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Order aggressiveness and Quantity: how are they determined in a limit order market?

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Abstract:

Dealers trading in a limit order market must choose both the order aggressiveness and the quantity for their orders. Since little research has considered how dealers make this trade-off, we empirically investigate how dealers jointly make these decisions in the foreign exchange market using a unique simultaneous equations model. Our model uses an ordered probit model to account for the discrete nature of order aggressiveness and a censored regression model to capture the quantity decision recognizing the clustering of orders at the smallest available quantity, $1 million. Using two currency pairs with very different trading characteristics, we find evidence of a trade-off between order aggressiveness and quantity as well as a significant role being played by factors related to the levels of information asymmetry and liquidity in the dealers' choice of both the order aggressiveness and quantity.

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Dealers trading in a limit order market must choose both the order aggressiveness and the quantity for their orders. Since little research has considered how dealers make this trade-off, we empirically investigate how dealers jointly make these decisions in the foreign exchange market using a unique simultaneous equations model. Our model uses an ordered probit model to account for the discrete nature of order aggressiveness and a censored regression model to capture the quantity decision recognizing the clustering of orders at the smallest available quantity, $1 million. Using two currency pairs with very different trading characteristics, we find evidence of a trade-off between order aggressiveness and quantity as well as a significant role being played by factors related to the levels of information asymmetry and liquidity in the dealers' choice of both the order aggressiveness and quantity.

Introduction:

In a limit order market, traders submitting an order must choose both the order aggressiveness (price) and quantity. Order aggressiveness is defined according to the execution priority with market orders being the most aggressive because they are executed immediately at the best prices currently standing in the market. Limit orders are less aggressive because they are submitted at a set price so their execution is not guaranteed and they follow strict price and time priorities in execution. Despite orders being defined by both their price and quantity, much of the literature focuses on the relationship between various factors and order aggressiveness (i.e., Griffiths et al. (2000), Ranaldo (2004), and more recently Ellul, Holden, Jain and Jennings (2007) and Cao, Hansch and Wang (2008)). In the majority of existing studies, the quantity dimension is either ignored or treated as one of the explanatory variables rather than a choice variable. Although these papers recognize the costs associated with the risk of being picked off or not having trades executed, they frequently assume trades of a standard size and therefore ignore a key component of the overall cost to submitting orders.

Studies investigating order aggressiveness have found relationships between market volatility, the bid-ask spread, and the depth of the limit order book on the order aggressiveness decision (e.g., Al-Suhaibani and Kryzanowski (2000), Ahn, Bae and Chan (2001), Hall and Hautsch (2006 and 2007), and Foucault, Moinas and Theissen (2007)). Although some studies have empirically examined traders' quantity decision (e.g., Biais, Hillion and Spatt (1995), Al-Suhaibani and Kryzanowski (2000) and Moulton (2005)), their models do not consider the simultaneity of the price-quantity decision and the constraints in placing orders of different sizes. The theoretical literature addressing these issues includes studies such as Easley and O'Hara (1992) and Glosten (1994) and more recent papers such as Dridi and Germain (2004), Goettler, Parlour and Rajan (2005) and Foucault, Moinas and Theissen (2007) and they discuss a role for quantity and price, but do not explicitly examine the dynamic trade offs that traders make between price and quantity[1].

The ability to change the size of the order at different prices plays an important role in determining the price schedule (e.g., the market clearing price) over time and, as a result, the overall cost

to submitting orders at different levels of aggressiveness (the overall cost is the feature of most relevance to traders when submitting their orders). Our study therefore extends the existing literature by empirically examining some of the findings from these studies and how they relate to the price-quantity decision. This builds on classic studies such as Glosten (1994) and those who followed which describe the role played by adverse selection in dealers' trading costs and thus the prices and quantities they are willing to buy or sell in the market. Since the results from these models rely in many different assumptions, understanding what factors influence the price-quantity decision is important for researchers and practitioners as it provides important information regarding how liquidity is provided to the market and what factors lead dealers to demand and supply liquidity. We accomplish this by simultaneously estimating traders' choice of order aggressiveness and quantity to more completely model traders' order submission strategies. We consider both simultaneously because traders choose <u>both</u> order aggressiveness and quantity when submitting orders in a limit order market. Although order aggressiveness has been modeled before, including the joint role of quantity is new. In our 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 price aggressiveness.[2] Quantity is modeled using a censored regression framework, which allows our model to accommodate a wide variety of order sizes as well as the clustering of orders at $1 million. Our model therefore 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.

Beyond being the first study to present a detailed empirical model which more completely models the order submission process than currently exists in the literature, our study also contributes to the market microstructure literature by using foreign exchange data on two currency pairs with very different trading characteristics, the Deutsche Mark – US dollar and Canadian dollar – US dollar. We use data on firm orders from the Reuters D-2000-2 system. This system allows dealers to submit and cancel market orders and limit orders of different sizes at different price levels. This extends the existing microstructure literature in this area which currently focuses on equities markets, especially less liquid markets[3]. To

ensure the robustness of our results and investigate the possible role for differences in liquidity on our results and the existing results in the literature, we consider data from both the very actively traded Deutsche Mark-U.S. dollar market (referred to below as the DM) and the less actively traded Canadian dollar – U.S. dollar market (referred to below as the Canadian dollar). This allows us to consider the relationships between liquidity and trading as suggested by Demsetz (1968) and more recent studies such as Stoll (2000) among others.

Using foreign exchange data allows us to benefit from some of the differences in the structures of the equities and foreign exchange markets[4]. Investigating the order submission process for two different currency pairs, with very different trading characteristics, allows us to also examine the impact of differences in asset liquidity on the order submission decision. The foreign exchange market is a great market to consider because dealers are able to submit both market and limit orders twenty-four hours a day so our data is not impacted by formal opening and closing procedures or other institutional mechanisms which may influence order submission and execution. Consequently, our analysis is able to more carefully examine the influence of changes in the state of the order book, market conditions and liquidity on dealer's order submission decisions.

We can also examine the role of different types of private versus public information in the order submission process. Every order submitted over the trading day is contained in our dataset[5], but dealers using the Reuters D-2000-2 system can only observe the best price and corresponding quantity posted on both sides of the market in addition to information on the last five transactions. To investigate the potential differences in the roles of public and private information, we estimate a model using only the publicly available information on orders at the best quoted prices and past transactions and an extended model in which we also include information unobservable to traders on the orders behind the best quoted prices. This allows us to determine whether the information from the orders not directly observable by dealers affects their price and quantity decisions. If this extra information is not relevant in our analysis, this is 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. The

inclusion of this data in our analysis therefore allows us to examine the level of information available to dealers, how it influences their decision-making and therefore the degree of market efficiency.

