the common volatility and the volatility from the opposite side of the market. For example, the residual volatility from the ask side of the market is defined as the residual of the regression: $v_{ask} = a + b_1 v_{common} + b_2 v_{bid} + e_{ask}$ where v_{common} is defined as above and v_{bid} and v_{ask} are defined using the formula for v_{common} but replacing $p^{midquote}$ with p^{bid} and p^{ask} respectively. By construction the residual volatility is orthogonal to both the common volatility and the volatility from the opposite side of the market.

Hypothesis: As suggested by models such as Foucault (1999), if the increase in uncertainty is due to an increase in the asymmetry of information across traders, we should see an increase in the number of limit orders posted (i.e., orders submitted at less aggressive prices). On the other hand, Cohen et al. (1981) points out that as price uncertainty increases risk-averse traders place a premium on a definite outcome, especially regarding the execution of their trades. As a consequence their model suggests that we should see an increase in market orders (more aggressive orders) as volatility increases. Our analysis determines which effect is stronger. Furthermore, by differentiating between the volatility coming from the bid and the ask sides of the market, we can more clearly investigate the potential impact of differences in the uncertainty coming from different sides of the market.

2. **Depth at the best ask/ bid price**: the number of ask and bid quotes standing at the best price in the limit order book.

   Hypothesis: An increase in depth available at the best price has two implications: first, a large market order is less costly because it is less likely to have to walk up/down the order book to be fully executed. Second, it is more expensive to submit limit orders at the best price on the same side of the market because the increased depth at the best price means a longer queue for the order to be executed and thus greater execution risk. Consequently more depth should discourage limit orders at the best price on the same side of the market.

3. **Depth at the off-best ask/ bid price**: the number of ask and bid quotes standing at off-best prices in the limit order book.

   Hypothesis: The arguments are similar to the case of depth at the best price. When there is more depth on the same side of the market, limit orders are relatively more expensive than market orders because of an increase in the execution risk and competition from the existing limit orders.

4. **Difference between the best and worst prices**: For the ask (bid) side of the market, it is defined as the highest ask (best bid) price minus the best ask (lowest bid) price standing in the market.

   Hypothesis: The larger this difference, the more dispersed are the opinions of the asset's value among traders. This increase in asymmetry should lead to an increase in the return to supplying liquidity on that side of the market (e.g, more limit orders would be submitted). The potential asymmetry of information may, however, encourage more aggressive orders from the opposite side of the market.

In the change-in-state model, in addition to the volatility variables, we also include the following variables:

1. ***No. ask (bid) market orders executed***: the number of bid (ask) market orders executed during the last two minutes.

   Hypothesis: Microstructure theory proposes several competing mechanisms through which changes in the number of market orders could impact traders' behavior. We consider two alternatives here.

a) Information effects: Since market orders are essentially trades and trades are believed to be correlated with private information, investors use changes in market orders (trading behavior) to update their information set (e.g., Easley and O'Hara (1992), Evans and Lyons (2002, 2003, and 2005) and Goettler, Parlour and Rajan (2004)). The most detailed example is the dynamic equilibrium model of Goettler, Parlour and Rajan (2004) which suggests that changes in the efficient price of the asset induce an increase in the number of market orders to take advantage of this information. Subsequent traders entering the market would observe this and submit more aggressive orders to pick off the incorrectly priced limit orders in the book until the book has adjusted to the new information. Consequently we expect an increase in the submission of aggressive orders following the submission of market orders, especially on the same side of the market.

b) Erosion of market depth: If market orders are submitted due to idiosyncratic liquidity shocks, then the execution of market orders carries no price relevant information and the execution of market orders only uses up market depth. This increases the cost or price risk of submitting subsequent market orders on the same side of the market while lowering the cost of submitting limit orders on the opposite side because there are now fewer orders in the queue. As a result we would expect an increase in less aggressive orders on both sides of the market following the submission of market orders.

2. *No. ask (bid) best orders submitted*: the number of (bid) ask limit orders submitted at the best price during the last two minutes.

   Hypothesis: The submission of new best limit orders improves the best price on that side of the market. Since this will likely cause a narrowing of the spread, it results in a decrease in the cost of submitting market orders from the opposite side of the market but an increase in the cost to best limit orders on the same side of the market (e.g., the "crowding out" effect of Parlour (1998), and Goettler, Parlour and Rajan (2004)).

3. *No. ask (bid) behind best orders submitted*: the number of ask (bid) limit orders submitted behind the best price during the last two minutes.

   Hypothesis: The equilibrium of the model in Goettler, Parlour and Rajan (2004) shows that an increase in the depth behind the best price discourages both market orders and aggressive limit orders on the same side of market. Though their model does not make a statement about the opposite side of the market, we believe that an increase in depth on the opposite side of the market (more behind best limit orders) lowers the price risk for market orders, especially large orders.

4. *No. ask (bid) best orders cancelled*: the number of ask (bid) limit orders cancelled at the best price during the last two minutes.

   Hypothesis: Though there are several potential mechanisms through which canceling best orders can influence traders' decisions, we focus on the following two:

   a. Expectation of adverse price changes: The cancellation of orders at the best price reveals that traders are willing to give up their priority in trading on that side of the market. If the cancellations on the ask (bid) side are correlated with an expected increase (decrease) in price, this would lead traders to post more orders behind the best quotes on the same side of the market to accommodate adverse price changes and to post more market orders on the opposite side to execute the trade before the price change is realized.

   b. Erosion of market depth: Cancellation at the best price widens the spread making market orders from the opposite side of the market more costly. Consequently we would expect less market orders from the opposite side of the market. On the other hand, cancellation of best limit orders lowers the competition for best limit orders on the same side of the market, so we expect more best limit orders to be submitted on the same side of the market (e.g., Parlour (1998)).

5. *No. ask (bid) behind best orders cancelled*: the number of ask (bid) limit orders cancelled behind the best price during the last two minutes.

Hypothesis: Although the cancellation of orders at prices behind the best price does not affect the best price on the book, it does decrease the depth of orders standing in the book behind the best price. Thus we would expect the opposite effect to that of the submission of behind the best limit orders: an increase in the cancellation of orders on the same side of the market leads to more aggressive orders while cancellations on the opposite side of the market lead to less aggressive orders.

6. *Hourly dummy*: The dummy variables are defined to capture the changing features of the market over the trading day. There are six hourly-dummies running from 10:00 to 16:00 (GMT). This allows us to capture differences in the price aggressiveness and quantity at the opening and closing hours of the different markets. For example, we can determine whether orders are more aggressive or larger during the morning session in London or opening hours in New York.

   Hypothesis: Market openings are periods of uncertainty with a large quantity of new information arriving at the market from both informed and uniformed traders, so we expect less aggressive orders to be submitted at market openings but more aggressive orders as the uncertainty decreases over the trading day (e.g., Bloomfield, O'Hara and Saar (2004)).

For identification purposes we add the following variables to both versions of the order aggressiveness equation. These examine how order aggressiveness changes as the prices change

7. *Proportion of positive (negative) price changes*: the number of positive (negative) price changes within the past two minutes divided by the total number of quotes submitted within the past two minutes.

For the quantity equation, the variables we use as the identification restrictions are the proportion (based on the quantity) of best orders submitted from the ask side of the market and the proportion of orders which are large on both sides of the market as identification restrictions. They are defined as

8. *No. of large best ask orders/No. of all best ask orders*: We define large orders as orders over $1 million.[5] The variable is defined by the number of best ask orders submitted with a size larger than $1 million divided by the total number of best ask orders submitted within the past two minutes.
9. *No. of large best bid orders/No. of all best bid orders*: the number of best bid orders submitted with a size larger than $1 million divided by the total number of best bid orders submitted.

3.4 Removing Seasonality

As is typical in microstructure studies, all of our variables exhibit strong intra-day seasonalities. To compensate for this we deseasonalize our variables using the method proposed by Gallant, Rossi and Tauchen (1992). The first step is to regress each variable on a series of adjustment variables as follows:

$$x = d' l + u \tag{3}$$

The adjustment variables we use are 9 hourly dummies, one for each of the hours between 7:00 (GMT) and 16:00 (GMT). These dummies capture the hour-of-the-day effects of the quoting and trading activities shown in Figure 1. To remove the heteroscedasticity in our variables, the residuals are used in the regression

$$\log(u^2) = d'q + v \tag{4}$$

The adjusted or deseasonalized variables are then calculated as follows

$$x_{adj} = \bar{x} + \hat{d}_x \frac{\hat{u}}{\exp(d'q/2)} \tag{5}$$

where $\bar{x}$ is the unadjusted sample mean of the variables and $\hat{d}_x$ is the unadjusted sample standard deviation. The adjusted series have the same sample mean and variance as the unadjusted series, but the effect of seasonality on the mean and variance is removed.

3.5 Marginal Probability

To more clearly see how marginal changes in our explanatory variables affect the probability of order submission in each price aggressiveness category, we calculate the marginal probabilities by:

$$\frac{\partial \Pr[I=1]}{\partial x} = -f(\hat{m}_1 - qn^{*\prime}g - \bar{x}'\hat{b})\hat{b} \tag{6}$$

[5] Approximately half of all of the quotes are submitted for $1 million, which is the minimum quantity required to use the system.

$$\frac{\partial \Pr[I=2]}{\partial x} = -[f(\hat{m}_2 - qn^{*\prime}g - \bar{x}'\hat{b}) - f(m_1 - qn^{*\prime}g - \bar{x}'\hat{b})]\hat{b} \quad (7)$$

$$\frac{\partial \Pr[I=3]}{\partial x} = -[f(\hat{m}_3 - qn^{*\prime}g - \bar{x}'\hat{b}) - f(m_2 - qn^{*\prime}g - \bar{x}'\hat{b})]\hat{b} \quad (8)$$

$$\frac{\partial \Pr[I=4]}{\partial x} = -[f(\hat{m}_4 - qn^{*\prime}g - \bar{x}'\hat{b}) - f(m_3 - qn^{*\prime}g - \bar{x}'\hat{b})]\hat{b} \quad (9)$$

$$\frac{\partial \Pr[I=5]}{\partial x} = -[f(\hat{m}_5 - qn^{*\prime}g - \bar{x}'\hat{b}) - f(m_4 - qn^{*\prime}g - \bar{x}'\hat{b})]\hat{b} \quad (10)$$

$$\frac{\partial \Pr[I=6]}{\partial x} = f(\hat{m}_5 - qn^{*\prime}g - \bar{x}'\hat{b})\hat{b} \quad (11)$$

where $\hat{m}_i$ are the estimated thresholds and f is the normal distribution density. The marginal probability allows us to explicitly determine how each variable affects the probability of submitting orders at each level of aggressiveness avoiding difficulties in interpreting the coefficients in the ordered probit model.

