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Ingrid Lo and[1] Stephen G. Sapp[2]

[1]Financial Markets Department
Bank of Canada
Ottawa, Ontario, Canada K1A 0G9
ingridlo@bankofcanada.ca

[2]Richard Ivey School of Business
University of Western Ontario
London, Ontario, Canada N6A 3K7
ssapp@ivey.uwo.ca

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Abstract

Dealers trading in a limit order market must choose both the order aggressiveness and the quantity for their orders. We empirically investigate how dealers jointly make these decisions in the foreign exchange market using a unique simultaneous equations model. The model uses an ordered probit model to account for the discrete nature of order aggressiveness and a censored regression model to capture the clustering of orders placed at the smallest available quantity, $1 million. We find evidence of a clear trade-off between order aggressiveness and quantity: more aggressive orders tend to be smaller in size. The increased competition (demand) suggested by increased depth on the same (opposite) side of the market leads to less (more) aggressive orders in smaller (larger) size. This holds for the depths at both the best and off-best prices, even though off-best depths are not observable to dealers.

JEL classification: G14
Bank classification: Exchange rates; Financial markets

Résumé

Les placeurs d'ordres sur un marché avec carnet doivent décider à la fois de la compétitivité et de la taille de l'ordre. Au moyen de leur propre modèle à équations simultanées, les auteurs étudient empiriquement comment ces décisions sont prises en commun sur le marché des changes. Leur modèle englobe un modèle probit ordonné et un modèle de régression avec données censurées pour tenir compte respectivement de la nature discrète de la compétitivité des ordres et du fait qu'un grand nombre des ordres ont la taille minimale (qui est d'un million de dollars). Les auteurs constatent la présence d'un arbitrage clair entre la compétitivité et la taille des ordres : les ordres les plus compétitifs sont généralement de taille plus faible. La concurrence (demande) accrue qu'implique une hausse de la profondeur du même côté (du côté opposé) du carnet encourage la soumission d'ordres moins (plus) compétitifs portant sur de plus petits (plus gros) montants. Ce résultat se vérifie aussi bien aux meilleures limites qu'aux autres prix du carnet, même si les cambistes ne peuvent observer la profondeur des ordres qu'aux meilleures limites.

Classification JEL : G14
Classification de la Banque : Taux de change; Marchés financiers

Introduction:

In a limit order market, traders submitting an order must choose both the order aggressiveness and quantity. We define order aggressiveness by the execution priority. Market orders are the most aggressive, as they are executed immediately, and limit orders are less aggressive because their execution is not guaranteed and they follow strict price and time priorities in execution. Despite the dual nature of order submissions, much of the literature focuses on order aggressiveness (i.e., Griffiths et al. (2000), Cao, Hansch and Wang (2004), and Ranaldo (2004)). In these studies, the quantity dimension is ignored or treated as explanatory variables rather than a choice variable. A notable exception is Moulton (2003) who allows traders to choose quantity but only at the existing price. The study did not examine the potential trade off that dealers make between price and quantity.

Since traders choose both order aggressiveness and quantity when submitting orders in a limit order market, we simultaneously estimate the choice of order aggressiveness and quantity. Using the simultaneous equations method in Nelson, Forrest and Olsen (1978), we formally examine the trade-off between order aggressiveness and quantity, conditioning on the state of the limit order book. Though order aggressiveness has been modeled before, including the joint role of quantity is new. In the simultaneous equations model, order aggressiveness is estimated using an ordered probit model, as in Griffiths et al. (2000), Cao, Hansch and Wang (2004), and Ranaldo (2004). This accommodates the discrete nature of prices.[1] Quantity is modeled using a censored regression framework, which accommodates the minimum order size of $1 million and the clustering of orders at $1 million.

Our study makes several contributions to the market microstructure literature. The first contribution is to more completely model the order submission process. Our model captures both the simultaneous nature of the price-quantity decision as well as many of the empirical features of the data – price clustering, quantity censorship etc. We also extend the standard definition of the decision to cancel an order. Most studies only investigate order submissions and those which consider both submissions and cancellations (e.g. Cao, Hansch and 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 dealers – it is only available to those who have already submitted an order – 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 order 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].

Second our study uses data on firm orders submitted to the Reuters D-2000-2 system in the Deutsche Mark-U.S. dollar market. This differs from the majority of studies in this area which focus on U.S. equities markets and allows us to benefit from some of the differences in market structures. The system allows dealers to submit both market and limit orders twenty-four hours a day. Although every order submitted is observable in the dataset[3], dealers using the Reuters D-2000-2 system only observe the best price and corresponding quantity posted on both sides of the market and the most recent transaction activity. Since we have more information than dealers, we are able to determine whether the information from the orders not directly observable by dealers affects their price and quantity decisions. If this information is 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 overall traders are hesitant to submit more aggressive orders. They are least likely to submit market orders, than limit orders at the best price and limit orders improving the best price. Considering both prices and quantities, we find a negative tradeoff between order aggressiveness and quantity – the quantity tends to be smaller when the order is more aggressive. Further, there is evidence that dealers split large, aggressive orders into smaller orders because the submission of both $1-million market orders and aggressive limit orders on the same side of the market are positively autocorrelated[4]. Traders split orders for many reasons such as small market orders revealing less information and their individual price impact is smaller than one large market order which may have to walk up the order book to be completely filled. If the order book is resilient (i.e., limit orders arrive to refill the order book quickly after orders are executed), then breaking up large orders into small ones entails less execution cost. A further advantage of small, aggressive limit orders is that they face less risk of being picked-off if the value of the asset moves against the dealer and he cannot cancel the order in time.

Considering the impact of depth at different price levels on both sides of the order book, we find that dealers submit less aggressive orders with smaller sizes as market depth increases at the best price on the same side of the market. These results are consistent with the "crowding out" effect of Parlour (1998) where dealers avoid submitting more aggressive limit orders on the same side of the market to avoid competing with those orders. But different from empirical studies such as. Ellul et al. (2003) which suggest that traders compete to obtain priority in the order book by submitting more aggressive orders as the depth on the same-side of the market deepens. As depth decreases on the other side of the market, we find dealers are more willing to submit aggressive orders since they are less concerned about their orders walking up / down the order book to be executed.

Changes in market conditions also impact order submissions. As measures of market uncertainty (e.g., volatility and spread) increase, we find that both ask and bid orders become more aggressive and orders are larger in size. As in Cohen et al. (1981) this indicates that dealers want to ensure their orders are executed in an uncertain market. This also suggests that after the arrival of new information resulting in a widening of the spread, dealers update their information set and use this to place more aggressive orders which undo the previous change in the spread. This is consistent with Engle and Patton (2004) who find that the best bid and ask prices are cointegrated and revert to their equilibrium value after a shock. Considering the impact of residual volatility (volatility from only the bid or ask side), we find that dealers submit less aggressive orders (i.e. more behind best limit orders) when price uncertainty comes from the same side of the market, thereby reducing their risk of being picked-off. However, dealers 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.

The paper develops as follows. In the next section we discuss the data used. Section two presents our empirical model and our hypotheses. The third section discusses the results from the basic model. Section four considers how the performance of the market affects the submission and cancellation decisions and the final section concludes.

1. 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 dealers can submit both market and limit orders. Subscribers see the best bid and best ask quotes, the size supplied at these prices, the exact time they 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. We do not have information on the identity of the dealer submitting the order. As a result, we treat each submitted order as an independent submission conditional on the state of the limit order book. Although we observe every order submitted to the market, dealers can only observe the best bid and ask prices, their associated quantity and the most recent transactions. They can not observe the limit orders posted at off-best prices nor their cancellation. They do, however, have 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 foreign exchange trading activity following the event (for a discussion see Carlson and Lo (2004)), we exclude this day from our sample.