We find that dealers' willingness to submit aggressive orders varies by currency. For the Canadian dollar dealers are more willing to submit aggressive orders than for the DM. For both currencies the less aggressive orders are more concentrated in the middle of the day when the quantity also is at its peak. These results suggest that dealers are more interested in execution speed around market open and close, especially for the less liquid asset, the Canadian dollar.

Considering the state of the order book on the order submission decision, we find that the influence of different characteristics of the order book on dealers' order submission decisions varies across the DM and Canadian dollar. For the Canadian dollar we find that the order submission decisions appear to be designed to profit from the supplying of liquidity. The decisions in the DM market are more consistent with standard arguments related to traders wishing to minimize transaction and execution risks, especially in the presence of asymmetric information. Consequently our results for the DM are relatively consistent with those from existing studies, but less so for the Canadian dollar where the value to providing liquidity is likely much higher for dealers and thus plays a larger role in their order submission decisions.

Examining the role of private information on the order submission decisions, we find it played a limited role. The results are only significant for the DM and confirm our earlier results using only public information. Specifically, as depth increases, quantity increases due to increased liquidity and aggressiveness changes to transact quickly with the increase of the opposite side of the market but protect prices on the size side – consistent with the results discussed earlier using the public information.

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 obtained from the Reuters D2000-2 system for the Deutsche Mark-US dollar and the Canadian dollar – US dollar currency pairs. D2000-2 is an electronic order book to which foreign exchange dealers can submit both market and limit orders. We use data for the Deutsche Mark - US dollar currency pair from the evening of the 5th of October to midnight on the 10th of October 1997 and for the Canadian dollar – US dollar from the 1st of May 2005 to the 31st of June, 2005. For each of these currency pairs, subscribers see the last five transactions as well as the orders at the best bid and best ask prices, the quantity 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. In our data set, we have information on every order submitted to the market (not just those at the best bid and ask prices) so we have more information than dealers. Dealers cannot observe the limit orders posted at off-best prices nor their cancellation.

To ensure the integrity of our data, we remove periods during which there were significant announcements. Dealer order submission and cancellation behavior is likely to be impacted by these announcements and the expectations with respect to these announcements, but we are interested in the price-quantity order submission decision under standard market conditions. Consequently, we exclude October 9th, 1997 from our Deutsche Mark – US dollar data due to an unexpected change in interest rates by the Bundesbank on October 9th, 1997 (for a discussion of its unusual impact on the foreign exchange trading activity following the event see Carlson and Lo (2006))[6]. Similarly, for the Canadian dollar we include only the days without major macroeconomic announcements[7]. For both currency pairs, we also exclude weekends and public holidays and focus on the most active part of the trading days – from 7:00 GMT to 17:00 GMT for the Deutsche Mark and 7:00 EST to 17:00 EST for the Canadian dollar.

Although most existing studies in this area consider different equity markets, we use the foreign exchange market because it has several advantages over the more commonly used equity data. First, the foreign exchange market is the largest financial market in the world, so it has fewer problems resulting from illiquid trading, information asymmetries and other errors in the measurement of microstructure

characteristics. The Reuters D2000-2 system we use for our data is an increasingly important part of this large market. Although only 37% of brokered trade in the inter-dealer foreign exchange market occurred on the Reuter's platform in 1997 (Goodhart and Payne (1999)), it has been rapidly increasing in importance and around 85% of interdealer foreign exchange trading currently goes through electronic limit order books (Sager and Taylor (2006)). 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 foreign exchange market is also a valuable market because it has no special institutional restrictions on trading. It is a 24-hour a day, 7-day a week market with no specific opening and closing hours and no corresponding special procedures. This allows our analysis to cover the full trading day without having to worry about special market clearing mechanisms at the opening or closing of markets (e.g., Hamao and Hasbrouck (1995) and Davies (2004)). Consequently, we are able to more completely examine how the changes in the number of traders and level of trading activity which occur naturally over the trading day influence the prices and quantities for orders submitted by dealers[8]. Further, in the foreign exchange market there is no market maker or features such as "iceberg orders" which may have unexpected impacts on the observed market liquidity and its influence on dealer behavior. Thus, our dataset allows us to more clearly study how the supply and demand for an asset develop over the day and influence dealers' decisions[9]. 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.

The Reuters D2000-2 dataset also has several advantages over other data for the foreign exchange market because our Reuters D2000-2 data is the only dataset available with complete tick-by-tick information on the limit order book in the inter-dealer foreign exchange market. Other studies such as Evans (2002), Evans and Lyons (2002a), Evans and Lyons (2002b), Osler (2003) and Mende, Menkhoff and Osler (2005) use similar, but more limited information (e.g., from a single dealer or for completed transactions and therefore not for the complete order book). Our study complements theirs in examining the order submission activities of all dealers in this market including both withdrawn and executed orders.

Finally, we use two currency pairs to ensure that our results are not being driven by certain trading characteristics of one of the currencies. For example, the Deutsche Mark - US dollar was the most heavily traded currency pair before the introduction of Euro with significant trading in both Europe and North America (BIS (1999)) where as the Canadian dollar – US dollar currency pair is a liquid but relatively thinly traded currency with some European-based trading but a large amount of North American based trading (BIS (2005)). This allows our results to evaluate potential differences in how dealers make their order submission decisions which may be harder to evaluate in the context of equity markets.

The complete data set consists of 130,526 quotes over five days for the Deutsche Mark – US dollar and 390,629 for the Canadian dollar-US dollar over a sixty day period. For both currency pairs, we focus on order submission and cancellation activities from 6:00 to 17:00 in the major market in which each currency pair is traded. In Figure 1a, we see the trading activity for the Deutsche Mark. There is a significant increase in trading activity as European markets open (most importantly London) around 7:00 (GMT), followed by a gradual decline until North American markets open. When the markets in North America open, there is a dramatic increase in trading activity followed by a decline until the close of trading in London. Trading activity for the Canadian dollar (Figure 1b) is concentrated in North America. Trading activity starts slowly before North American markets open but increases very rapidly as the markets open in North America. Activity gradually declines following the opening of markets in North America, except for a slight increase in trading activity around noon (as European markets are closing).

Looking at specific characteristics for the orders submitted in both markets, Table 1 presents some descriptive statistics for each currency pair. For the Deutsche Mark, Table 1a breaks-down the order submissions into four categories to capture the varying degrees of aggressiveness: market orders (17%), marketable limit orders / limit orders improving the existing best price (24%), limit orders placed at the best price (25%), and off-best limit orders (33%). The proportions are similar for the ask side and the bid side of the market. Table 1a also shows the proportion of different order sizes in each category. Generally orders cluster at $1 million – the minimum quantity allowed to be submitted on the Reuters

D2000-2 system. The percentage of $1 million orders submitted at each level of aggressiveness ranges from 39% for marketable limit orders to 60% for off-best limit orders. Because of this clustering at the minimum quantity, we use a censored regression model for quantity in the empirical analysis.