4. Empirical Findings

The first two sub-sections present the results from our analysis of the price aggressiveness and the corresponding quantity for the orders submitted by traders in the foreign exchange market using the depth and the change-in-state models (models (1) and (2)), respectively. In the third sub-section we present the results from the investigation of the aggressiveness of the order cancellation decision. Although quantity may impact the choice of which orders to cancel, it is not a true choice variable (traders can only cancel existing orders), so only include it as an explanatory factor in model (1').

4.1 Order Submission Decision-depth model

The results of the estimation of the price and quantity decisions for each order are presented in Table 4. We consider the ask and bid sides of the market separately as well as in a model pooling the two sides of the market. The pooled model allows us to investigate whether there are asymmetric responses across the ask and bid sides of the market using a set of slope dummy variables for observations coming from the ask side of the market. When interpreting the results a positive coefficient in the price aggressiveness (quantity)

equation means that the factor increases the price aggressiveness (quantity) of the order submitted and a significant slope dummy indicates an asymmetry in reaction between the ask and bid sides of the market.

Trade-off between price and quantity

Price aggressiveness and quantity are negatively related to each other. The estimated coefficient on the aggressiveness variable is significantly negative in both the ask and bid quantity equations (-1.07 and -0.92 respectively) and the estimated coefficients on quantity are also negative in the price aggressiveness equations, although not statistically significant. This suggests that when dealers submit more aggressive orders, they use smaller quantities. The marginal probability analysis in Table 8 shows that the impact of quantity is greatest on market orders and more aggressive limit orders. This is consistent with larger market orders being subject to greater price risk since they may have to walk up (down) the order book to be executed and larger best limit orders carrying a larger adverse selection risk. On the other hand, traders submit less aggressive limit orders (orders behind the best prices) when they are less concerned about the costs of execution risk and adverse selection risk so quantity can increase.

Another potential explanation for the negative relationship between price aggressiveness and quantity is that larger orders convey more information to the market. Easley and O'Hara (1992), for example, suggest that large orders reveal more information. Consequently informed traders will want to submit small, aggressive orders. This will allow them to benefit from their information, while only gradually revealing their information and maximizing the execution probability for their orders. Our results are therefore consistent with traders considering a balance between price aggressiveness and quantity when making their order submission decisions.

Volatility

Table 4 shows that both bid and ask orders become significantly more aggressive and the quantity increases as overall volatility increases. At these times, best limit orders, marketable limit orders and market orders are more likely to be submitted to the market (Table 8). There are two potential explanations for this finding. One is that traders submitting orders place a premium on execution when price uncertainty increases, consistent with the hypothesis of Cohen et al (1981). Another is that traders want to post off-best prices but

the volatility of the market results in these orders being best quotes by the time they arrive at the market. The pooled model suggests that the impact is asymmetric – the ask side is significantly more aggressive than the bid side with the coefficient on the ask dummy on mid-quote volatility being significantly positive (0.097). On the quantity dimension, ask orders are submitted in smaller quantities: the ask dummy on mid quote volatility in the quantity equation is significantly negative (-0.21). Therefore traders selling the asset want to transact quickly and in smaller amounts than buy side traders. This indicates that traders view overall market uncertainty differently depending on whether they wish to buy or sell the asset.

Even though microstructure models do not distinguish between volatility originating from traders wishing to buy or sell, our results suggest that order aggressiveness and quantity respond differently to volatility from the same and the opposite side of the market. As our residual volatility measure is orthogonal to both the common volatility and the volatility from the opposite side of the market, it represents the price uncertainty that can only be attributed to the bid or the ask side of the market. From the pooled submission results in Table 4, we find that an increase in the residual volatility from the same side of the market is related to a significant decrease in the price aggressiveness and a significant decrease in quantity of the orders being submitted. The response is symmetric: the ask dummies corresponding to the same side volatility in both the aggressiveness and quantity equations are not statistically significant. For the residual volatility from the opposite side of the market, we that as it increases significantly more aggressive orders with larger quantity are more likely. The response of the two sides of the market is asymmetric with the ask side of the market being significantly more aggressive when the opposite side residual volatility increases.

To summarize, we find evidence that an increase in the overall level of uncertainty results in traders who wish to sell the asset submitting more aggressive and larger orders to rapidly increase their position. The side from which the uncertainty is arriving also affects the order submissions. The response is asymmetric with ask orders being more aggressive as the volatility on opposite side of the market increases.

Depth at best price

Depth at the best price on the same side of the market discourages both aggressive orders and large orders – the coefficients in both the price aggressiveness and the quantity equations are significantly

negative. Table 8 shows that the probability of limit orders at the best price drops on both sides of the market as the depth increases. This is consistent with the "crowding out" hypothesis of Parlour (1998): as the depth of best limit orders increases, the queue and thus the competition for placing aggressive limit orders increases. This increased competition results in traders refraining from submitting aggressive limit orders. The bid and the ask side of the market are influenced symmetrically by this effect: the ask dummies in neither equations are statistically significant,

An increase in the depth at the best price on the opposite side of the market, however, encourages the submission of more aggressive orders with large sizes. This is because market orders are less likely to have to walk up the order book at these times so the marginal cost of submitting market orders is lower. Similar to the case for changes in the depth on the same side of the market, the bid and ask sides of the market react symmetrically to this effect in terms of both price aggressiveness and quantity.

Depth at the off-best price

The response of price aggressiveness to changes in the depth at the off-best prices is similar to that of changes in the depth at the best price. Orders are significantly more aggressive for changes on the opposite side of the market but less aggressive for changes on the same side of the market. The quantity for ask orders tends to be larger (with p-value of 7%) when the ask off-best depth rises and it drops significantly when the off-best bid depth rises. The bid quantity also increases significantly when the off-best bid depth rises. These findings differ from the results for changes in the depth at the best price, in which quantity drops (rises) with increased depth on the same (opposite) side of the market. One possible explanation for this difference in how the quantity offered changes as the depth changes at the best and off-best prices is that depth placed at off-best prices may reveal information on the expected price changes. If this is the case, placing a larger order at a less aggressive price on the same side of the market is less likely to suffer from adverse selection risk. The same argument works on placing a smaller order at a more aggressive price on the opposite side of the market: if price is expected to move adversely on the opposite side of the market, as it is less risky to place a smaller order.

Difference between best and worst price

An increase in the difference between the best and the worst prices on the opposite (same) side of market leads to more (less) aggressive orders. This is consistent with this variable measuring the presence of asymmetric information and traders benefiting from supplying liquidity as market uncertainty increases on the same side of the market.

Time of Day Effects

We find that the order aggressiveness differs between the London and the New York markets. Compared to the most active hours in London (7:00 to 10:00 (GMT)), ask orders are more aggressive during the most active hours in New York (12:00 to 15:00 (GMT)). The corresponding coefficients on bid orders are not significant (except from 12:00 to 13:00 (GMT)) suggesting that the bid aggressiveness is symmetric between London and New York. On the other hand, as market activity slows, the dummies from 10:00 to 12:00 and from 15:00 to 16:00, ask orders become less aggressive and bid orders become more aggressive. Since trading reveals information, traders are less concerned about adverse selection risk later in the day, especially at the close of the trading day, and thus place more aggressive orders at these times. Our results suggest that bid traders are more concerned about being picked off, so they tend to place more aggressive orders as the trading day draws to a close.

Proportion of Positive and Negative Price changes

We find that an increase in the proportion of positive price changes leads to ask (bid) orders being submitted at more (less) aggressive prices. The reverse happens after negative price changes. Since the future price would be expected to be increasing when the past price movements were positive, traders are most concerned about price increases at these times. As a result we would expect the ask prices to be "less aggressive" following price increases rather than more aggressive. These results may, however, be the consequence of price movements occurring more rapidly than dealers are able to update their quoted prices, so an order that had been intended to be an offbest ask may be a best ask by the time it reaches the market.

Proportion of Large Bid/Ask orders

When there are more large orders (order size larger than $1 million) in either side of the market, the subsequent order size increases. As described in Easley and O'Hara (1992), informed traders tend to trade on

the same side of the market and prefer to submit larger orders. Given a larger proportion of large orders in the past two minutes, it could convey information so traders are more confident and therefore submit larger orders.

4.2 Order Submission Decision – Change-in-State Model

In this section, we examine how changes in the state of the order book affect traders' order submission decisions. To measure the changes, we consider the execution of market orders, the submission of marketable limit orders, the submission of limit orders at three aggressiveness level (orders improving the best price, at the best price, and at off-best prices) and the cancellation of limit orders at the best and off-best prices. These factors allow us to capture all of the ways in which changes can occur in the liquidity and depth of the limit order book. As the results for the quantity and volatility variables are similar to those from the depth model, we focus our discussion in this section on the new factors – the factors related to changes in the state of the limit order book.

Number of market/marketable limit orders

The impact of an increase in the number of market or marketable limit orders on price aggressiveness is consistent with the erosion of depth hypothesis – the submission of same side market orders makes it more costly to submit aggressive orders (see Table 5)[6]. The coefficients on the number of same side market orders and marketable limit orders in the past 2 minutes are significantly negative on both the bid and ask sides in Table 5. The order size is also smaller. The corresponding coefficients for marketable limit orders are significantly negative for both the sides of the market, however, the magnitudes differ. Compared to the bid orders, the ask side reacts more aggressively than the bid side to an increase in the number of marketable limit orders on the same side of the market with the slope coefficient for same-side marketable limit orders being significantly positive.

An increase in the execution of market or marketable limit orders on the opposite side of the market has the opposite effect. With the erosion of market depth on the opposite side of the market, it becomes less costly to submit more aggressive orders. As the number of past bid market orders increases, ask order sizes

[6] Or, equivalently, it can be more advantageous to supply liquidity to the market by submitting less aggressive orders.

are significantly larger. Again we find that the two sides of the market respond asymmetrically. The ask orders are significantly more aggressive in response to opposite side market orders (with p-value 0.08) and the orders are larger (with p-value 0.07) than the bid side.

Submission of limit orders—improving the best price/ at the best price/off-best price

The effect of an increase in the submissions of limit orders on the order submission decision is consistent with the "crowding out" hypothesis of Parlour (1998) and Goettler, Parlour and Rajan (2004). Traders are more likely to submit less aggressive orders on the same side of the market as the number of limit orders placed on the same side increases. The opposite holds for an increase on the opposite side of the market. The effect also depends on the aggressiveness of the limit orders placed previously. Limit orders improving the existing best price have the largest impact followed by orders placed at the existing best price and off-best orders. The intuition is that as the number of aggressive orders submitted on the same side of the market increases, it is more costly to improve the existing price so traders tend to place less aggressive orders. On the other hand, when more aggressive orders are placed on the opposite side of the market, traders recognize the increase in market liquidity so they are willing to place more aggressive orders.