The use of the foreign exchange market has several advantages over the more commonly used equity data. First, the foreign exchange market does not have specific opening and closing procedures. Also, there is no market maker or features such as "iceberg orders" which may have unexpected impacts on the observed market liquidity. Thus, our dataset allows us to more completely study how the supply and demand for this currency pair develop over the day and influence dealers' decisions. This data set therefore provides an ideal environment within which to study how order aggressiveness and quantity are impacted by changes in the state of the limit order book. Another advantage of this dataset is that, despite the short time span of the dataset, it is the only dataset available with complete information on the limit order book in the inter-dealer foreign exchange market. Other studies such as Evans and Lyons (2004a), Evans and Lyons (2004b), Osler (2003) and Mende, Menhkoff and Osler (2005) use information from a single dealer. Our study complements theirs in examining the trading activities of all dealers in this market. Further, the Deutsche Mark - US dollar was the most heavily traded currency pair before the introduction of Euro. The size of the market limits potential problems resulting from illiquid trading, information asymmetries and other errors in the measurement of microstructure characteristics. Although only 37% of brokered trade in the inter-dealer market occurred on the Reuter's platform in 1997 (Payne (1999)), understanding this market is increasingly important as around 85% of the interdealer trade in major currencies currently goes through the electronic limit order book (Sager and Taylor (2005)). Without any other limit order book data available in the foreign exchange market, this dataset provides a unique perspective into the order submission strategies of dealers in this highly liquid market.

The complete data set consists of 130,526 quotes. Because we focus on 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 consists of 91,086 submitted quotes and 48,455 cancellations. Table 1 breaks-down the order aggressiveness of these order submissions into six categories: market orders (17%), marketable limit orders (11%), best limit orders improving existing best price (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 price (24%). The proportions are similar for the ask side and the bid side of the market. Table 1 also shows the proportion of different order sizes in each category. A general observation is that orders cluster at $1 million – the minimum quantity allowed to be submitted on the Reuters D2000-2 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 and are similar for the ask and the bid sides of the market. Because of this clustering at the minimum quantity, we use a censored regression model for quantity in the empirical analysis. 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 order 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 and 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 pick-off risk decreases so dealers are increasingly willing to place limit orders consistent with Bloomfield, O'Hara and Saar (2004). Cancellation activities mirror those of submissions. There are relatively more best limit orders cancelled in the morning while more limit orders at prices more than 2 pips away from the best price are cancelled at the end of the trading day. Because of the more efficient pricing over the day, 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 whereas the proportion of larger orders increases over the trading day. This pattern suggests that the size of orders increases as information asymmetries decline over the trading day.

In studying the trade-off between order aggressiveness and quantity, we condition on the state of the limit order book using a set of explanatory variables. The summary statistics for these explanatory variables are presented in Table 3. An interesting observation is that the depth on the bid side of the market is larger than on the ask side. This is true 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.

2. Model:

We empirically model the simultaneous nature of the order aggressiveness and quantity of orders submitted in a limit order market. By formally accounting for both of these characteristics of the orders submitted to the limit order book, our model extends the existing work which only considers certain order aggressiveness – quantity combinations. We also extend these studies by modeling the order submission and cancellation decisions separately – we do not assume cancellations are simply the least aggressive form of order submission as in most existing studies.

2.1 Order submission – Simultaneous Ordered Probit and Quantity Regressions

To investigate the order submission process, we jointly model the order aggressiveness and quantity decisions. For our analysis we define order aggressiveness based on the priority of execution. Specifically 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, we model this by assuming the vector of the discrete choices of order submissions of type, I_s, depends on the latent order aggressiveness variable, I_s^*, which is assumed to be continuous. The latent order aggressiveness is related to the choice of order type as follows

I_s = 1 if $-\infty < I_s^* \le \mu_1$ (off-best limit order placed more than 1 pip away from the best quote)

= 2 if $\mu_1 < I_s^* \le \mu_2$ (off-best limit order placed within 1 pip of the best quote

= 3 if $\mu_2 < I_s^* \le \mu_3$ (best order placed at the existing best quote)

=4 if $\mu_3 < I_s^* \le \mu_4$ (best order improving the existing best quote)

=5 if $\mu_4 < I_s^* \le \mu_5$ (marketable limit order)

=6 if $\mu_5 < I_s^* \le \infty$ (market order)

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

For the quantity, 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_s, depends on the latent quantity, qn_s^*, such that:

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

We estimate both the latent order aggressiveness and the latent quantity within a simultaneous equation framework. The latent order aggressiveness variable, I_s^*, depends on the latent quantity, qn_s^*, and factors related to market depth and liquidity. The latent regression model is therefore given by:

$$I_s^* = \gamma_1 qn^*{}_s + \beta^{I_s^*}{}' x_s^{I_s^*} + \varepsilon^{I_s^*} \quad (1)$$

where qn_s^* 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, $z_x^{I^*}$, for identification purpose. The latent order aggressiveness is estimated within an ordered probit framework. Turning to the specification of quantity, the latent quantity equation is specified as:

$$qn^*{}_s = a + \gamma_2 I_s^* + b^{qn}{}' x_s^{qn} + \varepsilon^{qn} \quad (2)$$

where $x_s^{qn} = [x_s \quad z_x^{qn}]$ combines the same set of predetermined variables, x_s, as for equation (1) as well as the predetermined variables not in the latent price regression, z_x^{qn}, for identification purposes. Equation (2) is estimated using a censored regression model.

The two equations are estimated using a method analogous to the two-stage least squares method of Nelson, Forrest and Olsen (1978). In the first stage, we estimate the reduced-form equations to obtain the instruments for the order aggressiveness $\hat{I}_s^* = \hat{\varphi}_{I^*}{}' x_s^{I_s^*}$ using an ordered probit model and for the quantity $\hat{q}n_s = \hat{\phi}' x_x^{qn}$ using a censored regression model. In the second stage, $\hat{I}_s^*$ replaces its counterpart in the quantity equation and the quantity equation is estimated via a censored regression model. Similarly,

$\hat{q}n_s$ is substituted for qn in the latent variable equation for order aggressiveness and the order aggressivness equation is estimated via an ordered probit model.

2.2 Order Cancellation

To examine the order cancellation decision, we only need to model the latent variable for order aggressiveness. Quantity is not a choice variable as traders can only cancel orders that were submitted earlier. Just as in the order submission case, the order aggressiveness is defined as:

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

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

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

Though quantity is not a choice variable in the order cancellation decision, it could affect the decision of which order to ultimately cancel. Thus it is used as an exogenous variable in the ordered probit model for cancellation:

$$I_c^* = \gamma_3 qn_c + \beta^{I_c^*}{}' x_s + \varepsilon^{I_c^*} \qquad (1')$$

where I_c^* is the latent variable for cancellation and the explanatory variables include those exogenous variables used in the model for the submission of orders and quantity, x_s.

2.3 Hypothesis and control variables

Overall we expect that order aggressiveness is negatively related to quantity, because the potential cost of large market orders is high – a large trade may reveal more information and may have to walk further up or down the order book to be completely executed. Although not as strong a concern, large, aggressive limit orders may also reveal more information and there is a larger potential cost of being picked off if the value of the asset moves against the dealer and he cannot cancel the larger order.

In studying the trade-off between order aggressiveness and quantity, we control for the impact on order aggressiveness and quantity decisions of volatility, spread and market depths at the best price. The following are the control variables and how we expect them to impact dealers' price and quantity choices:

1. ***Volatility:*** We consider both the common realized volatility (the uncertainty of the value of the currency) and the residual volatility (the uncertainty affecting only the ask side or the bid side of the market). The common realized volatility is the volatility of the mid-quote, the average of the best bid and best ask quotes standing in the market, for every order submitted during the past 2 minutes: $v_{common,i} = \sqrt{\frac{\sum_{j=1}^{n}(p^{mid-quote} - \overline{p^{mid-quote}})^2}{(n-1)}}$.

   The residual volatility is the volatility associated with only the ask side 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: $v_{ask} = \alpha + \beta_1 v_{common} + \beta_2 v_{bid} + \varepsilon_{ask}$ 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. The residual volatility is a measure not considered in previous studies and it is intended to capture the potentially asymmetric impact of uncertainty affecting only one side of the market.

   Hypothesis: As suggested by Foucault (1999), if the increase in uncertainty is due to an increase in the asymmetry of information across dealers, 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) point out that as price uncertainty increases, risk-averse dealers place a premium on certainty in the execution of their trades. As a consequence, their model suggests 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 orders 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 encourage market orders initiated from the opposite side of the market but 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 orders 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. ***Spread***: the spread between the best bid and ask prices

   Hypothesis: Since the best bid and best ask prices are cointegrated (e.g., Engle and Patton (2004)), we expect that orders submitted following a widening of spread should improve the best prices to return the spread to its equilibrium value. On the other hand, a larger bid-ask spread means a higher cost of submitting market orders since dealer have to pay half the spread when submitting market orders. Thus dealers would refrain from submitting market orders at these times.