The results are somewhat similar for the Canadian dollar in Table 1b. For the Canadian dollar, we see that the majority of all orders for the Canadian dollar are marketable limit orders (limit orders submitted at prices better than the best prices standing in the market at the time the order was submitted). The next most frequently submitted orders were market orders with limit orders at the best price or behind the best price being much less. It is interesting to note that there is also a difference in the sizes of the orders – market orders and limit orders behind the best prices are more likely for larger orders.

Since there are clearly differences in the aggressiveness and size of orders that are submitted, we look at how these change over the trading day: do traders submit larger and/or more aggressively priced orders early or late in the day? Table 2 illustrates how the order aggressiveness and quantity of orders change over the trading day. For both the Deutsche Mark and Canadian dollar (Tables 2a and 2b respectively), the patterns in our data set are qualitatively similar to those from other studies using shorter periods of firm quote data[10] (e.g., Goodhart, Ito and Payne (1996) and Goodhart and Payne (1999)). We find relatively more aggressive orders at the beginning and end of the trading day. This suggests that the asymmetry of information narrows as traders become increasingly active over the trading day but increases again as markets approach closing. Consequently there is an apparent decrease in the risk of being "picked-off" in the middle of the day, so dealers are more willing to place limit orders at these times. This is consistent with the model of Bloomfield, O'Hara and Saar (2005). Turning to the quantities, we find that the proportion of $1 million orders submitted declines (i.e., the proportion of large orders increases) over the trading day peaking at around mid-day. These patterns suggest that the aggressiveness of orders decreases and 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. The summary statistics for the explanatory variables we use to describe the state of

the limit order book are presented in Table 3. The values confirm that there are a number of significant differences across currencies. The prices for the Canadian dollar are less volatile but the spreads are wider than those for the Deutsche Mark. Not surprisingly, the depth and the number of orders submitted in each period of time for each side of the order book is significantly larger for the Deutsche Mark than the Canadian dollar. The types of orders submitted for the DM are also more likely to be market orders or limit orders at the best price or better than the best price.

Consequently, these findings demonstrate that there are significant differences in how order submission decisions are made for these two currencies. As a result, it is possible that we will observe different price-quantity choices for both currency pairs and that they may be related to the differences in liquidity and trading activity across currencies. These need to, however, be formally investigated below.

2. Model:

Our empirical model is designed to capture 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, our model extends the existing work which only considers, at most, certain order aggressiveness – quantity combinations. Further, our model explicitly deals with the potential left-hand censorship of our quantity measure because of the minimum size restrictions on orders submitted in the foreign exchange market. These types of restrictions (either explicit or practical) are not considered in other models in the literature.

2.1 Order submission – Simultaneous Ordered Probit and Quantity Regressions

To investigate the order submission process, we start by modeling the order aggressiveness decision. 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) and marketable limit orders (limit orders submitted at prices better than the best price standing on the opposite side of the market), 2) best limit orders placed at prices better than the existing best price, 3) limit orders placed at the existing best price, and 4) limit orders placed at prices worse than the best price

standing in the market. Formally, we model this by assuming the vector of the discrete choices of order aggressiveness at time t, I_t, depends on the latent order aggressiveness variable, I_t^*, which is assumed to be continuous. The latent order aggressiveness is related to the choice of order type as follows:

I_t = 1 if $-\infty < I_t^* \leq \mu_1$ (marketable limit order and market order)

= 2 if $\mu_1 < I_t^* \leq \mu_2$ (limit orders improving the best quote)

= 3 if $\mu_2 < I_t^* \leq \mu_3$ (limit orders at the best quote)

= 4 if $\mu_3 < I_t^* \leq \infty$ (limit orders behind the best quote)

where μ_i, $i = 1, 2, \text{and } 3$, are the thresholds to be estimated.

In modeling the quantity decision, we recognize that there is a minimum quantity one can place in the limit order book, US$1 million, and about half of all orders cluster at this quantity. Therefore we adopt a censored regression framework where we explicitly account for this clustering by modeling the observed quantity at time t, qn_t, as depending on the latent quantity that the dealer wants to submit, qn_t^*, such that:

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

We estimate both the latent order aggressiveness and the latent quantity within a simultaneous equation framework via maximum likelihood in a two-stage method similar to Nelson, Forrest and Olsen (1978). More specifically, in the first stage of estimation the latent order aggressiveness is estimated within an ordered probit framework using maximum likelihood. The specification is given by:

$$I_t^* = \alpha + \beta_1 x_t^I + \beta_2 z_t^I + \varepsilon_t \qquad (1)$$

where x_t^I consists of a set of control variables believed to influence both order aggressiveness and quantity.. For example, we control for market conditions using measures of volatility, the spread and the depth of the orders standing in the limit order book as well as variables to control for serial correlation in

order submissions. The variable z_t^I is a set of variables believed to play a more significant role for order aggressiveness than quantity and therefore are used as identifying restrictions (or instruments) in the simultaneous equation framework (see below for a discussion). We use the number of orders submitted behind the best quotes at the same side of the market during the past 5-minute interval as the identifying restriction.

Similar to the estimation for the order aggressiveness, the latent quantity is estimated using:

$$qn^*_t = a + b_1 x_t^{qn} + b_2 z_t^{qn} + e_t \qquad (2)$$

where x_t^{qn} contains similar variables to those used in equation (1). The vector z_t^{qn} contains variables used to aid in the identification of the model – measures believed to play a more significant role in the quantity than the price aggressiveness decision. Specifically, we use the quantity submitted behind the best prices on the same side of the market during the past 5-minute interval as the exclusion restriction. The censored regression model of Equation (2) is estimated via maximum likelihood.

In the second stage of the estimation, the latent order aggressiveness is given by

$$I_t^* = \kappa + \lambda_0 \hat{qn}_t^* + \lambda_1 x_t + \xi_t \qquad (3)$$

where $\hat{qn}_t^*$ is the estimated value from Equation (2) obtained via maximum likelihood within an ordered probit framework. Similarly, the latent quantity is given by

$$qn^*_t = \eta + \gamma_0 \hat{I}_t^* + \gamma_1 x_t + \varsigma_t \qquad (4)$$

where $\hat{I}_t^*$ is the estimated via maximum likelihood from Equation (1) using our censored regression framework. The estimation allows both order aggressiveness and quantity to be optimally determined recognizing their interaction with one another.

Before moving on to formally motivate our use of these variables and how they are measured, we discuss two important issues in estimating the simultaneous equation model. The first is the identification restrictions used in Equations (1) and (2). The consistency of the estimated parameters used in Equations (3) and (4) depends critically on the instruments used for identification in Equations (1) and (2). A good

instrument should satisfy two conditions: first, it should not be correlated with the error terms. Second, it should be correlated with the control variables. Our chosen instruments can be seen to satisfy these criteria. Since order submission activities behind the best quotes are not observable to market participants, they should not be correlated with the error term, theoretically speaking. Furthermore, as shown in Table 4, these variables are significantly correlated with some of the control variables. Thus our instruments should be valid and lead to consistent estimation.