Cancellation of best and off-best limit orders

As with the submission of off-best limit orders, these results are consistent with the erosion of depth hypothesis. The coefficients on the off-best canceled orders for both bid and the ask side submissions are significantly positive. The cancellation of off-best limit orders on the same side of the market erodes market depth on that side, so new limit orders on the same side of the market face less competitive pressure. The opposite holds for cancellations at behind the best prices on the opposite side of the market: they increase the price risk for aggressive orders so orders become less aggressive (only the ask side is significant).

The results for the cancellation of orders at the best price are different and the evidence is mixed. Order submissions on the ask side of the market do not respond to an increase in the cancellation of orders at the best price on either side of the market. Order submissions on the bid side, however, become more aggressive and are larger in size when there are more cancellations at the best price on the opposite side of the market. Thus the cancellation of bid orders at the best price seems to be consistent with the information

hypothesis. However, bid orders also become more aggressive when more best bid orders were cancelled. One potential explanation is that when the best orders are canceled relatively quickly and the bid price is moving down rapidly, an intended off-best order becomes best when it comes into the market.

As reported in Table 5, the response is different for the two sides of the market. The coefficients for the ask dummy corresponding to the number of same-side canceled orders at both best and off-best price are significantly negative so ask orders become less aggressive than bid orders in response to cancellations.

4.3 Cancellation Decision—Depth Model

Because there is relatively little work on what factors affect the order cancellation decision, we have little theory to build on. Nevertheless we use the theory related to order submissions to hypothesize how order size, measures of market depth and price uncertainty affect the order cancellation decision. We investigate the impact of these variables on the price aggressiveness of the orders being cancelled in Table 6. A positive value for the estimated coefficients denotes the cancellation of a more aggressive order.

Quantity

As the quantity of unexecuted orders remaining in the market increases, we find that traders are more likely to cancel less aggressive orders. This suggests that larger orders that are further behind the best price are more likely to get cancelled. Given that these orders are less likely to be executed, it is not surprising that these are more likely to be cancelled.

Price Volatility

We find that price uncertainty impacts the order cancellation decision. An increase in the overall level of price uncertainty leads to an increase in the cancellation of more aggressive orders – traders are more concerned about price movements moving against them. Only the ask cancellation responds significantly to changes in the residual or side-specific volatility – ask orders are cancelled at more aggressive prices when ask volatility increases (with coefficient statistically significant at -0.6265). Since the best limit orders are the first to get hit in these volatile times, traders cancel their most aggressive orders to decrease their adverse selection risk as uncertainty rises. Ask orders are also cancelled at less aggressive prices when bid volatility

increases (0.7101). To take advantage of the uncertainty on the opposite side of the market, we find that ask traders cancel their less aggressive orders and resubmit at more aggressive prices.

Depth at best/ off-best price

Cancellations are more active when there are changes in the depth on the same side of the market. Increasing depth at the best price on the same side of the market leads to an increase in the cancellation of less aggressive orders. The coefficients for the depth at the best prices from the same side of the market are significant and negative for both bid and ask cancellations. Since increased depth at the best price implies that orders at less aggressive prices are less likely to be hit, it increases their execution risk so orders at off-best prices are more likely to be cancelled. On the other hand, increased depth at off-best prices on the same side of the market leads to more cancellations of both bid and ask orders. Increased depth at the off-best prices on the same side of the market indicates that more traders are willing to sell at a higher ask price or buy at a lower bid price than the current best prices. This reveals that the market expects adverse price movements, so orders standing at the best price are more likely to suffer from adverse selection risk and thus more aggressive orders are more likely to be cancelled.

Difference between worst and best price

Because the results on the different sides of the market are ambiguous, we examine the results from the pooled model. Cancellation at more aggressive prices occurs when the spread between the best and worst prices widens on both the bid side and the ask side. This suggests that aggressive orders are sensitive to increased uncertainty on both sides of the market. Comparing the two sides of the market, cancellations on the ask side are at significantly less aggressive prices than the bid cancellations – the ask dummies are significantly negative.

Price change

We find that more aggressive bid (ask) orders and less aggressive ask (bid) orders are cancelled as the proportion of positive (negative) price changes is increasing. Because a larger proportion of positive price changes means the overall price level is increasing, these results indicate that dealers recognize the

upward price trend and cancel their more aggressive ask orders. They also submit less aggressive ask orders to sell at a higher price if the trend continues. We see the reverse when the price is decreasing.

4.4 Cancellation Decision — Change-in-State Model

As in the case of the order submission model, we focus on the impact of the factors measuring changes in the state of the order book. The results corresponding to the effect of quantity, price volatility and the proportion of price changes are similar to the depth model so they are not repeated.

Execution of market/marketable limit orders

Changes in the execution of market orders can reveal important information regarding the expected future changes in the value of the asset and the likelihood of orders being executed. Cancellations therefore depend on the number of market orders executed on each side of the market. More market orders submitted on the same side of the market leads to a significant increase in the number of cancellations at more aggressive prices. The increase in market orders from the same side of the market carries information about the direction of future price changes and it erodes depth and widens spreads, so traders cancel their orders and resubmit at better prices.

Submission of orders improving the best / at-best /or at off-best prices

Submission of orders improving the best prices on the same side of the market leads to the cancellation of more aggressive orders. This is because orders improving best prices, like market orders, carry information pertaining to future price changes so orders at more aggressive prices are canceled and resubmitted later. The submission of at-best orders, however, leads to the cancellation of orders at less aggressive prices on the same side of the market. This is because more depth at the best price leads to higher execution risk for the off-best orders so they are cancelled more often.

Even though the off-best orders are unobservable to the traders, we find that following an increase in the number of off-best limit orders submitted on the same (opposite) side of the market, traders tend to cancel more (less) aggressive ask (bid) orders. The reaction is similar to the case of residual volatility. This suggests that an increase in the activity in the offbest orders on the same side of the market is interpreted as

an increase in the uncertainty of the value of the asset on that side of the market. As a consequence, traders cancel their most aggressive orders on that side and wait for the price to settle at its new equilibrium price.

Cancellation of best / off-best limit orders

Canceling best orders on the same side of the market appears to result in the cancellation of less aggressive orders on the same side of the market. Both the best ask cancellation coefficient (-0.0024) and the best bid cancellation coefficient (-0.019) are statistically significant at the 5% significance level. This suggests that canceling best ask (bid) orders signals to traders the direction the market expects prices to be moving in the future and thus traders cancel less aggressive orders which they believe will have a lower likelihood of being executed. On the other hand, past cancellations at off-best prices do not seem to influence the cancellation decision – all coefficients are statistically insignificant.

5. The Role of Market Performance

In this section, we examine how order aggressiveness and quantity trade off when prices are rising, falling or staying constant. In the basic model, we study the impact of a marginal change in price uncertainty and market depth on a trader's order placement strategy. The impact of the explanatory variables may switch with the state of the market (i.e., the impact may be different if the value of the asset is increasing rather than decreasing), so we investigate the possibility that, for example, the effect of an increase in volatility in a rising market can be different from an increase in volatility in a falling market. Buy traders may be willing to submit more aggressive orders in an uncertain but rising market. We create three dummy variables, d_1, d_2 and d_3, to capture the state of the market. They are obtained by fitting the following price trend regression for all of the mid-quotes submitted over the past two minute interval

$$p_{mid-quote,t} = a + bt + e \qquad (12)$$

where $p_{mid-quote,t}$ is the mid-quote and t is the distance in seconds since the first observation in the two minute interval. The value of β will be positive if the mid-quote price is increasing over this interval, negative if the price is decreasing and not significantly different from zero if the price does not follow an apparent trend. As a result, we use this regression to define the dummy variables as follows:

$d_1 = 1$ if $\hat{b}$ is significantly positive, $d_1 = 0$ otherwise

$d_2 = 1$ if $\hat{b}$ is significantly negative, $d_2 = 0$ otherwise

$d_3 = 1$ if $\hat{b}$ is not statistically different from zero, $d_3 = 0$ otherwise

Consequently, d_1 captures the time during which prices are rising, d_2 when prices are falling and d_3 when price changes are transient or price levels are fairly stable. Since the changes in price depend on other factors, we measure the interaction between the market performance dummy variables and the volatility and market depth. As a result the order aggressiveness regression estimated earlier now becomes

$$I_s^* = g_1 qn + d_1 b^{I_s^*\prime} x_s^{I_s^*} + d_2 b^{I_s^*\prime} x_s^{I_s^*} + d_3 b^{I_s^*\prime} x_s^{I_s^*} + e^{I_s^*} \tag{13}$$

and the quantity regression becomes

$$qn_s = a + g_2 I_s^* + d_1 b^{qn\prime} x_s^{qn} + d_2 b^{qn\prime} x_s^{qn} + d_3 b^{qn\prime} x_s^{qn} + e^{qn} \tag{14}$$

5.1 Empirical Findings of the Role of Market Performance

We find that past price changes play an interesting role in the traders' order submission decisions. Assuming that past price changes provide insight into the market performance of an asset, our model characterizes how past trends in prices interact with our explanatory variables to influence the traders' price and quantity decisions for order submissions (see Table 7).

Volatility

Increases in the overall volatility lead to an increase in the price aggressiveness of both the bid and ask prices when prices are relatively stable (e.g., when there is little new information arriving). This suggests that traders are most worried about execution risk when the overall price level is constant but the variance of prices is increasing. The only other condition under which overall volatility impacts the order submission decision is when prices are falling. At this time we find that orders submitted from the bid side of the market are more aggressive when the price trend is negative. As a result traders appear to view periods when the prices are volatile and falling as buying opportunities that may reverse quickly.

Considering volatility from just one side of the market, we find that both bid and ask orders become less aggressive as same-side volatility increases when the price trend is constant. This suggests that traders

want to avoid adverse selection risk when they are uncertain about the value of the asset (i.e., the residual same side volatility is increasing) yet the price level is stable. On the other hand, both bid and ask orders become more aggressive as the opposite side volatility increases when the price trend is constant. When there are trends in prices we only find an impact on the ask side. Ask quotes become more aggressive with increased opposite side volatility when the price is falling. This suggests that traders are trying to take advantage of price uncertainty on the opposite side of the market – they are trying to pick-off the highest bid orders as the price falls. This will minimize their losses if the price settles at a lower level.

Depth at the best price

When there is more depth at the best ask price, ask orders become less aggressive when the price is either increasing or remaining constant. Ask orders are potentially placed at prices further away from the best price at these times for two reasons: to avoid competition with the existing best orders standing in the market, or in the belief that the limit orders at the best ask price will be executed soon so they can take advantage of the increasing prices. Bid orders respond to changes in the best ask depth in all market conditions – bid orders become more aggressive with increasing ask depth. This would allow the traders to avoid execution risk of their buy orders if the increased depth on the ask side is a signal of future changes in the market.