5. ***Hourly dummy*****:** Six hourly-dummies running from 10:00 to 16:00 (GMT) are created to capture differences in the order aggressiveness and quantity over the trading day.

   Hypothesis: Compared to the London opening hours, our base case, we expect order placements for the rest of the London trading session, 10:00-12:00 (GMT), to be less aggressive and continue to decrease until the close in New York. This is because the asymmetry of information is widest at the opening in London and narrows as trading updates the dealers' information set (i.e., Bloomfield, O'Hara and Saar (2004)).

For identification purposes, we add the following variables to examine how order aggressiveness changes as prices change

1. ***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.

   For the quantity equation, the variables we use for identification are the proportion of large best orders submitted on each side of the market. More specifically,

2. ***No. of large best ask (bid) orders/No. of all best ask (bid) orders*****:** the number of large best ask (bid) orders, defined as orders over $1 million, divided by the total number of best ask (bid) orders submitted within the past two minutes.

2.4 Removing Seasonality

As is typical in microstructure studies, all the explanatory variables exhibit intra-day seasonalities. To compensate for this, the explanatory variables are deseasonalized 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:

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

The adjustment variables used are 9 hourly dummies, d (a 9×1 vector), 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

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

where θ are the coefficients associated with the hourly dummies. The adjusted or deseasonalized variables are then calculated as follows

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

where $\bar{x}$ is the unadjusted sample mean of the variables and $\hat{\delta}_x$ 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.

2.5 Marginal Probability

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

$$\frac{\partial \Pr[I=1]}{\partial x} = -\phi(\hat{\mu}_1 - qn^{*\prime}\gamma - \bar{x}'\hat{\beta})\hat{\beta} \quad (6)$$

$$\frac{\partial \Pr[I=2]}{\partial x} = -[\phi(\hat{\mu}_2 - qn^{*\prime}\gamma - \bar{x}'\hat{\beta}) - \phi(\mu_1 - qn^{*\prime}\gamma - \bar{x}'\hat{\beta})]\hat{\beta} \quad (7)$$

$$\frac{\partial \Pr[I=3]}{\partial x} = -[\phi(\hat{\mu}_3 - qn^{*\prime}\gamma - \bar{x}'\hat{\beta}) - \phi(\mu_2 - qn^{*\prime}\gamma - \bar{x}'\hat{\beta})]\hat{\beta} \quad (8)$$

$$\frac{\partial \Pr[I=4]}{\partial x} = -[\phi(\hat{\mu}_4 - qn^{*\prime}\gamma - \bar{x}'\hat{\beta}) - \phi(\mu_3 - qn^{*\prime}\gamma - \bar{x}'\hat{\beta})]\hat{\beta} \quad (9)$$

$$\frac{\partial \Pr[I=5]}{\partial x} = -[\phi(\hat{\mu}_5 - qn^{*\prime}\gamma - \bar{x}'\hat{\beta}) - \phi(\mu_4 - qn^{*\prime}\gamma - \bar{x}'\hat{\beta})]\hat{\beta} \quad (10)$$

$$\frac{\partial \Pr[I=6]}{\partial x} = \phi(\hat{\mu}_5 - qn^{*\prime}\gamma - \bar{x}'\hat{\beta})\hat{\beta} \quad (11)$$

where $\hat{\mu}_i$ are the estimated thresholds and ϕ is the normal distribution density. The marginal probabilities allow 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.

3. Empirical Findings

This section presents the results from the analysis of the order aggressiveness and the corresponding quantity for the order submissions as well as for the order cancellations.

3.1 Order Submission

The results from the estimation of the price and quantity decisions are presented in Table 5. We first consider the ask side and the bid side of the market separately and then we estimate a model pooling both sides of the market. The pooled model allows us to examine whether there are asymmetric responses across the ask side and bid side 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 order aggressiveness (quantity) equation means that the factor increases the order aggressiveness (quantity) of the order submitted and a significant slope dummy indicates an asymmetry in the reaction between the ask and bid sides of the market.

Trade-off between price and quantity

After controlling for the state of the limit order book, order aggressiveness and quantity are negatively related to each other. The estimated coefficient on the aggressiveness variable is significantly negative in both the ask equation and the bid quantity equation (-1.10 and -0.93 respectively). The estimated coefficients on quantity are also negative in the order aggressiveness equations, although not statistically significant. The marginal probability analysis in Table 7 shows that dealers submitting orders at more aggressive prices are more likely to submit smaller orders. This suggests that dealers submit aggressive orders with small quantities.

There are two potential reasons why more aggressive orders are smaller: order splitting or order consolidating. In the order consolidation case, dealers submit small orders to fulfill immediate liquidity needs. In the order splitting case, dealers split their orders into smaller lots for information reason – large orders, as suggested in Easley and O'Hara (1992), may reveal more information. Consequently dealers may break up large market orders into a string of smaller market orders to more gradually reveal their information. If the order book is resilient (i.e., the order book is refilled quickly after an order is filled) this breaking up of orders may also lower the execution cost. Further penalizing large orders is the fact that large, aggressive limit orders have a larger risk of being picked off – the dealer losing when the value of the currency moves against the dealer and he is not able to cancel the order in time. Consequently, dealers put in small aggressive limit orders which have priority in execution and at the same time minimize the pick-off risk.

As we do not know the identity of the dealer submitting an order, we examine the time series of order submission activities to determine whether order splitting or order consolidation account for this finding. If it were order splitting, we would expect the placement of small orders to be positively autocorrelated on the same side of the market. Dealers will submit a series of small orders until the order is completely executed. In the case of order consolidation, there is no theoretical reason why the orders would be autocorrelated on the same side of the market—dealers just submit a small order for liquidity reasons and subsequently leave the market. We employ a linear autoregressive model to examine the placement of $1 million orders in 10 second intervals. We count the number of $1-million market orders[5] and aggressive limit orders[6] in each interval and run an AR(10) model on each side of the market for each trading day.

$$x_t = \sum_{i=1}^{10} \rho_i x_t + \varepsilon_t \qquad (12)$$

where x_t is the number of market orders or aggressive limit orders in the 10-second interval at time t. The estimation results in Table 4 show that the placement of both $1-million market orders and aggressive limit orders are positively autocorrelated. The 1st-order autocorrelation coefficients on both sides of the market are around 0.3 and most of the autocorrelation coefficients are significantly positive at the 5% level or better. The findings therefore suggest that dealers split their orders to either hide their information or to decrease the execution costs.

Volatility

Table 5 shows that both bid and ask orders become significantly more aggressive and the quantity increases as volatility increases. At these times, best limit orders, marketable limit orders and market orders are more likely to be submitted (Table 7). This finding suggests that dealers submitting orders place a premium on execution certainty when price uncertainty is increasing, consistent with the hypothesis of Cohen et al. (1981). 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 (0.012). 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 (-0.017). Therefore dealers selling the asset want to transact more quickly and in smaller amounts than buy side dealers. This indicates that dealers view overall market uncertainty differently depending on whether they wish to buy or sell the asset.

We also find that the choice of order aggressiveness and quantity respond differently to volatility from the different sides of the market. The residual volatility measure is defined to be orthogonal to both the common volatility and the volatility from the opposite side of the market, so it represents the price uncertainty arising from just the bid or just the ask side of the market. The results suggest that dealers are more adverse to being picked off when uncertainty comes from the same side of the market so they place less aggressive orders. On the other hand, when the uncertainty is on the other side, dealers pick-off orders on the opposite side of the market by placing more aggressive orders. Further, the pooled submission result in Table 5 shows that the response of the two sides of the market is symmetric with the ask dummies not being statistically significant. As the residual volatility from the opposite side of the market increases, however, we see significantly more aggressive ask orders with larger quantities.

Depth at the best price

An increase in the depth at the best price on the same side of the market discourages both aggressive orders and large orders – the coefficients in both the order aggressiveness and the quantity equations are significantly negative. Table 7 shows that the marginal probability of limit orders being submitted at the best price drops 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 dealers refraining from submitting aggressive limit orders. The effect is similar on both sides of the market.