The second issue we need to address in our estimation procedure is the heteroskedasticity of the errors in Equations (1) to (4). To control for heteroskedasticity in both the quantity and order aggressiveness equations, we model the variance of the residuals from both equations. This is estimated using only control variables. The variance of the probit regression is specified as

$$Var(\varepsilon_t) = \exp(y_t'\gamma)$$

where the set of exogenous variables used in this model, y_t, is a vector consisting of volatility, the bid-ask spread, the number of market orders on the same side of the market in the past 10 quotes, the number of best limit orders or better on the same side of the market and the depth on the same side and opposite side of the market at the best price. Similarly, the variance of the quantity model is specified as:

$$Var(e_t) = \exp(y_t'\lambda)$$

2.2 Control variables and Hypothesis

Based on the existing literature, we expect that order aggressiveness should be negatively related to quantity. The potential cost of large market orders is high – a large trade may reveal more information, may have to walk further up or down the order book to be completely executed, and there is a larger potential cost of being "picked off" if the value of the asset moves against the dealer. Consequently, small orders are more likely to be executed quickly with little price impact or pick-off risk, so they can be submitted at more aggressive prices. Overall we expect dealers to decrease order aggressiveness (quantity) as they increase the quantity (order aggressiveness). This can be related to the adverse

selection risk of models such as Glosten (1994) and more recent models such as Parlour (1998) and Goettler, Parlour and Rajan (2005) among others where order size is related to the level of information possessed by the dealer. Consequently, it is important to empirically study the role of various factors related to liquidity and the asymmetry of information on the order submission decision.

In studying the trade-off between order aggressiveness and quantity, we control for the impact on order aggressiveness and quantity decisions of key factors such as volatility, spread, market depths at different price levels and intraday seasonalities. Below we discuss how we expect them to impact dealers' price and quantity choices. Most of the literature focuses on the price aggressiveness of orders with little discussion of quantity, so our hypotheses are generally framed within the context of price aggressiveness and extended to quantity. Our empirical analysis is designed to determine the trade-off that dealers are willing to make between price and quantity as each of these factors changes in our samples.

1. ***Volatility****:* the realized volatility of returns in the past 30-minutes. This is estimated as the volatility of the average of the mid-quote standing in the market every minute during the past 30 minutes**.**

   Hypothesis: Volatility can be both induced by trading activity and influence trading activity. Consequently, we need to consider both the seasonality in volatility as well as the transitory effects. The intraday pattern has been well-documented by Admati and Pfleiderer (1988), Biais, Hillion and Spatt (1995) and in the foreign exchange market by Dacrogna et al. (2001) among many others, so we control for these patterns below and focus on the transitory component here. As suggested by Foucault (1999) and Foucault, Kadan and Kandel (2005) among others, if the increase in uncertainty captured by rising volatility 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. With respect to the quantity decision,

previous studies suggest that liquidity is inversely related to volatility (e.g., Ahn, Bae and Chan (2001), Bae, Jang and Park (2003), Ranaldo (2004) and Foucault, Moinas and Theissen (2007)). Consequently, we expect to see a decrease in the size of the orders submitted as the level of uncertainty in the market (as measured by volatility) increases.

2. ***Spread***: the spread between the best bid and ask prices at the time the order is submitted.

   Hypothesis: A large bid-ask spread is generally related to an increase in market volatility (e.g., Foucault, Moinas and Theissen (2007)) and therefore increases in price risk which increases the likelihood of traders submitting less aggressive orders (e.g., Foucault (1999) and Ahn, Bae and Chan (2001)). Further there is evidence that 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 be limit orders designed to increase the supply of liquidity to the market. The dealers submitting these orders expect to benefit from the supplying of liquidity. This will improve the best prices to return the spread to its equilibrium value (e.g., Goettler, Parlour and Rajan (2005)). Thus we expect that dealers would refrain from submitting market orders as the spread increases. Similarly, we expect a decrease in the quantity for orders submitted as the spread increases – dealers will submit orders to profit from supplying liquidity at this time, but they will put less at risk with each order. In addition, informed traders will try to hide their information by keeping their orders similar in size to those of other, uninformed traders in the market.

3. ***Depth at the best price***: the depth or quantity of orders standing at the best price in the market. It is observable to all market participants at the time the order was submitted.

   Hypothesis: An increase in depth available at the best price on the *opposite* side of the market from the submitted order has two implications. First, large market orders are less costly because they are 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. As suggested by Goettler, Parlour and Rajan (2005) this increase in the

supply of liquidity on the opposite side of the market will provide dealers with increased motivation to submit market orders that can execute against the increased depth at the best prices but decreased motivation to submit limit orders (unless they are at the best price) due to the increased execution risk for off-best limit orders. 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. Similarly, more depth on the opposite side of the market will result in a lower expected cost for transacting a certain quantity and thus would allow dealers to submit larger orders at a lower cost.

In contrast, an increase in the depth on the *same* side of the market would indicate an increase in the competition for order execution resulting in dealers wanting to submit smaller, more aggressive orders to try to increase their likelihood of timely execution and thus decrease the costs associated with non-execution (e.g., Biais, Hillion and Spatt (1995) and Hall and Hautsch (2006 and 2007)).

4. ***Hourly Dummy Variables*:** We use a series of hourly dummy variables over the trading day. Since we focus on the most active trading periods, we have dummy variables going from before the opening of markets in Europe (North America) around 7:00 going until the close of markets in Europe (North America) around 17:00 for the Deutsche Mark (Canadian dollar) in GMT (EST)[11].

   Hypothesis: We expect traders' order placement strategies to change as trading activity varies over the day. For example, as markets are opening we expect traders will use more aggressive orders to realize gains at this time due to the larger asymmetry of information (e.g., Bloomfield, O'Hara and Saar (2005) and Lo and Sapp (2008)). As information unfolds through the trading day due to the increased number of counterparties being present and larger trading volumes (e.g., Kaul and Sapp (2009)), we would therefore expect there to be a decrease in the aggressiveness of orders submitted over the day. These patterns reverse at the end of the trading day when there is a renewed increase in the asymmetry of information. Matching the patterns in order aggressiveness, we expect an increase (decrease) in the size of the orders submitted as the

asymmetry of information decreases (increases) over the trading day. We use dummy variables for each hour of the trading day to capture the time-varying nature of these changes in the asymmetry of information and their impact on order submission strategies.

5. ***Lagged Order Submission and Quantity*:** We use four variables measuring the past levels of activity for market orders and limit orders at the best price or better than the best prices.