When the depth at the best bid price is increasing, ask (bid) orders become more (less) aggressive independent of the market conditions. This result indicates that changes in the depth at the best bid price contain a significant amount of information for the order submission decision – more than is contained in past market conditions. The ask (bid) quantity also becomes larger (smaller) when the price trend is constant or decreasing. Ask orders are larger because there is less risk of walking down the order book with a deeper bid depth even in a declining market. Bid orders are smaller to avoid exposure to adverse selection risk in a declining market. These results suggest that traders wishing to sell (buy) the asset try to avoid execution (price) risk as the depth increases on the bid side – potentially signaling future changes in market conditions.

Depth at off- best prices

Depth at off-best ask prices has a significant impact on order aggressiveness when prices are constant. When the market is relatively calm, ask (bid) orders become less (more) aggressive when the

market is deeper at off-best ask prices. The intuition is that traders interpret depth at off-best ask prices as indications of future price increases so ask orders are placed at higher prices to avoid being picked off. Bid orders are submitted at more aggressive prices to get the asset before a rise in prices. Depth at off-best bid prices has a significant positive (negative) impact on ask (bid) aggressiveness when the price is constant. Ask (bid) orders become more (less) aggressive when the market is calm. The intuition for this result is the same as in the case of depth at the off-best ask prices.

One surprising finding is that bid orders become more aggressive when the price drops and depth increases at the off-best bid prices. A potential explanation is that traders want to place those bid orders at off-best prices but the price is dropping too quickly – when the bid orders arrive at the market, they are actually at the best bid price standing in the market.

6. Conclusions

In this paper we investigate two of the most important components of a trader's order submission decision – the aggressiveness of the price and the quantity at which they are willing to transact. Despite the importance of the quantity decision for every order submitted, the quantity aspect of the order submission decision has received relatively little attention in the microstructure literature. Using a simultaneous equation model, we investigate the factors influencing the traders' decisions concerning both the aggressiveness of prices and the associated quantity as well as how they interact.

Using data on firm quotes submitted to the Reuters D-2000-2 system in the Deutsche Mark-U.S. dollar market, we find that traders make negative trade offs between the price and quantity when submitting orders. Aggressive orders are submitted in smaller amounts. This is because quantity affects the price risk of market orders – a larger market order may have to walk up or down the book to ensure complete execution inducing price uncertainty. Quantity also affects the adverse selection risk of limit orders, because larger limit orders suffer larger losses when the efficient price moves against the order.. In a related fashion, we find that changes in the depth of the market and the price uncertainty on each side of the market have a significant impact on the price and quantity of submitted orders. Depth on the opposite side of the market

encourages more aggressive orders of larger size. The opposite happens when depth accumulates on the same side of the market. This supports the "crowding-out" hypothesis in Parlour(1998) and Goetteler, Parlour and Rajan 92004). Although changes in the off-best depth are not observable to the traders, they still significantly affect the price aggressiveness and quantity decision. This suggests that traders use sources of information other than the Reuters screen (e.g. private information from their customers). Changes in the state of the order book also affect the order submission decision with orders becoming more aggressive if there were more aggressive orders submitted in the past on the opposite side of the market.

For the order cancellation decision we find that there are several factors influencing which orders traders cancel. Although quantity is not an explicit component of this decision, we do find that traders are more likely to cancel orders that are less likely to be executed based on factors such as their size, the expected future price changes and liquidity changes. If traders believe the future price will be increasing, for example, traders are more (less) likely to cancel orders that are behind the best bid (ask) price and thus are less (more) likely to be executed.

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Figure 1:

This graph presents the average number of orders submitted in each half hour time bin using the data from the Reuters D-2002 electronic brokerage system for the week of October 6-10, 1997.

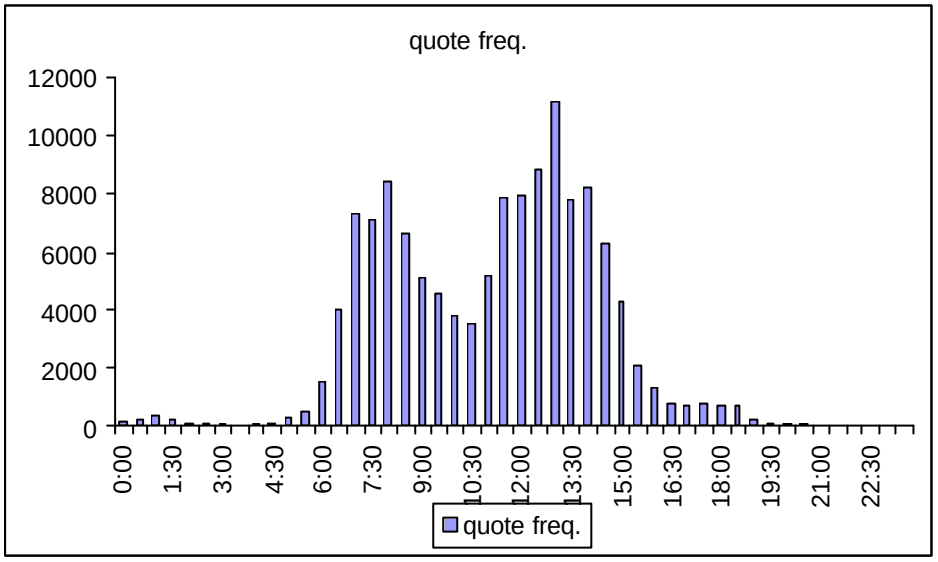

Table 1: Order Aggressiveness and Quantity

The proportion of all of the orders submitted and cancelled falling into each of the six categories for price aggressiveness and the proportion in each of the three quantity categories using the data from the Reuters D-2000-2 electronic brokerage system for the week of October 6-10, 1997.

Order submission	proportion of aggressiveness	proportion of quantity in each catergory		
		qn=1	qn=2	qn>=3
Pooled				
limit order more 1 pip from best price	0.24	0.64	0.19	0.17
limit order within 1 pip of best price	0.11	0.52	0.25	0.23
limit order at best price	0.23	0.50	0.26	0.25
limit order improving best price	0.14	0.41	0.29	0.30
marketable limit order	0.11	0.34	0.27	0.40
Market order	0.17	0.55	0.25	0.20
Ask				
limit order more 1 pip from best price	0.23	0.65	0.18	0.17
limit order within 1 pip of best price	0.11	0.53	0.25	0.22
limit order at best price	0.23	0.50	0.26	0.24
limit order improving best price	0.15	0.42	0.28	0.30
marketable limit order	0.11	0.33	0.26	0.40
market order	0.17	0.55	0.25	0.20
Bid				
limit order more 1 pip from best price	0.25	0.63	0.19	0.18
limit order within 1 pip of best price	0.11	0.51	0.26	0.23
limit order at best price	0.23	0.50	0.25	0.25
limit order improving best price	0.14	0.39	0.31	0.30
marketable limit order	0.11	0.34	0.27	0.39
market order	0.17	0.55	0.24	0.20

Order cancellation	proportion of aggressiveness	proportion of quantity in each catergory		
		qn=1	qn=2	qn>=3
Pooled				
limit order more 2 pip from best price	0.34	0.62	0.20	0.19
limit order within 2 pip of best price	0.30	0.47	0.26	0.27
limit order at best price	0.36	0.38	0.29	0.33
Ask				
limit order more 2 pip from best price	0.33	0.63	0.19	0.18
limit order within 2 pip of best price	0.30	0.46	0.26	0.28
limit order at best price	0.37	0.38	0.29	0.33
Bid				
limit order more 2 pip from best price	0.35	0.61	0.20	0.19
limit order within 2 pip of best price	0.30	0.47	0.26	0.26
limit order at best price	0.36	0.37	0.30	0.33

Table 2: Intra-day Proportion of Orders by Price Aggressiveness and Quantity Category

The table shows the proportion of orders submitted for the Deutsche Mark-US dollar quotes in the Reuters D-2000-2 systemt falling into each price aggressiveness category and the proportion of quantity at each hourly interval

Order submission

	Limit order more than 1 pip from best price	Limit order within 1 pip of best price	Limit order at the best price	Limit order better than best price	Marketable limit order	Market order	qn=1	qn=2	qn>=3
7:00	0.23	0.11	0.22	0.14	0.11	0.19	0.55	0.22	0.23
8:00	0.26	0.11	0.22	0.11	0.12	0.18	0.55	0.22	0.23
9:00	0.22	0.12	0.24	0.13	0.11	0.18	0.54	0.21	0.24
10:00	0.22	0.11	0.23	0.15	0.12	0.16	0.55	0.22	0.23
11:00	0.26	0.10	0.22	0.15	0.12	0.17	0.53	0.22	0.25
12:00	0.24	0.11	0.23	0.14	0.11	0.16	0.48	0.26	0.26
13:00	0.24	0.13	0.24	0.12	0.11	0.16	0.48	0.27	0.25
14:00	0.23	0.11	0.24	0.16	0.11	0.16	0.46	0.28	0.26
15:00	0.22	0.08	0.22	0.26	0.07	0.14	0.48	0.33	0.20

Order cancellation

	Limit order more than 2 pips from the best price	Limit order within 2 pips of best price	Best orders	qn=1	qn=2	qn>=3
7:00	0.36	0.31	0.33	0.53	0.21	0.26
8:00	0.38	0.31	0.30	0.54	0.21	0.25
9:00	0.33	0.33	0.34	0.54	0.20	0.26
10:00	0.34	0.31	0.35	0.55	0.20	0.25
11:00	0.36	0.29	0.35	0.52	0.21	0.27
12:00	0.34	0.30	0.36	0.45	0.27	0.28
13:00	0.33	0.31	0.37	0.45	0.28	0.27
14:00	0.31	0.30	0.40	0.41	0.30	0.29
15:00	0.29	0.23	0.48	0.45	0.35	0.20

Table 3: Descriptive Statistics for Explanatory Variables

For each of the explanatory variables defined in section 3, we present the mean, standard deviation, maximum, median and minimum values. These were obtained using the data from the Reuters D-2000-2 electronic brokerage system for the week of October 6-10, 1997.