Considering changes in the depth on the opposite side of the market, we find that an increase in the depth at the best price on the opposite side of the market encourages the submission of more aggressive orders with larger sizes. This is because market orders, for example, are less likely to have to walk up the order book, 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 in terms of both order aggressiveness and quantity.

Depth at the off-best price

The response of order 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 in off-best depth on the opposite side of the market but become less aggressive for changes in off-best depth on the same side of the market. The effect of changes in depth at the off-best prices is, however, much smaller than changes in depth at the best price. In the ask order aggressiveness equation, for example, the coefficient on the depth at the off-best ask price (-0.0006) is less than one thirtieth the coefficient on the depth at the best ask price (-0.191). The results suggest that either (i) changes in the depth at off-best prices carry less information than at the best prices or (ii) changes in the off-best depth are less transparent to market participants (dealers can not directly observe them so they react less to these changes). Nevertheless, changes in off-best depth still significantly affect dealers' order submission strategies in the same direction as the changes at the best price.

The quantity of the orders reacts quite differently to the changes in depth at the off-best prices than it did for changes in the depth at the best prices. The quantity for ask orders tends to be larger (with a p-value of 7%) when the off-best ask depth rises and it drops significantly when the off-best bid depth rises. In the bid equations, the bid quantity also increases significantly when the off-best bid depth rises. These are the opposite of the results for changes in the depth at the best price, where the quantity drops (rises) with increased depth on the same (opposite) side of the market. One possible explanation for this difference is that the depth at the off-best price on the other side of the market is a measure of the marginal cost of executing large market orders. As a result, dealers tend to submit smaller orders to avoid walking up the order book when the depth deepens only at the off-best prices on the opposite side of the market while depth at the best price remains unchanged.

Spread

Orders become more aggressive and larger in size when the spread widens. In fact, the marginal likelihood of a limit order being submitted at the best price or limit orders improving the best price increases. This means that, following a widening of the spread, dealers observe the new information, update their information set and settle on new equilibrium price. Based on this new price, dealers place more at-best and improving-best limit orders, which eventually narrows the spread again. This is consistent with the empirical findings in Engle and Patton (2004). Using equity data, they find that best bid and ask prices are cointegrated and they revert to their equilibrium value after a shock to the spread.

Another interesting finding related to the spread is that the marginal likelihood for marketable limit orders and market orders also increases following a widening of the spread. This is contrary to the intuition that market orders become more expensive as the spread widens. The results suggest that dealers become more concerned about ensuring their orders are executed in an uncertain market as in Cohen et al. (1981).

Turning to the pooled submission results in Table 5, we find that the two sides of the market react symmetrically to changes in the spread in terms of order aggressiveness but not in terms of quantity. For the order aggressiveness equation, we find that the spread impacts order aggressiveness symmetrically – the ask dummy related to spread is not significant. However, for the quantity equation, the ask dummy on spread is significantly negative (-0.0125). This suggests that the ask orders are significantly smaller than the bid orders when spread widens.

Time of Day Effects

We find that the nature of the order aggressiveness differs between the London and the New York markets. Ask orders are more aggressive during the most active hours in New York (12:00 to 15:00 (GMT)) than during the most active hours in London (7:00 to 10:00 (GMT)). The bid aggressiveness is symmetric during their active hours. On the other hand, as market activity slows following the initial surge at the opening in London and New York, from 10:00 to 12:00 and from 15:00 to 16:00 respectively, ask orders become less aggressive and bid orders become more aggressive. These results suggest that dealers placing bid orders become more concerned about being picked off over the day, since trading reveals information, thereby reducing the information asymmetry through the trading day, especially at the close of the trading day. Thus they place more aggressive bid orders at these times.

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. To examine why this is the case, we run a regression of the present change in mid-quote prices on the previous changes in the mid-quote:

$$\Delta midquote_i = \beta \Delta midquote_{i-1} + \varepsilon_i \quad (13)$$

The autocorrelation coefficient, β (-0.181), is significantly negative at the 1% level. This suggests that when market participants see a series of positive price changes, they expect the price to revert in the future and thus place more aggressive sell orders. The opposite happens after a series of negative price changes.

Proportion of Large Bid/Ask orders

When there are more large orders (orders larger than $1 million) on either side of the market, the subsequent order size increases. As described in Easley and O'Hara (1992), informed dealers tend to trade on the same side of the market and prefer to submit larger orders. Given an increasing proportion of large orders in the past two minutes, it could convey information so dealers are more confident and therefore submit larger orders.

3.2 Cancellation Decision

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 aggressiveness of the orders being cancelled in Table 6.

Quantity

As the quantity of unexecuted orders remaining in the market increases, we find that dealers are more likely to cancel less aggressive orders[7]. Thus 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 an increase in the overall level of price uncertainty leads to an increase in the cancellation of more aggressive orders. The result suggests that dealers are more concerned about price changes going against them and therefore being picked off at times of price uncertainty. This is particularly evident in the equation where ask orders are cancelled at more aggressive prices when ask side volatility increases (with the statistically significant coefficient of -0.0618). Less aggressive ask orders are also cancelled when the bid volatility increases (0.0754). This finding ties in with the order submission decision. As the residual volatility from the opposite side of the market increases, dealers submit more aggressive orders to pick off orders on the opposite side of the market. At these times, ask dealers would therefore cancel their less aggressive ask 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. Increased depth at the best price on the same side of the market leads to an increase in the cancellation of less aggressive bid and ask orders. Since increased depth at the best price implies that orders at less aggressive prices are less likely to be hit, their execution risk increases so orders at off-best prices are more likely to be cancelled.

On the other hand, increased depth at the off-best prices on the same side of the market leads to cancellations of more aggressive orders. Increased depth at the off-best prices on the same side of the market indicates that more dealers are selling at a higher ask price or buying at a lower bid price than the current best prices. As a result, orders standing at the best price are more likely to suffer from pick-off risk so dealers cancel aggressive orders to avoid being picked off.

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. As found in equation (13), price changes tend to be negatively autocorrelated. With a series of positive price changes, dealers expect prices to revert in the future. As a result, they cancel more aggressive bid orders to avoid the "pick-off" risk. They also cancel less aggressive ask orders because they are less likely to be executed with a future drop in price. We see the reverse when the price is decreasing.

4. The Role of Market Performance

In this section, we examine how dealers trade-off order aggressiveness and quantity as prices are changing. In the previous analyses we investigate the impact of a marginal change in factors related to market uncertainty and market depth on a dealer's order placement strategy. Since the impact of these variables may depend on the state of the market (i.e., the impact may be different if prices are rising rather than falling), we investigate the possibility that, for example, the effect of an increase in volatility in a rising market may be different from an increase in a falling market. To examine the role of market performance, we create three dummy variables, d_1, d_2 and d_3, to capture whether the market is rising, falling or relatively stable. These dummies are determined by fitting the following price trend regression to all of the mid-quotes submitted over the past two-minute interval

$$p_{mid-quote,t} = \alpha + \beta\tau_t + \varepsilon \qquad (13)$$

where $p_{mid-quote,t}$ is the mid-point of the best prices at time t and τ_t is the distance in seconds between the $(t\text{-}1)^{st}$ and t^{th} orders during the two minute interval. The value of β would 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 $\hat{\beta}$ is significantly positive, $d_1 = 0$ otherwise

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

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

Since the changes in order aggressiveness have been found to depend on many factors, we supplement model (1) by adding the interaction between the market performance dummy variables and both the measures of volatility and market depth. As a result the order aggressiveness regression estimated earlier now becomes

$$I_s^* = \gamma_1 qn + d_1 \beta^{I_s^*}{}' x_s^{I_s^*} + d_2 \beta^{I_s^*}{}' x_s^{I_s^*} + d_3 \beta^{I_s^*}{}' x_s^{I_s^*} + \varepsilon^{I_s^*} \qquad (14)$$

and the quantity regression in model (2) becomes

$$qn_s = a + \gamma_2 I_s^* + d_1 b^{qn}{}' x_s^{qn} + d_2 b^{qn}{}' x_s^{qn} + d_3 b^{qn}{}' x_s^{qn} + \varepsilon^{qn} \qquad (15)$$

4.1 Empirical Findings of the Role of Market Performance

We find that past price changes provide insight into the future market performance of an asset. Our model characterizes how this information influences the impact of our explanatory variables on the dealers' price and quantity decisions when submitting orders (see Table 8).