   Hypothesis: As pointed out in Biais, Hillion and Spatt (1995), order submissions are autocorrelated and thus are not completely independent over time. To capture this effect, we include lagged measures for the submissions of market and limit orders at the best price or better than the best prices. The reason we only incorporate lagged values for market orders and limit orders submitted at the best or better than the best price is that they are the only orders observable to all market participants. The first variable we include is the number of market orders submitted on the same side of the market among the last 10 quotes. The second variable is the number of limit orders submitted at the best or better than the best price on the same side of the market within the last 10 quotes. The third variable is the total quantity of market orders submitted among the last 10 quotes and the fourth variable is the total quantity of limit orders submitted at /better than the best quote submitted within the last 10 quotes. In all cases, we expect to observe a degree of serial correlation in these values. Consequently, we expect to see an increase in the likelihood that the next order is a market (limit) order as the number of market orders (limit orders) increases within the past 10 orders, all else equal. Similarly, we expect that more orders of smaller size in the past 10 orders will suggest that the next order will also be small.

6. ***Depth at the behind best price***: depth standing behind the best quote in the market (Note: this is not observable to market participants.)

   Hypothesis: The arguments with respect to the influence of this information on dealers' order submission strategies are similar to those for the depth at the best price. Recent studies such as Bloomfield, O'Hara and Saar (2005), Kaniel and Liu (2006) and Goettler, Parlour and Rajan (2005 and 2007) show that informed traders optimally submit limit orders so the depth behind the

best price represents bets backed up by real money on the future direction of price change. As a result, traders submit smaller and less aggressive orders when the behind best depth increases.

The principal difference is that this is private information so we would expect the impact of this information to be less than that for the publicly available information on the depth at the best prices. Depending on the level of efficiency in the market and the availability of private information, we should not expect to see an impact of the off-best depth on the order submission process

3. Empirical Estimation

To investigate the influence of various market conditions and the state of the limit order book on dealers' order submission decisions, we use both a basic model using only information that is publicly available to all market participants and an extended model including both public and private information (i.e., information publicly observable to all market participants).

3.1 Basic Model

To investigate the relationship between order aggressiveness and quantity, we start by estimating our basic model. In the basic model, we include only the information that is observable by all market participants in both our set of control variables and our exclusion restrictions:

$$\begin{aligned} I_t^* = {} & \gamma_1 \hat{qn}^*{}_t + \beta_{sameside}^{best} Depth_{sameside,t}^{best} + \beta_{oppside}^{best} Depth_{oppside,t}^{best} \\ & + \beta_{sameside}^{market,past} Number_{sameside,t}^{market,past} + \beta_{sameside}^{best,past} Number_{sameside,t}^{best} + \beta^{vlty} Vlty_t + \beta^{sprd} Sprd_t \\ & + \beta^{TimeofDay} D_t^{TimeofDay} + \varepsilon_t \end{aligned}$$

$$\begin{aligned} qn^*{}_t = {} & a + \gamma_2 \hat{I}_t^* + b_{sameside}^{best} Depth_{sameside,t}^{best} + b_{oppside}^{best} Depth_{oppside,t}^{best} \\ & + b_{sameside}^{market,past} Number_{sameside,t}^{market,past} + b_{sameside}^{best,past} Number_{sameside,t}^{best} + b^{vlty} Vlty_t + b^{sprd} Sprd_t \\ & + b^{TimeofDay} D_t^{TimeofDay} + e_t \end{aligned}$$

And the residuals are modeled as:

$$\begin{aligned} \varepsilon_t = {} & b_{sameside}^{best,past} Number_{sameside,t}^{best,past} + b_{sameside}^{behindbest,past} Number_{sameside,t}^{behindbest,past} + b^{vlty} Vlty_t + b^{sprd} Sprd_t + \\ & + b_{sameside}^{best} Depth_{sameside,t}^{best} + b_{oppside}^{best} Depth_{oppside,t}^{best} \end{aligned}$$

$$e_t = \sigma + b^{best,past}_{sameside} Number^{best,past}_{sameside,t} + b^{behindbest,past}_{sameside} Number^{behindbest,past}_{sameside,t} + b^{vlty} Vlty_t + b^{sprd} Sprd_t +$$
$$+ b^{best}_{sameside} Depth^{best}_{sameside,t} + b^{best}_{oppside} Depth^{best}_{oppside,t}$$

where $Depth^{best}_{sameside,t}$ is the depth standing at the best price on the same side of the market that the order was submitted when the order was submitted (i.e., at time t), $Number^{best,past}_{sameside,t}$ is number of same side limit orders submitted at the best price or better in the last 10 quotes, $Vlty_t$ is the realized volatility as defined in the previous section, $Sprd_t$ is the bid-ask spread and $D_t^{TimeofDay}$ is the dummy variable for the different times of day (one for each hour between 7:00 and 17:00.

The results from the estimation of the basic model price and quantity decisions are presented in Table 5. When interpreting the results it is important to remember that a positive coefficient in the order aggressiveness (quantity) equation means that as the factor increases the distance from the best price (quantity) of the order submitted increases.

Trade-off between price and quantity

In model 3 (4) for price (quantity), we include the estimated latent level of quantity (price). Our results find a significantly negative relationship between quantity and the order aggressiveness (in panels 5a and 5c for the DM and Canadian dollar respectively), however, we do not find significant evidence of an influence for order aggressiveness on the quantity decision for either the DM or the Canadian dollar (in panels 5b and 5d). Consequently, it appears that there is a trade-off for dealers between quantity and order aggressiveness. Since the most significant relationship is from quantity to order aggressiveness but not the reverse, these results suggest that there is a strong correlation between quantity and aggressiveness – larger orders tend to be more aggressively priced. Because it is a one-way relationship between order aggressiveness and quantity, this suggests that there are other factors which influence order size more directly than the level of price aggressiveness, despite the evidence of an interaction of these two aspects of the order submission decision.

Volatility and Spread

For these measures, Table 5 shows a decrease in the order aggressiveness for both the DM and the Canadian dollar as the volatility increased, but an increase in the quantity for the Canadian dollar and a decrease in the quantity for the DM. These results provide partial support for our hypotheses. The relation between order aggressiveness and volatility is consistent with theoretical studies like Foucault (1999) and empirical studies such as Ranaldo (2004) and Bae, Jang and Park (2003). The divergent results for quantity across our currency pairs could be the result of differences in the overall liquidity of these markets. For the less liquid Canadian dollar, the increase in volatility may be related to an increase in trading volume (i.e., quantity) as prices in the Canadian dollar would be more sensitive to changes in trading volume than the more liquid DM. This is consistent with the correlation results in Table 4. This suggests a role for liquidity in how traders react to changing market conditions.