	mean	std	max	med	min
Common volatility*	0.19	0.13	0.91	0.16	0.00
Residual ask price volatility	0.01	0.02	0.29	0.00	-0.07
Residual bid price volatility	0.01	0.02	0.27	0.00	-0.14
Depth at best ask price	1.91	1.33	14.00	1.00	1.00
Depth at best bid price	1.94	1.37	21.00	1.00	1.00
Depth at off best ask price	42.08	11.10	83.00	42.00	2.00
Depth at off best bid price	45.05	12.57	88.00	44.00	3.00
Max Ask-Best Ask*	18.75	13.27	56.80	15.50	3.50
Best Bid-Min Bid*	14.41	6.70	50.10	12.20	1.80
No. offbest ask cancelled	18.40	12.03	93.00	16.00	0.00
No. offbest bid cancelled	19.39	12.13	78.00	17.00	0.00
No. best ask cancelled	9.80	5.16	38.00	9.00	0.00
No. best bid cancelled	9.98	5.22	33.00	9.00	0.00
No. offbest ask submitted	19.33	13.84	85.00	16.00	0.00
No. offbest bid submitted	20.35	15.08	141.00	17.00	0.00
No. best ask at existing quote submitted	12.03	6.84	49.00	11.00	0.00
No. best bid at existing quote submitted	12.16	6.62	46.00	11.00	0.00
No. best ask improving existing quote submitted	7.27	3.72	23.00	7.00	0.00
No. best bid improving existing quote submitted	6.99	3.65	22.00	6.00	0.00
No. ask marketable limit order submitted	6.94	7.21	62.00	5.00	0.00
No. bid marketable limit order submitted	6.86	6.42	49.00	5.00	0.00
No. ask market order submitted	9.59	8.68	70.00	8.00	0.00
No. bid market order submitted	9.82	7.80	45.00	8.00	0.00
proportion of price change >0**	18.30	5.10	57.14	18.06	0.00
proportion of price change <0**	18.17	4.94	62.50	17.86	0.00
proportion of ask size >1**	49.82	13.07	100.00	49.32	0.00
proportion of bid size >1**	50.34	13.01	100.00	50.00	0.00

* variable measured in pips

** variables measured in percentage

Table 4: Order Submission—Depth Model

The results from the estimation of model (1) for price aggressiveness and model (2) for quantity. These are estimated for both the order submission decision on both the ask and bid sides of the market, as well as pooling the ask and the bid side together using the data from the Reuters D-2000-2 electronic brokerage system for the week of October 6-10, 1997.

Ask Submission Price Aggressiveness			**Quantity**		
Parameter	*Estimate*	*ProbChiSq*		Estimate	Probt
m_1	-0.8270	0.00	intercept	0.1847	0.04
m_2	0.3371	0.00			
m_3	0.9384	0.00			
m_4	1.3441	0.00			
m_5	1.7350	0.00			
Quantity	-0.2520	0.25	aggressiveness	-1.0740	0.00
Mid-quote volatility	0.1883	0.00	Mid-quote volatility	0.0064	0.94
Residual ask volatility	-0.4593	0.00	Residual ask volatility	0.0402	0.92
Residual bid volatility	1.4559	0.00	Residual bid volatility	0.2973	0.57
Depth at best ask price	-0.0175	0.00	Depth at best ask price	-0.0275	0.00
Depth at best bid price	0.0109	0.00	Depth at best bid price	0.0441	0.00
Depth at off best bid price	-0.0010	0.00	Depth at off best ask price	0.0016	0.07
Depth at off best ask price	0.0023	0.00	Depth at off best bid price	-0.0032	0.00
Max Ask-Best Ask	0.0001	0.63	Max Ask-Best Ask	0.0022	0.00
Best Bid-Min Bid	0.0027	0.00	Best Bid-Min Bid	-0.0048	0.01
proportion of price change >0	0.0123	0.00	proportion of ask size >1	0.0104	0.00
proportion of price change <0	-0.0121	0.00	proportion of bid size >1	0.0020	0.01
h10	-0.0748	0.00	h10	-0.0207	0.77
h11	-0.0330	0.16	h11	0.0048	0.94
h12	0.0467	0.02	h12	0.2771	0.00
h13	0.1346	0.00	h13	0.2194	0.00
h14	0.0535	0.01	h14	0.2807	0.00
h15	-0.0509	0.08	h15	0.0868	0.27

Bid Submission					
Price Aggressiveness			**Quantity**		
Parameter	*Estimate*	*ProbChiSq*		Estimate	Probt
m_1	-0.7059	0.00	intercept	-0.0770	0.37
m_2	0.3242	0.00			
m_3	0.9171	0.00			
m_4	1.2999	0.00			
m_5	1.6764	0.00			
quantity	-0.2672	0.24	aggressiveness	-0.9298	0.00
Mid-quote volatility	0.1044	0.00	Mid-quote volatility	0.2185	0.00
Residual ask volatility	0.5414	0.00	Residual ask volatility	0.7326	0.07
Residual bid volatility	-0.5753	0.00	Residual bid volatility	-0.9596	0.04
Depth at best ask price	0.0118	0.00	Depth at best ask price	0.0491	0.00
Depth at best bid price	-0.0163	0.00	Depth at best bid price	-0.0211	0.00
Depth at off best bid price	0.0016	0.00	Depth at off best ask price	-0.0011	0.20
Depth at off best ask price	-0.0006	0.05	Depth at off best bid price	0.0019	0.01
Max Ask-Best Ask	0.0005	0.04	Max Ask-Best Ask	0.0009	0.12
Best Bid-Min Bid	-0.0032	0.00	Best Bid-Min Bid	-0.0009	0.61
proportion of price change >0	-0.0112	0.00	proportion of ask size >1	0.0015	0.04
proportion of price change <0	0.0137	0.00	proportion of bid size >1	0.0103	0.00
h10	0.1071	0.00	h10	-0.0151	0.82
h11	0.1072	0.00	h11	0.0265	0.66
h12	0.0392	0.04	h12	0.2618	0.00
h13	0.0024	0.90	h13	0.3473	0.00
h14	0.0129	0.51	h14	0.3691	0.00
h15	0.0853	0.00	h15	0.0672	0.36

Pooled Submission					
Price Aggressiveness			**Quantity**		
Parameter	*Estimate*	*ProbChiSq*		Estimate	Probt
m_1	-0.7863	0.00	intercept	0.0366	0.54
m_2	0.3301	0.00			
m_3	0.9265	0.00			
m_4	1.3202	0.00			
m_5	1.7034	0.00			
quantity	-0.1179	0.20	aggressiveness	-1.0017	0.00
Mid-quote volatility	0.0990	0.00	Mid-quote volatility	0.2166	0.00
Residual same side volatility	-0.6313	0.00	Residual same side volatility	-0.9495	0.04
Residual opposite side volatility	0.5289	0.00	Residual opposite side volatility	0.7559	0.05
Depth at best same side price	-0.0183	0.00	Depth at best same side price	-0.0263	0.00
Depth at best opposite side price	0.0145	0.00	Depth at best opposite side price	0.0604	0.00
Depth at off best opposite side price	-0.0002	0.28	Depth at off best opposite side price	0.0009	0.18
Depth at off best same side price	0.0015	0.00	Depth at off best same side price	-0.0009	0.30
Max same side-Best same side	-0.0018	0.00	Max same side-Best same side	-0.0011	0.34
Max opposite side-Best opposite side	0.0000	0.80	Max opposite side-Best opposite side	-0.0019	0.00
proportion of price change >0	-0.0116	0.00	proportion of same size >1	0.0010	0.13
proportion of price change <0	0.0140	0.00	proportion of opposite size >1	0.0098	0.00
Dummy Mid-quote volatility	0.0917	0.01	Dummy mid-quote volatility	-0.2192	0.04
Dummy residual same side volatility	0.0171	0.93	Dummy residual same side volatility	0.8927	0.14
Dummy residual opposite side volatility	0.9589	0.00	Dummy residual opposite side volatility	-0.4130	0.50
Dummy depth at best same side price	0.0001	0.96	Dummy depth at best same side price	-0.0006	0.93
Dummy depth at best opposite side price	-0.0015	0.55	Dummy depth at best opposite side price	-0.0046	0.55
Dummy depth at off best opposite side price	-0.0008	0.01	Dummy depth at off best opposite side price	0.0006	0.54
Dummy depth at off best same side price	0.0003	0.29	Dummy depth at off best same side price	-0.0018	0.08
Dummy same side price difference	0.0020	0.00	Dummy same side price difference	0.0032	0.01
Dummy opposite side price difference	-0.0013	0.00	Dummy opposite side price difference	0.0040	0.00
Dummy proportion of price change >0	0.0237	0.00	Dummy proportion of ask side size >1	0.0100	0.00
Dummy proportion of price change <0	-0.0264	0.00	Dummy proportion of bid side size >1	-0.0077	0.00
h10	0.0050	0.75	h10	-0.0678	0.17
h11	0.0211	0.13	h11	-0.0166	0.71
h12	0.0266	0.03	h12	0.2251	0.00
h13	0.0521	0.00	h13	0.2608	0.00
h14	0.0178	0.14	h14	0.3160	0.00
h15	0.0038	0.83	h15	0.1146	0.04

Table 5: Order Submission-Changes of State Model
The results from the estimation of model (1) for price aggressiveness and model (2) for quantity. These are estimated for both the order submission decision on the ask and bid sides of the market, as well as pooling the ask and bid side together using the data from the Reuters D-2000-2 electronic brokerage system for the week of October 6-10, 1997. Parameters in italics indicates ask slope dummy.

Ask Submission					
Price Aggressiveness			**Quantity**		
Parameter	*Estimate*	*ProbChiSq*		Estimate	Probt
m_1	-0.8539	0.00	intercept	0.0793	0.23
m_2	0.3377	0.00			
m_3	0.9403	0.00			
m_4	1.3484	0.00			
m_5	1.7424	0.00			
Quantity	0.0024	0.99	aggressiveness	-2.1442	0.00
Mid-quote volatility	0.0860	0.02	Mid-quote volatility	0.1245	0.28
Residual ask volatility	-0.3701	0.02	Residual ask volatility	-0.2434	0.61
Residual bid volatility	0.8716	0.00	Residual bid volatility	1.2366	0.07
No. offbest ask cancelled	0.0033	0.00	No. offbest ask cancelled	0.0021	0.36
No. offbest bid cancelled	-0.0022	0.00	No. offbest bid cancelled	-0.0008	0.65
No. best ask cancelled	0.0011	0.26	No. best ask cancelled	-0.0023	0.41
No. best bid cancelled	0.0007	0.46	No. best bid cancelled	0.0105	0.00
No. offbest ask submitted	-0.0001	0.87	No. offbest ask submitted	-0.0034	0.02
No. offbest bid submitted	0.0010	0.03	No. offbest bid submitted	0.0016	0.24
No. best ask at existing quote submitted	-0.0024	0.00	No. best ask at existing quote submitted	-0.0015	0.55
No. best bid at existing quote submitted	0.0020	0.01	No. best bid at existing quote submitted	0.0019	0.41
No. best ask improving existing quote submitted	-0.0042	0.00	No. best ask improving existing quote submitted	0.0021	0.65
No. best bid improving existing quote submitted	0.0048	0.00	No. best bid improving existing quote submitted	0.0001	0.98
No. ask marketable limit order submitted	-0.0048	0.00	No. ask marketable limit order submitted	-0.0085	0.02
No. bid marketable limit order submitted	0.0035	0.00	No. bid marketable limit order submitted	-0.0003	0.92
No. ask market order submitted	-0.0067	0.00	No. ask market order submitted	-0.0031	0.49
No. bid market order submitted	0.0067	0.00	No. bid market order submitted	0.0113	0.02
proportion of price change >0	0.0046	0.00	proportion of price change >0	0.0097	0.00
proportion of price change <0	-0.0036	0.00	proportion of price change <0	0.0021	0.01
h10	-0.0935	0.00	h10	-0.1209	0.16
h11	-0.0495	0.03	h11	-0.0501	0.47
h12	0.0325	0.09	h12	0.3089	0.00
h13	0.1217	0.00	h13	0.3475	0.00
h14	0.0398	0.04	h14	0.3198	0.00
h15	-0.0715	0.01	h15	0.0148	0.87