Volatility

There are three major findings with respect to overall volatility. The first finding is that increases in the overall volatility lead to an increase in the order 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 dealers are most worried about execution risk when the overall price level is constant but the uncertainty of prices is increasing. The second finding is that in a rising and volatile market, ask orders tend to be smaller (the coefficient in the ask quantity equation is significantly negative with a value of -0.1034). This suggests that dealers minimize their risk of being picked-off at these times by placing smaller sell orders. The third finding is that overall volatility only impacts the bid order submission decision when prices are falling. Bid orders are more aggressive when prices are falling (the related coefficient (0.039) is significantly positive at the 1% level) and larger size (related coefficient (0.0782) is significantly positive at the 5% level). Dealers therefore appear to view periods when the prices are volatile and falling as buying opportunities.

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 dealers want to avoid being picked-off when there is uncertainty about the value of the asset from the same side of the market (i.e., the coefficients of same side residual volatility, -0.0661 for ask orders and -0.1007 for bid orders, are both significantly negative at the 1% significance level). On the other hand, both bid and ask orders become more aggressive as the opposite side residual volatility increases when the price trend is constant (the coefficients for opposite side residual volatility are (0.0073) for ask orders and (0.0084) for bid orders and are both significantly positive at the 1% significance level). When there are trends in prices we only find an impact on ask submissions. Ask orders become more aggressive with increased opposite side volatility when the price is falling suggesting that dealers 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 regardless of price movements (coefficients are all negative at the 10% significance level) and they are smaller in quantity (coefficients are all negative at 2% significance level). Thus ask orders are placed at prices further away from the best price to avoid competition with the existing best orders standing in the market. The submission of bid orders also responds to changes in the best ask depth in all market conditions. Bid orders become more aggressive and come in larger size with increasing ask depth (the related coefficients are all positive at the 5% significance level). More depth at the best ask price would decrease the execution risk of dealers' buy orders especially 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. The ask (bid) quantity also becomes significantly 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 best bid depth even in a declining market. Bid orders are smaller to avoid exposure to pick-off risk in a declining market. These results suggest that dealers wishing to sell (buy) the asset try to avoid price (pick-off) risk as the depth increases on the bid side.

Depth at off- best prices

Similar to the baseline order submission model, the impact of depth at off-best ask prices is smaller in magnitude than depth at best ask price. The impact on order aggressiveness is concentrated at the times when prices are constant. When the market is deeper at off-best ask prices, ask (bid) orders become significantly less (more) aggressive. Similarly, depth at the 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 the results is similar to the case of depth at best price.

5. Conclusions

In this paper we investigate two of the most important components of a dealer's order submission decision – the aggressiveness of the price and the quantity at which dealers are willing to transact. Despite the importance of the quantity decision for every order submitted, this 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 dealers' order submission and cancellation decisions concerning both the aggressiveness of prices and the associated quantity as well as how they interact.

The data comes from firm quotes submitted to the Reuters D-2000-2 system in the Deutsche Mark-U.S. dollar market. We find that dealers make negative trade offs between the price and quantity when submitting orders. Aggressive orders are submitted in smaller amounts. This is because (i) 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 pick-off 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 Goettler, Parlour and Rajan (2004). Although changes in the off-best depth are not observable to the dealers, they still significantly affect the order aggressiveness and quantity decision. This suggests that dealers use sources of information other than the Reuters screen (e.g. private information from their customers).

For the order cancellation decision we find that there are several factors influencing which orders dealers cancel. Although quantity is not an explicit component of this decision, we do find that dealers 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 dealers believe the future price will be increasing, for example, dealers 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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Footnotes:

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

[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] However, the identity of the dealer is anonymous. We cannot distinguish who is submitting an order.

[4] As we do not have the identity of the trader, we can only examine whether dealers are splitting orders by statistical measures.

[5] Market orders here refers to both market orders and marketable limit orders.

[6] Aggressive limit orders here refers to limit orders at the best price and limit orders improving the best price.

[7] A positive value for the estimated coefficients denotes the cancellation of a more aggressive order.

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.

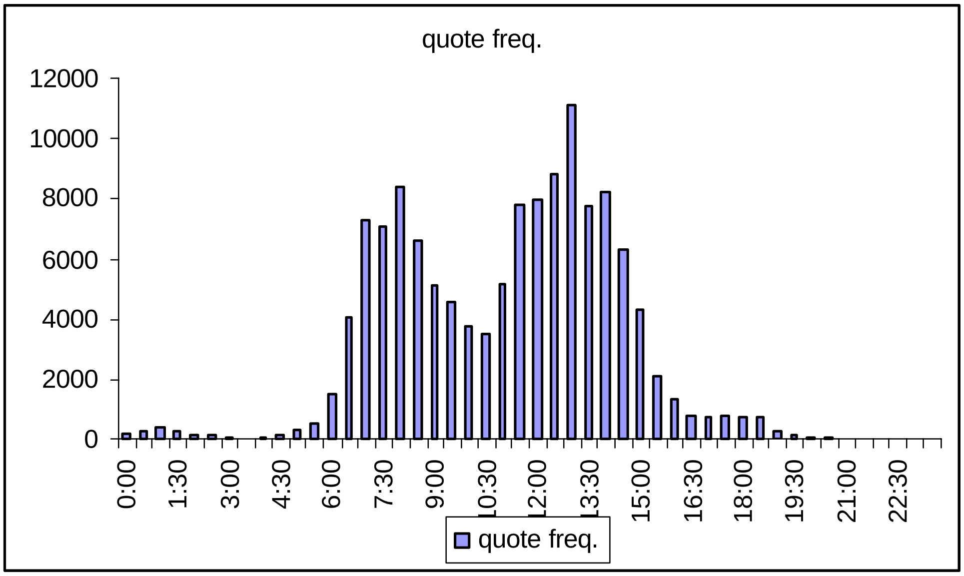

Table I: Order Aggressiveness and Quantity

The table presents the proportion of orders submitted and cancelled in terms of order aggressiveness and quantity. Panel A presents the proportion of order submitted. Orders aggressiveness are divided into six order aggressiveness category: market orders, marketable limit orders, limit orders improving the best price, limit orders at the best price, limit orders within 1 pip of best price and limit orders more than 1 pip from bst price. The proportion of quantity is divided into three categories: quantity equal to 1 million, quantity equal to 2 million and quantity greater than and equal to 3 million. Panel B presents the proportion of orders cancelled. Cancellation is divided into 3 categories: limit orders cancelled at the best price, limit order cancelled within 2 pips of the best price and limit orders cancelled at more than 2 pips from the best price. The data comesfrom the Reuters D-2000-2 electronic brokerage system for the week of October 6-10, 1997.

Panel A: Order submission	proportion of aggressiveness	proportion of quantity in each category		
		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

Panel B: Order cancellation	proportion of aggressiveness	proportion of quantity in each category		
		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 II: Intra-day Proportion of Orders by Order 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 system falling into each order aggressiveness category and the proportion of quantity at each hourly interval. Orders aggressiveness are divided into six order aggressiveness category: market orders, marketable limit orders, limit orders improving the best price, limit orders at the best price, limit orders within 1 pip of best price and limit orders more than 1 pip from bst price. The proportion of quantity is divided into three categories: quantity equal to 1 million, quantity equal to 2 million and quantity greater than and equal to 3 million.