For the spread, we found that an increase in the bid-ask spread was associated with a decrease in the size of orders for both the DM and Canadian dollar. Interestingly, an increase in the bid-ask spread was associated with an increase for Deutsche Mark orders but a decrease in the aggressiveness for Canadian dollar orders. Once again, the differences in the results for these two currencies suggest that there are different factors at work for the DM and the Canadian dollar. For example, an increase in the spreads for the Deutsche Mark may indicate the rapid arrival of information (good or bad) leading traders to submit more aggressive orders to ensure execution at these times. For the Canadian dollar, the widening spread may be a signal of bad news or a decline in liquidity leading to an increase in the use of limit orders to decrease the costs of being "picked off".

Consequently, our results confirm the role played by market uncertainty in the order submission decision and extend the literature by suggesting a role played by an asset's liquidity in the role of our standard measures of uncertainty in dealers' trading behavior. Traders adjust their orders in both the order aggressiveness and the quantity dimensions to avoid risk as documented in previous studies, but the information being sent by increasing volatility and spreads may be different for different assets. On a

related note, the higher significance for the estimated coefficients on the spreads suggests that traders are especially sensitive to changes in spread as suggested in Kumar and Seppi (1992).

Depth at the best price

As the depth of orders on the same side of the market increased, we found an increase in the aggressiveness of orders and an increase in the quantity. These results suggest that there is a need to increase aggressiveness to execute trades at these times. This is consistent with the predictions in Parlour (1998) – an increase in depth on the same side of the market encourages the submission of aggressive market orders and discourages the submission of limit orders because limit orders have to join a longer queue when depth on the same side of the market is thick. Consequently order aggressiveness should increase.

Moving to the depth on the opposite side of the market, we see significant differences in the results for the DM and Canadian dollar. For the DM, we find an increase in the depth on the opposite side of the market is related (though not statistically significant) to a decrease in the quantity ordered and an increase in price aggressiveness. This result suggests an asymmetry of information leading to dealers being more cautious submitting orders – they submit smaller more aggressive quotes to ensure faster execution. The dealers submitting the orders on the other side of the market are hoping to benefit by supplying liquidity to the deep other side of the market. However, for the Canadian dollar, an increase in the depth on the opposite side of the market is related to an increase in quantity but a decrease in order aggressiveness. This suggests dealers are more willing to provide liquidity in a market such as the Canadian dollar where the benefits from supplying liquidity may be larger and this is performed using limit orders which protect the price at which they supply liquidity.

Although it is not included in the basic model, it is possible that all of the information relevant for dealers' order submission decisions is not included in the depth at the best price. Consequently, we consider an extended model in the next section where we include the information on market depth at prices behind the best price. This will allow us to test the suggestions from studies such as Biais, Hillion

and Spatt (1995), Pascual and Veredas (2004) or Kaniel and Lin (2006) that there is differential information at the best prices.

Lagged number of orders

Since it is reasonable to assume that there is important information in the types of orders submitted in the recent past, we look at the number of past market and limit orders out of the past 10 orders submitted on the same side of the market as the current order. Considering the number of market orders and the number of limit orders submitted at the best price or better than the best price submitted out of the past 10 orders, we find a positive relationship between this and the quantity ordered for both currency pairs. Consequently there is a correlation in the information contained in the types of orders submitted in the recent past and the size of orders being submitted currently. Though our estimated order aggressiveness did not have a significant influence on the quantity, we do find that the pattern of past types of orders being submitted does have a significant impact with more aggressive orders in the past leading to smaller sized orders. This suggests that there is valuable information contained in the past types of orders submitted

Interestingly, we find mixed relationships between these lagged values and order aggressiveness. These results indicate that submitting a series of market orders in the past results in an increase in the quantity ordered as well as an increase in the aggressiveness of orders for the DM but not the Canadian dollar therefore it appears that the information arriving influences the submission of market orders resulting in dealers buying or selling larger quantities at more aggressive prices. Consequently, it appears that dealers try to benefit from a past increase in demand for liquidity (the use of market orders) by increasing the supply of liquidity. On the other hand, an increase in the number of lagged limit orders for the DM (Canadian dollar) results in a decrease (increase) in order aggressiveness. Traders view this differently for these two assets. More limit orders in DM means more asymmetry of information so traders submit more limit orders to protect their positions or react to new information. Not so for the Canadian dollar.

Although we do not investigate this, it is also possible that dealers split their orders to improve their execution costs and decrease the flow of information from their orders. We do not have information on the identity of the dealer submitting the order. Thus, although it is possible that there is some order splitting, we treat each submitted order as an independent submission.

Time of Day Effects

Consistent with what we found in the raw data and has been documented in existing studies, we find intraday seasonalities for both the quantity/size of orders as well as the aggressiveness of orders submitted over the trading day. These patterns persist even after correcting for the other factors believed to influence these order characteristics. Looking at the size of submitted orders, we find that the quantity increases rapidly for both currency pairs as the markets open with a peak shortly after the opening in both markets. The trading activity generally decreases from the peak shortly after opening until closing. The only deviations from these patterns are that there is a second peak in trading activity in the Deutsche Mark as the markets in North America open and there is a surge in trading activity for the Canadian dollar just before the markets in North America close.

Moving to the order aggressiveness, we see the aggressiveness of orders for both the Canadian dollar and Deutsche Mark starting high during early market trading and moving up and down systematically with the size of orders (i.e., increasing/decreasing as size decreases/increases) over the rest of the day. Consequently, when order sizes are smallest, we see the highest order aggressiveness. The lowest point for trading activity and the highest for order aggressiveness is therefore at the close of the North American markets for the Canadian dollar but, somewhat surprisingly, there is an increase in order aggressiveness for the Canadian dollar at the close of European markets. A potential explanation for this difference is that there still exist trading opportunities in North America when the European markets close so the existence of this liquidity allows European traders to use more aggressive orders to close their positions than a North American trader in the Canadian dollar would have at the North American close.

Conditional Variance:

The potential heteroskedasticity in our residuals is modeled and the results presented in the second column of Table 5. These estimated coefficients describe how the variance of the order aggressiveness and quantity are impacted by changes in some of our explanatory variables. In Tables 5a and 5c, we see how the volatility of the order aggressiveness depends on our set of explanatory variables. Our results indicate that the variance in order aggressiveness increases as price volatility increases, as the quantity of orders on either side of the market increases and as spreads decrease. Since increasing order size and tightening spreads indicate a decrease in information asymmetry, it is logical that we find the level of order aggressiveness becomes more stable at these times. The positive relationship with price volatility may indicate a role for new information arrival which is consistent with our earlier results. The differences in the relationship between market depth on the same and opposite sides of the market on the volatility of price aggressiveness may be a result of differences in the liquidity for the DM and Canadian dollar as discussed above. The results for the DM are consistent with those from previous studies – there is more (less) stability for the order aggressiveness when there is greater depth on the same (opposite) side of the market. We find the reverse for the Canadian dollar where liquidity effects may be reflected differently in the depths on each side of the market.