Bid Submission					
Price Aggressiveness			**Quantity**		
Parameter	*Estimate*	*ProbChiSq*		Estimate	Probt
m_1	-0.7412	0.00	intercept	0.0204	0.75
m_2	0.3248	0.00			
m_3	0.9191	0.00			
m_4	1.3040	0.00			
m_5	1.6835	0.00			
quantity	-0.3266	0.12	aggressiveness	-1.7727	0.00
Mid-quote volatility	0.1182	0.00	Mid-quote volatility	0.2908	0.01
Residual ask volatility	0.4693	0.00	Residual ask volatility	0.6116	0.15
Residual bid volatility	-0.2601	0.15	Residual bid volatility	-0.8097	0.11
No. offbest ask cancelled	-0.0006	0.29	No. offbest ask cancelled	0.0012	0.45
No. offbest bid cancelled	0.0057	0.00	No. offbest bid cancelled	0.0026	0.27
No. best ask cancelled	0.0024	0.01	No. best ask cancelled	0.0089	0.00
No. best bid cancelled	0.0036	0.00	No. best bid cancelled	0.0042	0.13
No. offbest ask submitted	0.0010	0.05	No. offbest ask submitted	-0.0014	0.30
No. offbest bid submitted	-0.0011	0.01	No. offbest bid submitted	-0.0008	0.52
No. best ask at existing quote submitted	0.0015	0.03	No. best ask at existing quote submitted	0.0004	0.84
No. best bid at existing quote submitted	-0.0027	0.00	No. best bid at existing quote submitted	-0.0025	0.29
No. best ask improving existing quote submitted	0.0032	0.03	No. best ask improving existing quote submitted	-0.0011	0.78
No. best bid improving existing quote submitted	-0.0016	0.26	No. best bid improving existing quote submitted	0.0003	0.94
No. ask marketable limit order submitted	0.0042	0.00	No. ask marketable limit order submitted	0.0012	0.64
No. bid marketable limit order submitted	-0.0057	0.00	No. bid marketable limit order submitted	-0.0092	0.01
No. ask market order submitted	0.0057	0.00	No. ask market order submitted	0.0037	0.22
No. bid market order submitted	-0.0074	0.00	No. bid market order submitted	-0.0039	0.35
proportion of price change >0	-0.0049	0.00	proportion of price change >0	0.0013	0.10
proportion of price change <0	0.0061	0.00	proportion of price change <0	0.0105	0.00
h10	0.1110	0.00	h10	0.0603	0.42
h11	0.1122	0.00	h11	0.1041	0.13
h12	0.0435	0.02	h12	0.2838	0.00
h13	0.0053	0.77	h13	0.3395	0.00
h14	0.0165	0.39	h14	0.3688	0.00
h15	0.0901	0.00	h15	0.1198	0.12

Pooled Submission					
Aggressiveness					
Parameter	Estimate	ProbChiSq		Estimate	Probt
Intercept	-0.8122	0.00	Intercept	0.0687	0.14
Intercept2	0.3312	0.00			
Intercept3	0.9297	0.00			
Intercept4	1.3263	0.00			
Intercept5	1.7131	0.00			
Quantity	-0.0882	0.32	agg	-2.0458	0.00
Mid-quote volatility	0.1011	0.00	Mid-quote volatility	0.2991	0.01
Residual same side volatility	-0.2821	0.06	Residual same side volatility	-1.1387	0.02
Residual opposite side volatility	0.3930	0.00	Residual opposite side volatility	1.1031	0.01
No. offbest same side cancelled	0.0060	0.00	No. offbest same side cancelled	0.0042	0.07
No. offbest opposite side cancelled	-0.0011	0.02	No. offbest opposite side cancelled	0.0000	0.99
No. best same side cancelled	0.0035	0.00	No. best same side cancelled	0.0063	0.02
No. best opposite side cancelled	0.0015	0.07	No. best opposite side cancelled	0.0094	0.00
No. offbest same side submitted	-0.0014	0.00	No. offbest same side submitted	-0.0015	0.26
No. offbest opposite side submitted	0.0004	0.37	No. offbest opposite side submitted	-0.0012	0.37
No. best same side at existing quote submitted	-0.0040	0.00	No. best same side at existing quote submitted	-0.0043	0.08
No. best opposite side at existing quote submitted	0.0017	0.00	No. best opposite side at existing quote submitted	0.0014	0.49
No. best same side improving existing quote submitted	-0.0024	0.05	No. best same side improving existing quote submitted	-0.0025	0.49
No. best opposite side improving existing quote submitted	0.0030	0.02	No. best opposite side improving existing quote submitted	0.0022	0.59
No. same side marketable limit order submitted	-0.0062	0.00	No. same side marketable limit order submitted	-0.0108	0.00
No. opposite side marketable limit order submitted	0.0043	0.00	No. opposite side marketable limit order submitted	0.0036	0.18
No. same side market order submitted	-0.0075	0.00	No. same side market order submitted	-0.0051	0.15
No. opposite side market order submitted	0.0055	0.00	No. opposite side market order submitted	0.0059	0.04

Proportion of price change >0	-0.0047	0.00	proportion of same side size >1	0.0015	0.04
Proportion of price change <0	0.0061	0.00	proportion of opposite side size >1	0.0101	0.00
dummy mid-quote volatility	0.0103	0.83	dummy mid-quote volatility	-0.2345	0.11
dummy residual same side volatility	-0.0749	0.71	dummy residual same side volatility	0.4221	0.51
dummy residual opposite side volatility	0.5506	0.01	dummy residual opposite side volatility	0.2622	0.68
dummy no. offbest same side cancelled	-0.0022	0.00	dummy no. offbest same side cancelled	-0.0026	0.25
dummy no. offbest opposite side cancelled	-0.0008	0.21	dummy no. offbest opposite side cancelled	-0.0009	0.67
dummy no. best same side cancelled	-0.0022	0.04	dummy no. best same side cancelled	-0.0095	0.01
dummy no. best opposite side cancelled	-0.0005	0.66	dummy no. best opposite side cancelled	0.0007	0.85
dummy no. offbest same side submitted	0.0016	0.00	dummy no. offbest same side submitted	-0.0023	0.22
dummy no. offbest opposite side submitted	0.0009	0.13	dummy no. offbest opposite side submitted	0.0031	0.10
dummy no. best same side at existing quote submitted	0.0019	0.03	dummy no. best same side at existing quote submitted	0.0033	0.23
dummy no. best opposite side at existing quote submitted	0.0009	0.30	dummy no. best opposite side at existing quote submitted	0.0002	0.93
dummy no. best same side improving existing quote submitted	-0.0016	0.31	dummy no. best same side improving existing quote submitted	0.0056	0.23
dummy no. best opposite side improving existing quote submitted	0.0028	0.10	dummy no. best opposite side improving existing quote submitted	-0.0023	0.64
dummy no. same side marketable limit order submitted	0.0018	0.06	dummy no. same side marketable limit order submitted	0.0036	0.25
dummy no. opposite side marketable limit order submitted	-0.0004	0.70	dummy no. opposite side marketable limit order submitted	-0.0047	0.14
dummy no. same side market order submitted	0.0012	0.18	dummy no. same side market order submitted	0.0034	0.23
dummy no. opposite side market order submitted	0.0017	0.08	dummy no. opposite side market order submitted	0.0053	0.07
dummy proportion of price change >0	0.0089	0.00	dummy proportion of ask side size >1	0.0076	0.00
dummy proportion of price change <0	-0.0095	0.00	dummy proportion of bid side size >1	-0.0076	0.00
h10	0.0066	0.66	h10	-0.0402	0.41
h11	0.0288	0.04	h11	0.0188	0.67
h12	0.0290	0.01	h12	0.2795	0.00
h13	0.0568	0.00	h13	0.3472	0.00
h14	0.0258	0.03	h14	0.3441	0.00
h15	0.0059	0.73	h15	0.0608	0.26

Table 6: Order Cancellation—Depth Model

The results from the estimation of model (1') for price aggressiveness. The model is estimated for both the order cancellation decision on both the ask and bid sides of the market using the data from the Reuters D-2000-2 electronic brokerage system for the week of October 6-10, 1997.

	Ask		**Bid**		**Pooled**	
Parameter	*Estimate*	*ProbChiSq*	*Estimate*	*ProbChiSq*	*Estimate*	*ProbChiSq*
m_1	-0.3197	0.00	-0.2634	0.00	-0.2813	0.00
m_2	0.8036	0.00	0.7908	0.00	0.7964	0.00
quantity	-0.0755	0.00	-0.0834	0.00	-0.0792	0.00
Mid-quote volatility	0.5105	0.00	0.5704	0.00	0.5514	0.00
Residual same (ask) side volatility	-0.6256	0.00	0.2375	0.19	0.2858	0.15
Residual opposite (bid) side volatility	0.7101	0.00	0.3345	0.11	0.2403	0.16
Depth at best same (ask) side price	-0.0442	0.00	-0.0017	0.41	-0.0367	0.00
Depth at best opposite (bid) side price	0.0017	0.45	-0.0414	0.00	-0.0017	0.45
Depth at off best opposite (ask) side price	0.0034	0.00	-0.0007	0.08	0.0036	0.00
Depth at off best same (bid) side price	-0.0001	0.80	0.0037	0.00	-0.0009	0.01
Max same (ask) side-Best same (ask) side	-0.0001	0.75	-0.0006	0.04	0.0014	0.00
Best opposite (bid) side-Min opposite (bid) side	0.0017	0.03	0.0014	0.07	0.0011	0.00
proportion of price change >0	-0.0082	0.00	0.0021	0.01	0.0022	0.01
proportion of price change <0	0.0043	0.00	-0.0054	0.00	-0.0052	0.00
Dummy Mid-quote volatility					-0.0173	0.75
Dummy residual same (ask) side volatility					-0.8971	0.00
Dummy residual opposite (bid) side volatility					0.4238	0.11
Dummy depth at best same (ask) side price					-0.0014	0.66
Dummy depth at best opposite (bid) side price					0.0028	0.37
Dummy depth at off best opposite (bid) side price					-0.0005	0.26
Dummy depth at off best same (ask) side price					0.0010	0.03
Dummy same (ask) side price difference					-0.0018	0.00
Dummy opposite (bid) side price difference					-0.0010	0.08
Dummy proportion of price change >0					-0.0106	0.00
Dummy proportion of price change <0					0.0095	0.00
h10	-0.0708	0.02	-0.0589	0.05	-0.0477	0.03
h11	-0.0679	0.02	-0.0017	0.95	-0.0223	0.28
h12	-0.0970	0.00	-0.0748	0.00	-0.0694	0.00
h13	-0.0482	0.03	-0.1702	0.00	-0.1006	0.00
h14	-0.1510	0.00	-0.1972	0.00	-0.1764	0.00
h15	-0.4014	0.00	-0.2727	0.00	-0.3464	0.00

Table 7 Cancellation-Changes of State Model

The results from the estimation of model (1') for price aggressiveness. These are estimated for both the order cancellation decision on the ask and bid sides of the market, as well as pooling the ask and bid side together using the data from the Reuters D-2000-2 electronic brokerage system for the week of October 6-10, 1997. Parameters in italics indicates ask slope dummy.