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 III: Descriptive Statistics for Explanatory Variables

For each of the explanatory variables defined in section 2, 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. Common realized volatility is the volatility of the mid-quote: $v_{common,i} = \sqrt{\frac{\sum_{j=1}^{n}(p^{mid-quote} - \overline{p^{mid-quote}})^2}{(n-1)}}$. The mid-quote is the average of the best bid and best ask quotes standing in the market at the time every order submitted during the past 2 minutes before order i is submitted. Residual volatility 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. Best (Off-best) depth the number of ask and bid quotes standing at the best (off-best) price in the limit order book. Spread is the difference between the best bid price and the best ask price. Proportion of positive (negative) price change is 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. The proportion of large ask (bid) orders is the number of best ask (bid) orders submitted with a size larger than $1 million divided by the total number of best ask (bid) orders submitted within the past two minutes

	mean	std	max	med	min
Common volatility*	1.93	1.30	9.12	1.56	0.00
Residual ask price volatility	0.06	0.22	2.92	0.05	-0.71
Residual bid price volatility	0.05	0.20	2.75	0.04	-1.41
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
Spread*	2.07	1.69	30.00	2.00	0.00
proportion of positive price change**	18.30	5.10	57.14	18.06	0.00
proportion of negative price change**	18.17	4.94	62.50	17.86	0.00
proportion of large ask orders**	49.82	13.07	100.00	49.32	0.00
proportion of large bidorders**	50.34	13.01	100.00	50.00	0.00

* variable measured in pips

** variables measured in percentage

Table IV: Order Submission at 1-Million

The table shows the estimation result of equation (12), $x_t = \sum_{i=1}^{10} \rho_i x_t + \varepsilon_t$ in which x_t is the number of market orders or aggressiveness limit orders in 10-seconds interval. The data comesfrom the Reuters D-2000-2 electronic brokerage system for the week of October 6-10, 1997.

	Ask Submission															
	6th Oct, 1997				7th Oct, 1997				8th Oct, 1997				10th Oct, 1997			
	market orders	**t-stat**	**aggressive limit orders**	**t-stat**	**market orders**	**t-stat**	**aggressive limit orders**	**t-stat**	**market orders**	**t-stat**	**aggressive limit orders**	**t-stat**	**market orders**	**t-stat**	**aggressive limit orders**	**t-stat**
?(1)	0.34	19.35	0.29	16.59	0.35	19.77	0.28	15.75	0.33	19.14	0.24	13.61	0.33	18.76	0.29	16.70
?(2)	0.04	2.11	0.09	4.69	0.05	2.52	0.08	4.56	0.01	0.59	0.08	4.47	0.06	3.51	0.07	3.98
?(3)	0.04	2.07	0.09	4.71	0.03	1.61	0.07	3.81	0.03	1.41	0.06	3.45	0.04	1.96	0.07	3.92
?(4)	0.06	3.50	0.07	3.91	0.05	2.63	0.08	4.59	0.10	5.38	0.05	2.55	0.09	5.07	0.09	4.96
?(5)	0.03	1.68	0.04	2.27	0.04	1.98	0.12	6.66	0.05	2.82	0.08	4.25	0.03	1.68	0.04	2.00
?(6)	0.05	2.68	0.08	4.33	0.08	4.32	0.04	2.18	0.04	2.04	0.07	4.01	0.05	2.87	0.08	4.46
?(7)	0.04	2.04	0.03	1.68	0.07	3.66	0.03	1.50	0.08	4.59	0.09	5.04	0.06	3.26	0.06	3.46
?(8)	0.08	4.45	0.03	1.67	0.10	5.44	0.06	3.27	0.05	2.95	0.07	3.81	0.05	2.62	0.06	3.51
?(9)	0.07	3.84	0.09	4.73	0.02	0.85	0.07	3.71	0.01	0.80	0.08	4.31	0.06	3.26	0.02	0.94
?(10)	0.08	4.44	0.07	3.80	0.07	4.04	0.06	3.69	0.10	5.57	0.06	3.61	0.04	2.20	0.09	5.15
	Bid Submission															
	6th Oct, 1997				7th Oct, 1997				8th Oct, 1997				10th Oct, 1997			
	market orders	**t-stat**	**aggressive limit orders**	**t-stat**	**market orders**	**t-stat**	**aggressive limit orders**	**t-stat**	**market orders**	**t-stat**	**aggressive limit orders**	**t-stat**	**market orders**	**t-stat**	**aggressive limit orders**	**bstlmt_t5**
?(1)	0.28	15.80	0.26	14.81	0.35	20.03	0.28	15.69	0.32	18.17	0.28	15.96	0.31	17.66	0.27	15.10
?(2)	0.06	3.40	0.09	5.17	0.07	3.62	0.06	3.31	0.04	2.10	0.05	2.54	0.07	3.74	0.05	2.93
?(3)	0.06	3.47	0.07	3.80	0.03	1.62	0.11	5.91	0.06	3.36	0.09	5.02	0.07	3.71	0.11	6.32
?(4)	0.08	4.15	0.05	2.70	0.05	2.76	0.06	3.49	0.09	4.99	0.09	4.88	0.05	2.98	0.06	3.52
?(5)	0.07	3.74	0.06	3.15	0.07	4.01	0.04	2.23	0.01	0.34	0.06	3.24	0.06	3.31	0.08	4.49
?(6)	0.06	3.25	0.05	2.56	0.06	3.27	0.06	3.23	0.07	4.05	0.08	4.23	0.01	0.57	0.05	2.50
?(7)	0.05	2.74	0.07	3.77	0.05	2.43	0.10	5.60	0.05	2.97	0.08	4.12	0.07	3.77	0.05	2.79
?(8)	0.03	1.57	0.06	3.22	0.03	1.55	0.08	4.21	0.04	2.08	0.06	3.41	0.07	3.65	0.06	3.27
?(9)	0.06	3.29	0.06	3.30	0.05	2.92	0.05	2.52	0.07	3.89	0.05	2.96	0.04	2.14	0.07	4.11
?(10)	0.06	3.48	0.12	6.62	0.08	4.46	0.06	3.24	0.07	3.77	0.04	2.02	0.07	4.27	0.07	3.84

Table V: Order Submission

The results from the simulataneous estimation of

$$I_s^* = \gamma_1 qn^*{}_s + \beta^{I_s^*}{}' x_s^{I_s^*} + \varepsilon^{I_s^*}$$ for order aggressiveness using ordered probit modeland

$$qn^*{}_s = a + \gamma_2 I_s^* + b^{qn}{}' x_s^{qn} + \varepsilon^{qn}$$ for quantity using censored regression model

where I_s^* is the latent order aggressiveness and $qn^*{}_s$ is the latent quantity, $x_s^{I_s^*}$ and x_s^{qn} are the explanatory variables for order aggressivness equation and quantity equation. Their definitions are provided in Table 3. H10 to H15 in the table represents the hourly dummy running from 10:00 (GMT) to 16: 00 (GMT). The system of equations 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					
Order aggressiveness			**Quantity**		
Parameter	*Estimate*	*ProbChiSq*		Estimate	Probability
			intercept	0.0740	0.38
$qn^*{}_s$	-0.2572	0.24	I_s^*	-1.1013	0.00
Mid-quote volatility	0.0167	0.00	Mid-quote volatility	-0.0012	0.88
Residual ask volatility	-0.0506	0.00	Residual ask volatility	-0.0015	0.97
Residual bid volatility	0.1354	0.00	Residual bid volatility	0.0139	0.79
Depth at best ask price	-0.0191	0.00	Depth at best ask price	-0.0278	0.00
Depth at best bid price	0.0090	0.00	Depth at best bid price	0.0453	0.00
Depth at off best ask price	-0.0006	0.08	Depth at off best ask price	0.0014	0.11
Depth at off best bid price	0.0024	0.00	Depth at off best bid price	-0.0018	0.03
Spread	0.0125	0.00	Spread	0.0017	0.64
proportion of positive price change	0.0122	0.00	proportion of large ask orders	0.0110	0.00
proportion of negative price change	-0.0124	0.00	proportion of large bid size orders	0.0020	0.01
h10	-0.0747	0.00	h10	-0.0283	0.69
h11	-0.0337	0.15	h11	0.0001	1.00
h12	0.0478	0.02	h12	0.2773	0.00
h13	0.1352	0.00	h13	0.2213	0.00
h14	0.0539	0.01	h14	0.2811	0.00
h15	-0.0505	0.08	h15	0.0915	0.25