Moving to the volatility in quantity for the orders (see Tables 5b and 5d) we find considerable consistency across the results for the DM and Canadian dollar. We find that the volatility of the quantity quoted decreases as the spread increases, but increases as the volatility of prices increases. The volatility of the quantities decreases as the quantity of orders on the same side of the market increases, but the volatility increases as the depth on either the same or opposite sides of the market increase. These results suggest that as the demand for liquidity increases (i.e., spreads and recent order sizes increase) the variability in order size decreases. But when we find evidence that the supply of liquidity and price uncertainty are increasing, there is a corresponding increase in the volatility of the size of orders being submitted.

3.2 Extended Model

The extended model we estimate next is designed to determine the role played by private information in the order submission decision. Although market participants only have access to certain information through the Reuters D2000-2 system from which we obtain our data, we want to determine if the extra information that was provided to us, but was not available to traders, influences the order submission decision. Specifically, traders using the Reuters D2000-2 system have access to information regarding the depth at the best prices and the last five transactions, but our data set includes a much broader picture of the true state of the limit order book by including the full depth of orders standing at any time, not just those at the best prices. Assuming that the limited information available through the Reuters D2000-2 system is all that market participants use is not entirely realistic. Market participants have access to information beyond that incorporated in our data set (e.g., they have access to their customer order flow and information from other trading platforms such as the Reuters FXFX system). Consequently our extended model is designed to estimate the impact of such outside sources of information by considering the impact of the extra information that we have in the data set going beyond what is publicly available. If such outside information has no value, we would expect the estimated coefficients on these variables to be statistically insignificant. The complete extended model is therefore:

$$I_t^* = \gamma_1 \hat{qn}^*{}_t + \beta_{sameside}^{best} Depth_{sameside,t}^{best} + \beta_{sameside}^{behindbest} Depth_{sameside,t}^{behindbest} + \beta_{oppside}^{best} Depth_{oppside,t}^{best} + \beta_{oppside}^{behindbest} Depth_{oppside,t}^{behindbest} + \\ + \beta_{sameside}^{market,past} Number_{sameside,t}^{market,past} + \beta_{sameside}^{best,past} Number_{sameside,t}^{best} + \beta^{vlty} Vlty_t + \beta^{sprd} Sprd_t + \beta^{TimeofDay} D_t^{TimeofDay} + \varepsilon_t$$

$$qn^*{}_t = a + \gamma_2 \hat{I}_t^* + b_{sameside}^{best} Depth_{sameside,t}^{best} + b_{sameside}^{behindbest} Depth_{sameside,t}^{behindbest} + b_{oppside}^{best} Depth_{oppside,t}^{best} + b_{oppside}^{behindbest} Depth_{oppside,t}^{behindbest} \\ + b_{sameside}^{market,past} Number_{sameside,t}^{market,past} + b_{sameside}^{best,past} Number_{sameside,t}^{best} + b^{vlty} Vlty_t + b^{sprd} Sprd_t + b^{TimeofDay} D_t^{TimeofDay} + e_t$$

and

$$\varepsilon_t = b_{sameside}^{market,past} Volume_{sameside,t}^{market,past} + b_{sameside}^{best,past} Volume_{sameside,t}^{best,past} + b^{vlty} Vlty_t + b^{sprd} Sprd_t + \\ + b_{sameside}^{best} Depth_{sameside,t}^{best} + b_{sameside}^{behindbest} Depth_{sameside,t}^{behindbest} + b_{oppside}^{best} Depth_{oppside,t}^{best} + b_{oppside}^{behindbest} Depth_{sameside,t}^{behindbest}$$

$$e_t = \sigma + b^{market,past}_{sameside} Volume^{market,past}_{sameside,t} + b^{best,past}_{sameside} Volume^{best,past}_{sameside,t} + b^{vlty} Vlty_t + b^{sprd} Sprd_t +$$
$$+ b^{best}_{sameside} Depth^{best}_{sameside,t} + b^{behindbest}_{sameside} Depth^{behindbest}_{sameside,t} + b^{best}_{oppside} Depth^{best}_{oppside,t} + b^{behindbest}_{oppside} Depth^{behindbest}_{sameside,t}$$

where $Depth^{behd}_{sameside,t}$ is depth at the behind best price on the same side of the market that the order is submitted, $Depth^{behindbest}_{oppside,t}$ is the depth behind the best price on the opposite side of the market that the order is submitted. We expect depth behind the best price would not affect order submission decision since it is not observable by market participants.

The results from the estimation of the extended model can be found in Table 6. In virtually every case, we find that the estimated coefficients on the variables included in the basic model remain, qualitatively speaking, unchanged after adding this extra information. As a consequence, we focus our discussion on the extra information provided by the inclusion of the information on the depth at prices behind the best price.

The first observation is that the estimated coefficients on the depth at prices behind the best price are all statistically significant. This suggests that there is, in fact, valuable extra information being provided to dealers that is correlated with the information included in the depth behind the best price. For both the Canadian dollar and the DM, we find that an increase in the depth at behind the best prices on both sides of the market leads to an increase in the size of orders placed. For the order aggressiveness, we find that an increase in the depth on the same side of the market but behind the best price leads to a decrease in order aggressiveness for the DM but has an insignificant impact on the Canadian dollar's order aggressiveness. For the depth on the opposite side of the market, an increase is related to an increase in order aggressiveness for both currency pairs but, once again, the results are only significant for the DM.

Since we are assuming that the depth behind the best price could reveal information on the underlying efficient price, it is interesting to see what these results tell us. Recent literature like Bloomfield, O'Hara and Saar (2005), Kaniel and Liu (2006) and Goettler, Parlour and Rajan (2007) point

out that informed traders optimally submit limit orders and much of the existing literature suggests important information can be found by looking at the entire limit order book. With informed traders placing limit orders, an increase in the depth behind the best price represents the best estimate of the direction of future price changes.

We find that an increase in the depth behind the best price on the opposite side of the market has a positive impact on the size of orders it suggests that dealers are ready to consume the liquidity existing in the limit order book. However, the decrease in DM order aggressiveness as the depth on the same side of the market at prices behind the best price increases suggests that there is still a concern about the price impact of trades and potential future changes in market prices. Looking at changes in the depth at behind the best prices on the opposite side of the market, we see a much lower level of statistical significance for both order size and aggressiveness. The results do, however, suggest that there is an increase in quantity as there are more orders on the opposite side of the market and an increase in order aggressiveness for the DM (the result is insignificant for the Canadian dollar). The lack of significance for the private information could be a result of dealers being able to obtain information from other sources such as the Reuters' EFX page as well as their own customer order flow.