	Pooled Cancellation		Ask cancellation		Bid Cancellation	
Parameter	Estimate	ProbChiSq	Estimate	ProbChiSq	Estimate	ProbChiSq
Intercept	-0.2393	0.00	-0.2538	0.00	-0.2113	0.00
Intercept2	0.7920	0.00	0.7983	0.00	0.7861	0.00
Quantity	-0.0770	0.00	-0.0746	0.00	-0.0798	0.00
Mid-quote volatility	0.2601	0.00	0.2926	0.00	0.2796	0.00
Residual same (ask) side volatility	0.4295	0.04	-0.3118	0.10	0.2113	0.26
Residual opposite (bid) side volatility	0.1457	0.41	0.3694	0.09	0.3557	0.10
No. offbest same (ask) side cancelled	0.0000	0.94	-0.0001	0.88	-0.0003	0.69
No. offbest opposite (bid) side cancelled	0.0001	0.91	-0.0004	0.58	0.0003	0.63
No. best same (ask) side cancelled	-0.0017	0.09	-0.0024	0.04	0.0018	0.12
No. best opposite (bid) side cancelled	0.0019	0.09	-0.0008	0.49	-0.0019	0.09
No. offbest same (ask) side submitted	0.0039	0.00	0.0039	0.00	-0.0012	0.06
No. offbest opposite (bid) side submitted	-0.0014	0.02	-0.0006	0.33	0.0034	0.00
No. best same (ask) side at existing quote submitted	-0.0034	0.00	-0.0018	0.05	-0.0019	0.04
No. best opposite (bid) side at existing quote submitted	-0.0020	0.03	-0.0008	0.37	-0.0036	0.00
No. best same (ask) side improving existing quote submitted	0.0043	0.02	0.0059	0.00	-0.0016	0.42
No. best opposite (bid) side improving existing quote submitted	-0.0015	0.38	0.0014	0.49	0.0043	0.02
No. same (ask) side marketable limit order submitted	0.0020	0.04	0.0014	0.16	0.0004	0.69
No. opposite (bid) side marketable limit order submitted	0.0002	0.81	-0.0003	0.79	0.0023	0.03
No. same (ask) side market order submitted	0.0042	0.00	0.0025	0.01	-0.0009	0.34
No. opposite (bid) side market order submitted	-0.0013	0.19	-0.0019	0.08	0.0042	0.00
proportion of price change >0	0.0039	0.00	-0.0088	0.00	0.0034	0.00
proportion of price change <0	-0.0062	0.00	0.0049	0.00	-0.0059	0.00

Cancellation-Changes of State Model(continued)

dummy mid-quote volatility	0.0334	0.63				
dummy residual same (ask) side volatility	-0.7978	0.01				
dummy residual opposite (bid) side volatility	0.2031	0.47				
dummy no. offbest same (ask) side cancelled	-0.0006	0.53				
dummy no. offbest opposite (bid) side cancelled	-0.0007	0.47				
dummy no. best same (ask) side cancelled	-0.0012	0.44				
dummy no. best opposite (bid) side cancelled	-0.0022	0.18				
dummy no. offbest same (ask) side submitted	0.0003	0.70				
dummy no. offbest opposite (bid) side submitted	0.0011	0.19				
dummy no. best same (ask) side at existing quote submitted	0.0015	0.20				
dummy no. best opposite (bid) side at existing quote submitted	0.0008	0.52				
dummy no. best same (ask) side improving existing quote submitted	0.0032	0.20				
dummy no. best opposite (bid) side improving existing quote submitted	0.0027	0.27				
dummy no. same (ask) side marketable limit order submitted	0.0000	1.00				
dummy no. opposite (bid) side marketable limit order submitted	-0.0012	0.39				
dummy no. same (ask) side market order submitted	-0.0016	0.25				
dummy no. opposite (bid) side market order submitted	-0.0010	0.47				
dummy proportion of price change >0	-0.0124	0.00				
dummy proportion of price change <0	0.0104	0.00				
h10	-0.0692	0.00	-0.0710	0.02	-0.0579	0.05
h11	-0.0343	0.08	-0.0680	0.02	-0.0014	0.96
h12	-0.0853	0.00	-0.0968	0.00	-0.0744	0.00
h13	-0.1030	0.00	-0.0465	0.04	-0.1661	0.00
h14	-0.1742	0.00	-0.1503	0.00	-0.1971	0.00
h15	-0.3296	0.00	-0.4008	0.00	-0.2723	0.00

Table 8 Marginal Probability

This table shows the marginal reactions of price aggressiveness in each category to a change in the explanatory variables. The values are obtained using equations 6 to 11.

Ask Submission-Depth Model

	Limit order more than 1 pip from best price	*Limit order within 1 pip of best price*	*Limit order at the best price*	*Limit order better than best price*	*Marketable limit order*	*Market order*
quantity	0.0668	0.0303	-0.0278	-0.0243	-0.0196	-0.0254
Mid-quote volatility	-0.0499	-0.0227	0.0208	0.0182	0.0146	0.0190
Residual ask volatility	0.1218	0.0553	-0.0507	-0.0443	-0.0357	-0.0463
Residual bid volatility	-0.3862	-0.1752	0.1608	0.1405	0.1133	0.1468
Depth at best ask price	0.0046	0.0021	-0.0019	-0.0017	-0.0014	-0.0018
Depth at best bid price	-0.0029	-0.0013	0.0012	0.0010	0.0008	0.0011
Depth at off best ask price	0.0003	0.0001	-0.0001	-0.0001	-0.0001	-0.0001
Depth at off best bid price	-0.0006	-0.0003	0.0003	0.0002	0.0002	0.0002
Max Ask-Best Ask	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Best Bid-Min Bid	-0.0007	-0.0003	0.0003	0.0003	0.0002	0.0003
proportion of price change >0	-0.0033	-0.0015	0.0014	0.0012	0.0010	0.0012
proportion of price change <0	0.0032	0.0015	-0.0013	-0.0012	-0.0009	-0.0012
h10	0.0199	0.0090	-0.0083	-0.0072	-0.0058	-0.0075
h11	0.0087	0.0040	-0.0036	-0.0032	-0.0026	-0.0033
h12	-0.0124	-0.0056	0.0052	0.0045	0.0036	0.0047
h13	-0.0357	-0.0162	0.0149	0.0130	0.0105	0.0136
h14	-0.0142	-0.0064	0.0059	0.0052	0.0042	0.0054
h15	0.0135	0.0061	-0.0056	-0.0049	-0.0040	-0.0051

Bid Submission-Depth Model

	Limit order more than 1 pip from best price	*Limit order within 1 pip of best price*	*Limit order at the best price*	*Limit order better than best price*	*Marketable limit order*	*Market order*
quantity	0.0829	0.0184	-0.0310	-0.0242	-0.0197	-0.0263
Mid-quote volatility	-0.0324	-0.0072	0.0121	0.0095	0.0077	0.0103
Residual ask volatility	-0.1679	-0.0373	0.0628	0.0491	0.0399	0.0534
Residual bid volatility	0.1784	0.0397	-0.0668	-0.0522	-0.0424	-0.0567
Depth at best ask price	-0.0036	-0.0008	0.0014	0.0011	0.0009	0.0012
Depth at best bid price	0.0050	0.0011	-0.0019	-0.0015	-0.0012	-0.0016
Depth at off best ask price	-0.0005	-0.0001	0.0002	0.0001	0.0001	0.0002
Depth at off best bid price	0.0002	0.0000	-0.0001	-0.0001	0.0000	-0.0001
Max Ask-Best Ask	-0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
Best Bid-Min Bid	0.0010	0.0002	-0.0004	-0.0003	-0.0002	-0.0003
proportion of price change >0	0.0035	0.0008	-0.0013	-0.0010	-0.0008	-0.0011
proportion of price change <0	-0.0042	-0.0009	0.0016	0.0012	0.0010	0.0013
h10	-0.0332	-0.0074	0.0124	0.0097	0.0079	0.0106
h11	-0.0332	-0.0074	0.0124	0.0097	0.0079	0.0106
h12	-0.0122	-0.0027	0.0046	0.0036	0.0029	0.0039
h13	-0.0007	-0.0002	0.0003	0.0002	0.0002	0.0002
h14	-0.0040	-0.0009	0.0015	0.0012	0.0009	0.0013
h15	-0.0264	-0.0059	0.0099	0.0077	0.0063	0.0084

Marginal Probability (continue d)