Bid Submission					
Order aggressiveness			**Quantity**		
Parameter	*Estimate*	*ProbChiSq*		Estimate	Probability
			intercept	-0.0543	0.51
qn^{*}_{s}	-0.0917	0.69	I^{*}_{s}	-0.9320	0.00
Mid-quote volatility	0.0037	0.24	Mid-quote volatility	0.0174	0.02
Residual ask volatility	0.0382	0.01	Residual ask volatility	0.0691	0.09
Residual bid volatility	-0.0955	0.00	Residual bid volatility	-0.1227	0.01
Depth at best ask price	0.0092	0.00	Depth at best ask price	0.0478	0.00
Depth at best bid price	-0.0176	0.00	Depth at best bid price	-0.0217	0.00
Depth at off best ask price	0.0014	0.00	Depth at off best ask price	-0.0010	0.26
Depth at off best bid price	0.0000	0.88	Depth at off best bid price	0.0025	0.00
Spread	0.0113	0.00	Spread	0.0094	0.01
proportion of positive price change	-0.0119	0.00	proportion of large ask orders	0.0014	0.06
proportion of negative price change	0.0132	0.00	proportion of large bid size orders	0.0103	0.00
h10	0.0952	0.00	h10	-0.0146	0.83
h11	0.0966	0.00	h11	0.0267	0.66
h12	0.0294	0.13	h12	0.2613	0.00
h13	-0.0060	0.75	h13	0.3474	0.00
h14	0.0038	0.85	h14	0.3694	0.00
h15	0.0726	0.01	h15	0.0678	0.36

Pooled Submission					
Order aggressiveness			**Quantity**		
Parameter	*Estimate*	*ProbChiSq*		Estimate	Probability
			intercept	-0.0168	0.78
qn_s^*	-0.1015	0.28	I_s^*	-1.0091	0.00
Mid-quote volatility	0.0047	0.07	Mid-quote volatility	0.0164	0.03
Residual same side volatility	-0.0915	0.00	Residual same side volatility	-0.1353	0.00
Residual opposite side volatility	0.0445	0.00	Residual opposite side volatility	0.0795	0.04
Depth at best same side price	-0.0195	0.00	Depth at best same side price	-0.0269	0.00
Depth at best opposite side price	0.0117	0.00	Depth at best opposite side price	0.0584	0.00
Depth at off best same side price	0.0003	0.14	Depth at off best same side price	0.0020	0.00
Depth at off best opposite side price	0.0012	0.00	Depth at off best opposite side price	-0.0007	0.35
Spread	0.0137	0.00	Spread	0.0128	0.00
proportion of positive price change	-0.0124	0.00	proportion of large ask orders	0.0011	0.09
proportion of negative price change	0.0135	0.00	proportion of large bid size orders	0.0100	0.00
Dummy Mid-quote volatility	0.0117	0.00	Dummy mid-quote volatility	-0.0174	0.10
Dummy residual same side volatility	0.0279	0.15	Dummy residual same side volatility	0.1392	0.02
Dummy residual opposite side volatility	0.0882	0.00	Dummy residual opposite side volatility	-0.0684	0.26
Dummy depth at best same side price	-0.0004	0.85	Dummy depth at best same side price	0.0003	0.97
Dummy depth at best opposite side price	-0.0012	0.64	Dummy depth at best opposite side price	-0.0014	0.85
Dummy depth at off best same side price	-0.0008	0.01	Dummy depth at off best same side price	-0.0006	0.50
Dummy depth at off best opposite side price	0.0007	0.03	Dummy depth at off best opposite side price	-0.0008	0.38
Dummy spread	-0.0009	0.59	Dummy spread	-0.0125	0.01
Dummy proportion of positive price change	0.0244	0.00	Dummy proportion of large ask orders	0.0104	0.00
Dummy proportion of negative price change	-0.0262	0.00	Dummy proportion of large bid size orders	-0.0079	0.00
h10	0.0041	0.79	h10	-0.0188	0.70
h11	0.0194	0.16	h11	0.0171	0.70
h12	0.0276	0.02	h12	0.2707	0.00
h13	0.0515	0.00	h13	0.2825	0.00
h14	0.0156	0.20	h14	0.3200	0.00
h15	-0.0021	0.90	h15	0.0782	0.16

Table VI: Order Cancellation

The results from the estimation of

$$I_c^* = \gamma_3 qn_c + \beta^{I_c^*}{}' x_s + \varepsilon^{I_c^*}$$

for order cancellation using ordered probit model. I_c^* is the latent aggressiveness of order cancellation. x_s are the explanatory variables for order aggressivness in cancellation. Their definitions are provided in Table 3. H10 to H15 in the table represents the hourly dummy running from 10:00 (GMT) to 16: 00 (GMT). The equantion is estimated for both the order cancellation 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		**Bid**		**Pooled**	
Parameter	*Estimate*	*ProbChiSq*	*Estimate*	*ProbChiSq*	*Estimate*	*ProbChiSq*
qn	-0.0758	0.00	-0.0836	0.00	-0.0795	0.00
Mid-quote volatility	0.0516	0.00	0.0578	0.00	0.0562	0.00
Residual same (ask) side volatility	-0.0618	0.00	0.0223	0.22	0.0391	0.05
Residual opposite (bid) side volatility	0.0754	0.00	0.0399	0.05	0.0196	0.26
Depth at best same (ask) side price	-0.0442	0.00	-0.0017	0.43	-0.0372	0.00
Depth at best opposite (bid) side price	0.0014	0.54	-0.0418	0.00	-0.0014	0.51
Depth at off best same (ask) side price	0.0035	0.00	-0.0006	0.10	0.0030	0.00
Depth at off best opposite (bid) side price	-0.0002	0.48	0.0034	0.00	-0.0007	0.05
Spread	0.0003	0.79	0.0000	0.99	0.0006	0.74
proportion of positive price change	-0.0080	0.00	0.0023	0.01	0.0025	0.00
proportion of negative price change	0.0043	0.00	-0.0055	0.00	-0.0053	0.00
Dummy Mid-quote volatility					-0.0028	0.61
Dummy residual same (ask) side volatility					-0.1034	0.00
Dummy residual opposite (bid) side volatility					0.0522	0.05
Dummy depth at best same (ask) side price					-0.0010	0.75
Dummy depth at best opposite (bid) side price					0.0024	0.44
Dummy depth at off best same (bid) side price					0.0000	0.98
Dummy depth at off best opposite (ask) side price					0.0006	0.17
Dummy Spread					-0.0016	0.54
Dummy proportion of positive price change					-0.0109	0.00
Dummy proportion of negative price change					0.0096	0.00
h10	-0.0707	0.02	-0.0589	0.05	-0.0655	0.00
h11	-0.0677	0.02	-0.0018	0.95	-0.0351	0.08
h12	-0.0969	0.00	-0.0748	0.00	-0.0868	0.00
h13	-0.0483	0.03	-0.1702	0.00	-0.1088	0.00
h14	-0.1509	0.00	-0.1971	0.00	-0.1775	0.00
h15	-0.4012	0.00	-0.2725	0.00	-0.3317	0.00

Table VII Marginal Probability

This table shows the marginal reactions of order aggressiveness in each category to a change in the explanatory variables. Orders aggressiveness are divided into six order aggressiveness category: market orders, marketable limit orders, limit orders improving the best price, limit orders at the best price, limit orders within 1 pip of best price and limit orders more than 1 pip from best price. The definitions of the explanatory variables are given in Table 3. The values are obtained using equations (6) to (11).

Ask 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*
quantity	0.0691	0.0299	-0.0285	-0.0249	-0.0201	-0.0255
Mid-quote volatility	-0.0045	-0.0019	0.0019	0.0016	0.0013	0.0017
Residual ask volatility	0.0136	0.0059	-0.0056	-0.0049	-0.0039	-0.0050
Residual bid volatility	-0.0364	-0.0157	0.0150	0.0131	0.0106	0.0134
Depth at best ask price	0.0051	0.0022	-0.0021	-0.0019	-0.0015	-0.0019
Depth at best bid price	-0.0024	-0.0010	0.0010	0.0009	0.0007	0.0009
Depth at off best ask price	0.0001	0.0001	-0.0001	-0.0001	0.0000	-0.0001
Depth at off best bid price	-0.0006	-0.0003	0.0003	0.0002	0.0002	0.0002
Spread	-0.0034	-0.0015	0.0014	0.0012	0.0010	0.0012
proportion of positive price change	-0.0033	-0.0014	0.0014	0.0012	0.0009	0.0012
proportion of negative price change	0.0033	0.0014	-0.0014	-0.0012	-0.0010	-0.0012
h10	0.0201	0.0087	-0.0083	-0.0072	-0.0058	-0.0074
h11	0.0091	0.0039	-0.0037	-0.0033	-0.0026	-0.0033
h12	-0.0128	-0.0056	0.0053	0.0046	0.0037	0.0047
h13	-0.0363	-0.0157	0.0150	0.0131	0.0105	0.0134
h14	-0.0145	-0.0063	0.0060	0.0052	0.0042	0.0053
h15	0.0136	0.0059	-0.0056	-0.0049	-0.0039	-0.0050