Ask Submission-Change-in-State Model						
	Limit order more than 1 pip from best price	*Limit order within 1 pip of best price*	*Limit order at the best price*	*Limit order better than best price*	*Marketable limit order*	*Market order*
Quantity	-0.0006	-0.0003	0.0003	0.0002	0.0002	0.0002
Mid-quote volatility	-0.0218	-0.0116	0.0092	0.0084	0.0068	0.0089
Residual ask volatility	0.0936	0.0499	-0.0398	-0.0360	-0.0294	-0.0384
Residual bid volatility	-0.2205	-0.1176	0.0937	0.0848	0.0693	0.0903
No. offbest ask cancelled	-0.0008	-0.0005	0.0004	0.0003	0.0003	0.0003
No. offbest bid cancelled	0.0006	0.0003	-0.0002	-0.0002	-0.0002	-0.0002
No. best ask cancelled	-0.0003	-0.0001	0.0001	0.0001	0.0001	0.0001
No. best bid cancelled	-0.0002	-0.0001	0.0001	0.0001	0.0001	0.0001
No. offbest ask submitted	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
No. offbest bid submitted	-0.0002	-0.0001	0.0001	0.0001	0.0001	0.0001
No. best ask at existing quote submitted	0.0006	0.0003	-0.0003	-0.0002	-0.0002	-0.0003
No. best bid at existing quote submitted	-0.0005	-0.0003	0.0002	0.0002	0.0002	0.0002
No. best ask improving existing quote submitted	0.0011	0.0006	-0.0005	-0.0004	-0.0003	-0.0004
No. best bid improving existing quote submitted	-0.0012	-0.0006	0.0005	0.0005	0.0004	0.0005
No. ask marketable limit order submitted	0.0012	0.0007	-0.0005	-0.0005	-0.0004	-0.0005
No. bid marketable limit order submitted	-0.0009	-0.0005	0.0004	0.0003	0.0003	0.0004
No. ask market order submitted	0.0017	0.0009	-0.0007	-0.0007	-0.0005	-0.0007
No. bid market order submitted	-0.0017	-0.0009	0.0007	0.0007	0.0005	0.0007
proportion of price change >0	-0.0012	-0.0006	0.0005	0.0004	0.0004	0.0005
proportion of price change <0	0.0009	0.0005	-0.0004	-0.0004	-0.0003	-0.0004
h10	0.0236	0.0126	-0.0100	-0.0091	-0.0074	-0.0097
h11	0.0125	0.0067	-0.0053	-0.0048	-0.0039	-0.0051
h12	-0.0082	-0.0044	0.0035	0.0032	0.0026	0.0034
h13	-0.0308	-0.0164	0.0131	0.0118	0.0097	0.0126
h14	-0.0101	-0.0054	0.0043	0.0039	0.0032	0.0041
h15	0.0181	0.0096	-0.0077	-0.0069	-0.0057	-0.0074

Marginal Probability (continue d)

Bid Submission-Change-in-State Model						
	Limit order more than 1 pip from best price	*Limit order within 1 pip of best price*	*Limit order at the best price*	*Limit order better than best price*	*Marketable limit order*	*Market order*
Quantity	0.0963	0.0287	-0.0367	-0.0299	-0.0248	-0.0336
Mid-quote volatility	-0.0348	-0.0104	0.0133	0.0108	0.0090	0.0122
Residual ask volatility	-0.1383	-0.0413	0.0528	0.0430	0.0356	0.0483
Residual bid volatility	0.0767	0.0229	-0.0292	-0.0238	-0.0197	-0.0268
No. offbest ask cancelled	0.0002	0.0001	-0.0001	-0.0001	0.0000	-0.0001
No. offbest bid cancelled	-0.0017	-0.0005	0.0006	0.0005	0.0004	0.0006
No. best ask cancelled	-0.0007	-0.0002	0.0003	0.0002	0.0002	0.0002
No. best bid cancelled	-0.0011	-0.0003	0.0004	0.0003	0.0003	0.0004
No. offbest ask submitted	-0.0003	-0.0001	0.0001	0.0001	0.0001	0.0001
No. offbest bid submitted	0.0003	0.0001	-0.0001	-0.0001	-0.0001	-0.0001
No. best ask at existing quote submitted	-0.0004	-0.0001	0.0002	0.0001	0.0001	0.0002
No. best bid at existing quote submitted	0.0008	0.0002	-0.0003	-0.0002	-0.0002	-0.0003
No. best ask improving existing quote submitted	-0.0009	-0.0003	0.0004	0.0003	0.0002	0.0003
No. best bid improving existing quote submitted	0.0005	0.0001	-0.0002	-0.0001	-0.0001	-0.0002
No. ask marketable limit order submitted	-0.0012	-0.0004	0.0005	0.0004	0.0003	0.0004
No. bid marketable limit order submitted	0.0017	0.0005	-0.0006	-0.0005	-0.0004	-0.0006
No. ask market order submitted	-0.0017	-0.0005	0.0006	0.0005	0.0004	0.0006
No. bid market order submitted	0.0022	0.0007	-0.0008	-0.0007	-0.0006	-0.0008
proportion of price change >0	0.0014	0.0004	-0.0005	-0.0004	-0.0004	-0.0005
proportion of price change <0	-0.0018	-0.0005	0.0007	0.0006	0.0005	0.0006
h10	-0.0327	-0.0098	0.0125	0.0102	0.0084	0.0114
h11	-0.0331	-0.0099	0.0126	0.0103	0.0085	0.0115
h12	-0.0128	-0.0038	0.0049	0.0040	0.0033	0.0045
h13	-0.0016	-0.0005	0.0006	0.0005	0.0004	0.0005
h14	-0.0049	-0.0015	0.0019	0.0015	0.0013	0.0017
h15	-0.0266	-0.0079	0.0101	0.0083	0.0068	0.0093

Table 9 Market Performance

This table shows the order submission strategies when price change is rising, falling or remaining constant.

Ask Submission							
Order Aggressiveness				*Quantity*			
Parameter	*price trend*	*Estimate*	*Prob*		*price trend*	*Estimate*	*Prob*
m_1		-0.8433	0.00	intercept		0.2644	0.00
m_2		0.3368	0.00				
m_3		0.9371	0.00				
m_4		1.3423	0.00				
m_5		1.7331	0.00				
quantity		0.0225	0.85	aggressiveness		-1.1072	0.00
Mid-quote volatility	positive	0.1429	0.33	Mid-quote volatility	positive	-0.4282	0.33
	negative	0.1796	0.30		negative	-0.0856	0.86
	constant	0.1964	0.00		constant	0.0635	0.49
Residual ask volatility	positive	0.8433	0.39	Residual ask volatility	positive	-1.4828	0.63
	negative	-0.0829	0.94		negative	1.3249	0.66
	constant	-0.6374	0.00		constant	-0.0903	0.84
Residual bid volatility	positive	-0.7323	0.43	Residual bid volatility	positive	-1.3588	0.64
	negative	2.8856	0.01		negative	0.9438	0.78
	constant	1.338	0.00		constant	0.2806	0.61
Depth at best ask price	positive	-0.012	0.02	Depth at best ask price	positive	-0.0338	0.04
	negative	-0.0113	0.11		negative	-0.0519	0.02
	constant	-0.0198	0.00		constant	-0.0259	0.00
Depth at best bid price	positive	0.0164	0.02	Depth at best bid price	positive	0.0328	0.13
	negative	0.0103	0.05		negative	0.0450	0.00
	constant	0.0092	0.00		constant	0.0447	0.00
Depth at off best ask price	positive	0.0007	0.49	Depth at off best ask price	positive	-0.0017	0.56
	negative	-0.0006	0.61		negative	0.0029	0.40
	constant	-0.0013	0.00		constant	0.0019	0.05
Depth at off best bid price	positive	0.0009	0.35	Depth at off best bid price	positive	-0.0029	0.35
	negative	0.0016	0.11		negative	-0.0063	0.04
	constant	0.0021	0.00		constant	-0.0029	0.00
Max Ask-Best Ask	positive	-0.0006	0.34	Max Ask-Best Ask	positive	0.0029	0.13
	negative	0.0003	0.61		negative	0.0013	0.53
	constant	0	0.99		constant	0.0022	0.00
Best Bid-Min Bid	positive	-0.0014	0.53	Best Bid-Min Bid	positive	-0.0065	0.35
	negative	-0.0028	0.34		negative	-0.0059	0.50
	constant	0.0026	0.00		constant	-0.0044	0.02
proportion of price change >0	positive	0.0063	0.01	proportion of ask size >1	positive	0.0127	0.00
	negative	0.0111	0.00		negative	0.0138	0.00
	constant	0.0119	0.00		constant	0.0100	0.00
proportion of price change <0	positive	0.0052	0.11	proportion of bid size >1	positive	0.0038	0.22
	negative	-0.0099	0.00		negative	0.0016	0.65
	constant	-0.0125	0.00		constant	0.0019	0.01

Market Performance (continue d)

Bid Submission							
Order Aggressiveness				*Quantity*			
Parameter	*price trend*	*Estimate*	*Prob*		*price trend*	*Estimate*	*Prob*
Intercept		-0.7072	0.00	intercept		0.0588	0.48
Intercept2		0.3242	0.00				
Intercept3		0.9175	0.00				
Intercept4		1.3004	0.00				
Intercept5		1.6767	0.00				
q_hat		-0.1051	0.40	agg		-1.0289	0.00
Mid-quote volatility	positive	-0.0106	0.93	Mid-quote volatility	positive	0.6632	0.07
	negative	0.4954	0.00		negative	1.1034	0.01
	constant	0.0867	0.00		constant	0.1243	0.15
Residual ask volatility	positive	1.1684	0.20	Residual ask volatility	positive	4.6260	0.08
	negative	0.6763	0.47		negative	5.4294	0.06
	constant	0.4683	0.00		constant	0.6703	0.11
Residual bid volatility	positive	-0.8682	0.37	Residual bid volatility	positive	-3.8301	0.18
	negative	1.1957	0.21		negative	0.4749	0.87
	constant	-0.6579	0.00		constant	-0.8701	0.08
Depth at best ask price	positive	0.0117	0.02	Depth at best ask price	positive	0.0445	0.00
	negative	0.0212	0.00		negative	0.0494	0.01
	constant	0.0108	0.00		constant	0.0506	0.00
Depth at best bid price	positive	-0.0206	0.01	Depth at best bid price	positive	-0.0232	0.31
	negative	-0.0208	0.00		negative	-0.0289	0.04
	constant	-0.0161	0.00		constant	-0.0226	0.00
Depth at off best ask price	positive	0.0008	0.42	Depth at off best bid price	positive	-0.0054	0.06
	negative	-0.0003	0.75		negative	0.0006	0.85
	constant	0.0016	0.00		constant	-0.0009	0.36
Depth at off best bid price	positive	-0.0016	0.11	Depth at off best ask price	positive	0.0030	0.31
	negative	0.0029	0.00		negative	0.0026	0.34
	constant	-0.0008	0.00		constant	0.0019	0.02
Max Ask-Best Ask	positive	0.0017	0.02	Max Ask-Best Ask	positive	0.0027	0.19
	negative	-0.0008	0.28		negative	0.0015	0.50
	constant	0.0004	0.09		constant	0.0006	0.34
Best Bid-Min Bid	positive	-0.0045	0.05	Best Bid-Min Bid	positive	0.0068	0.31
	negative	0.0001	0.98		negative	-0.0065	0.42
	constant	-0.0034	0.00		constant	-0.0020	0.27
proportion of price change >0	positive	-0.0038	0.09	proportion of ask size >1	positive	-0.0053	0.12
	negative	-0.0056	0.12		negative	0.0012	0.66
	constant	-0.0113	0.00		constant	0.0017	0.02
proportion of price change <0	positive	0.0075	0.03	proportion of bid size >1	positive	0.0092	0.00
	negative	0.0079	0.00		negative	0.0097	0.00
	constant	0.0137	0.00		constant	0.0104	0.00