Bid 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*
quantity	0.0249	0.0107	-0.0096	-0.0084	-0.0073	-0.0103
Mid-quote volatility	-0.0010	-0.0004	0.0004	0.0003	0.0003	0.0004
Residual ask volatility	-0.0104	-0.0045	0.0040	0.0035	0.0030	0.0043
Residual bid volatility	0.0259	0.0112	-0.0100	-0.0088	-0.0076	-0.0108
Depth at best ask price	-0.0025	-0.0011	0.0010	0.0008	0.0007	0.0010
Depth at best bid price	0.0048	0.0021	-0.0018	-0.0016	-0.0014	-0.0020
Depth at off best ask price	-0.0004	-0.0002	0.0002	0.0001	0.0001	0.0002
Depth at off best bid price	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Spread	-0.0031	-0.0013	0.0012	0.0010	0.0009	0.0013
proportion of positive price change	0.0032	0.0014	-0.0012	-0.0011	-0.0009	-0.0013
proportion of negative price change	-0.0036	-0.0015	0.0014	0.0012	0.0010	0.0015
h10	-0.0258	-0.0111	0.0100	0.0087	0.0075	0.0107
h11	-0.0262	-0.0113	0.0101	0.0089	0.0076	0.0109
h12	-0.0080	-0.0034	0.0031	0.0027	0.0023	0.0033
h13	0.0016	0.0007	-0.0006	-0.0006	-0.0005	-0.0007
h14	-0.0010	-0.0004	0.0004	0.0003	0.0003	0.0004
h15	-0.0197	-0.0085	0.0076	0.0067	0.0057	0.0082

Table VIII Market Performance

This table shows the order submission strategies when price change is positive, negative or constant. The system of equations estimated is

$I_s^* = \gamma_1 qn + d_1 \beta^{I_s^*}{}' x_s^{I_s^*} + d_2 \beta^{I_s^*}{}' x_s^{I_s^*} + d_3 \beta^{I_s^*}{}' x_s^{I_s^*} + \varepsilon^{I_s^*}$ for order aggressiveness using ordered probit model

$qn_s = a + \gamma_2 I_s^* + d_1 b^{qn}{}' x_s^{qn} + d_2 b^{qn}{}' x_s^{qn} + d_3 b^{qn}{}' x_s^{qn} + \varepsilon^{qn}$ for quantity using censored regression model

where I_s^* is the latent order aggressiveness and $qn^*{}_s$ is the latent quantity, $x_s^{I_s^*}$ and x_s^{qn} are the explanatory variables for order aggressivness equation and quantity equation, d_1, d_2 and d_3 are the dummies for positive, negative and constant price change. Their definitions are provided in Table 3. The system of equations are estimated for both the order submission 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 Submission							
Order Aggressiveness				*Quantity*			
Parameter	*price trend*	*Estimate*	*Prob*		*price trend*	*Estimate*	*Prob*
				intercept		0.1485	0.07
qn_s^*		-0.0014	0.99	I_s^*		-1.1251	0.00
Mid-quote volatility	positive	0.0094	0.49	Mid-quote volatility	positive	-0.1034	0.01
	negative	0.0075	0.66		negative	-0.0062	0.89
	constant	0.0174	0.00		constant	0.0057	0.53
Residual ask volatility	positive	0.0511	0.60	Residual ask volatility	positive	-0.5594	0.07
	negative	-0.0302	0.76		negative	0.2182	0.46
	constant	-0.0661	0.00		constant	-0.0035	0.94
Residual bid volatility	positive	-0.0577	0.53	Residual bid volatility	positive	-0.2225	0.44
	negative	0.2104	0.05		negative	0.1014	0.76
	constant	0.1242	0.00		constant	0.0214	0.69
Depth at best ask price	positive	-0.0121	0.02	Depth at best ask price	positive	-0.0385	0.02
	negative	-0.0122	0.08		negative	-0.0501	0.02
	constant	-0.0214	0.00		constant	-0.0258	0.00
Depth at best bid price	positive	0.0161	0.02	Depth at best bid price	positive	0.0303	0.16
	negative	0.0092	0.09		negative	0.0485	0.00
	constant	0.0073	0.00		constant	0.0460	0.00
Depth at off best ask price	positive	0.0007	0.43	Depth at off best ask price	positive	-0.0018	0.54
	negative	-0.0008	0.44		negative	0.0027	0.38
	constant	-0.0008	0.01		constant	0.0017	0.06
Depth at off best bid price	positive	0.0008	0.39	Depth at off best bid price	positive	-0.0017	0.57
	negative	0.0018	0.06		negative	-0.0056	0.05
	constant	0.0022	0.00		constant	-0.0016	0.08
Spread	positive	0.0051	0.23	Best Bid-Min Bid	positive	0.0322	0.01
	negative	0.0130	0.00		negative	-0.0088	0.49
	constant	0.0121	0.00		constant	0.0006	0.88
proportion of positive price change	positive	0.0056	0.02	proportion of large ask orders	positive	0.0141	0.00
	negative	0.0116	0.00		negative	0.0149	0.00
	constant	0.0119	0.00		constant	0.0105	0.00
proportion of negative price change	positive	0.0054	0.10	proportion of large bid orders	positive	0.0035	0.25
	negative	-0.0111	0.00		negative	0.0016	0.66
	constant	-0.0128	0.00		constant	0.0019	0.01

Market Performance (continued)

Bid Submission							
Order Aggressiveness				*Quantity*			
Parameter	*price trend*	*Estimate*	*Prob*		*price trend*	*Estimate*	*Prob*
				intercept		0.0732	0.35
qn_s^*		-0.0240	0.85	I_s^*		-1.0433	0.00
Mid-quote volatility	positive	-0.0158	0.21	Mid-quote volatility	positive	0.0610	0.08
	negative	0.0390	0.01		negative	0.0782	0.05
	constant	0.0025	0.42		constant	0.0077	0.37
Residual ask volatility	positive	0.0219	0.81	Residual ask volatility	positive	0.2859	0.28
	negative	0.0310	0.73		negative	0.3091	0.24
	constant	0.0370	0.01		constant	0.0647	0.12
Residual bid volatility	positive	-0.0978	0.32	Residual bid volatility	positive	-0.2539	0.37
	negative	0.0631	0.50		negative	-0.0676	0.82
	constant	-0.1007	0.00		constant	-0.1151	0.03
Depth at best ask price	positive	0.0094	0.05	Depth at best ask price	positive	0.0383	0.01
	negative	0.0193	0.00		negative	0.0481	0.02
	constant	0.0084	0.00		constant	0.0495	0.00
Depth at best bid price	positive	-0.0225	0.00	Depth at best bid price	positive	-0.0295	0.20
	negative	-0.0228	0.00		negative	-0.0285	0.04
	constant	-0.0172	0.00		constant	-0.0231	0.00
Depth at off best ask price	positive	0.0003	0.71	Depth at off best bid price	positive	-0.0041	0.14
	negative	-0.0005	0.58		negative	-0.0002	0.95
	constant	0.0015	0.00		constant	-0.0008	0.39
Depth at off best bid price	positive	-0.0011	0.26	Depth at off best ask price	positive	0.0044	0.13
	negative	0.0026	0.00		negative	0.0036	0.17
	constant	-0.0001	0.55		constant	0.0025	0.00
Spread	positive	0.0092	0.02	Best Bid-Min Bid	positive	0.0409	0.00
	negative	0.0064	0.11		negative	0.0098	0.43
	constant	0.0115	0.00		constant	0.0081	0.03
proportion of positive price change	positive	-0.0048	0.03	proportion of large ask orders	positive	-0.0053	0.10
	negative	-0.0050	0.16		negative	0.0010	0.72
	constant	-0.0120	0.00		constant	0.0017	0.03
proportion of negative price change	positive	0.0078	0.02	proportion of large bid orders	positive	0.0095	0.00
	negative	0.0078	0.00		negative	0.0093	0.01
	constant	0.0131	0.00		constant	0.0104	0.00