In the conditional variance part of the model, we find that an increase in the depth on either side of the market leads to an increase in the volatility of the size of orders being submitted. This is likely a result of the increasing depth of the order book generating more orders based on the increased flow of information and liquidity on one or both sides of the market. This suggests that dealers observe the increased depth on the same (opposite) side of the market and want to profit by consuming (providing) liquidity in the market. Consequently there is a wider range of order sizes at these times. For the volatility of order aggressiveness, it is interesting that an increase in the depth on the same side of the market results in an increase in volatility for order aggressiveness for dealers but changes on the opposite side of the market result in a decrease in volatility. This result suggests that an increase in the depth on the opposite side of the market results in dealers submitting orders with more similar levels of

aggressiveness – generally to consume liquidity. But an increase in the depth on the same side of the market increases the variability in the levels of aggressiveness.

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 decisions.

The data comes from firm quotes submitted to the Reuters D-2000-2 system for the Deutsche Mark-U.S. dollar and the Canadian dollar-US dollar. Since this data set includes information on every order submitted over the trading day (which includes information not visible to all market participants), we can investigate the role of public and private information on the order submission decision for a very heavily traded and thus very liquid currency and a less heavily traded or relatively illiquid currency.

We find a negative relationship between order aggressiveness and quantity – order size tends to be smaller when the order is more aggressive. By submitting smaller orders, traders submitting market orders avoid the potentially higher cost of execution resulting from having to walk up /down the order book for the order to be executed. The result is consistent with the theoretical model of Goettler, Parlour and Rajan (2005). Interestingly we do not find that order aggressiveness, itself, plays a significant role in the order size decision. Consequently, it is important to study both the order aggressiveness and quantity parts of the order submission decision.

Consistent with other studies, we also find a significant role for changes in market conditions on the order submission decision, however, we find that several of the relationships differ between the Deutsche Mark and the Canadian dollar. Most of the differences appear to be related to the differences in liquidity of the two currencies. For the more liquid DM the market reacts to changes in many of the

factors in a manner consistent with many theoretical studies (e.g., Parlour (1998), Foucault (1999), Foucault, Kadan and Kandel (2005)) and empirical studies such as Bae, Jang and Park (2003), Ranaldo (2004) and Ellul et al. (2007)). However, the reactions are not the same for the less liquid Canadian dollar where the changes in market conditions and the state of the limit order book can be interpreted differently. For the Canadian dollar, dealers can profit more by supplying liquidity so they react differently to changes in market conditions than in the already very liquid DM market.

For the private information on the orders behind the best price, we found that its impact is smaller than for the information at the best price but it still impacts both the order aggressiveness and order size decision even though it is unobservable to market participants. When the behind best depth increases on the same side of the market, order aggressiveness and order size decrease significantly. The intuition is that the depth behind the best price could reveal information on the underlying efficient price. Recent studies such as Bloomfield, O'Hara and Saar (2005), Kaniel and Liu (2006) and Goettler, Parlour and Rajan (2005 and 2007) show that informed traders optimally submit limit orders so the depth behind the best price represents bets backed up by real money on the future direction of price change. As a result, traders submit smaller and less aggressive orders when the behind best depth increases.

Consequently our analysis provides an important step in improving our understanding of how dealers make their price-quantity decisions when submitting limit orders. By using a simultaneous equations model, we can more clearly see this than in other studies. Our use of the Deutsche Mark and Canadian dollar further help us by highlighting the significant role played by the supply and demand for liquidity in both the order aggressiveness and order size decisions as well as their interactions.

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Footnotes:

[1] From a theoretical perspective the complexity of this problem is highlighted by the need to use numerical methods to obtain comparative static results in Goettler, Parlour and Rajan (2005).

[2] 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.

[3] The most similar studies investigating the price-quantity decision consider the Saudi market in Al-Suaibani and Kryzanowski (2000) or the Australian market in papers such as Hall and Hautsch (2006 and 2007) or Cao, Hansch and Wang (2007).

[4] For an interesting discussion of trading in the foreign exchange market see Evans (2002).

[5] However, it should be noted that we cannot distinguish who is submitting an order so all of the traders are anonymous.

[6] Note: the results are qualitatively similar including and excluding this day from the sample.

[7] The days upon which the following major macroeconomic announcements were made are removed from the sample: Bank of Canada rate decision, FOMC rate decision, Current Account (Canada), GDP (Canada), Industrial Product Price (Canada), International Merchandise Trade (Canada), Raw Material Price Index (Canada), Retail Sales (Canada), Change in NonFarm Payrolls (U.S.), Consumer Price Index (U.S.), Durable Orders (U.S.), GDP Advance(U.S.), Housing Starts (U.S.), Initial Jobless Claims (U.S.), Producer Price Index (U.S.), Retail Sales (U.S.), Trade Balance (U.S.)

[8] Intraday seasonalities are a well-known feature of microstructure data (e.g., Dacrogna et al. (2001)).

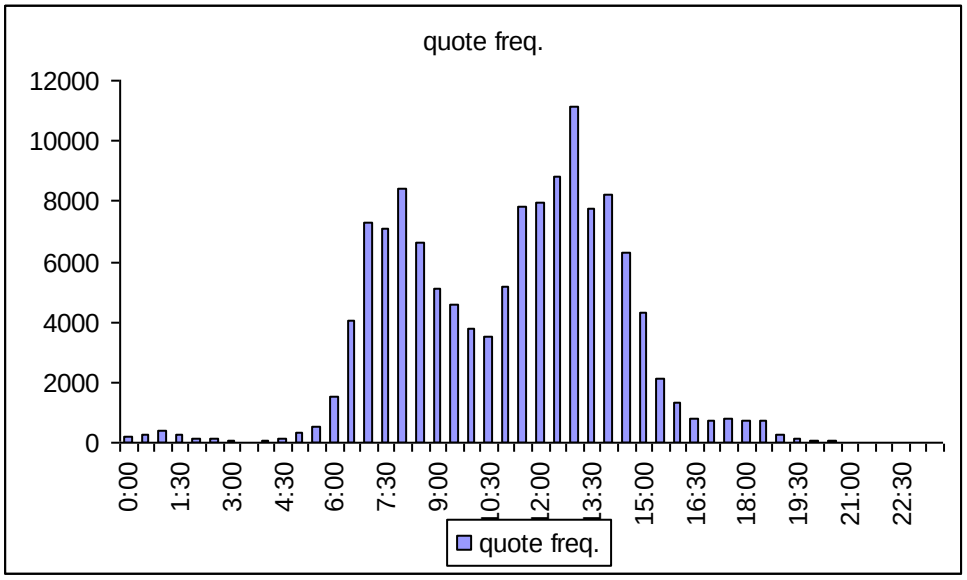
[9] As document in Kaul and Sapp (2009), changes in the levels of liquidity and other trading features can have a significant impact on dealer trading behaviour and market characteristics.

[10] Although these samples are generally for shorter periods, have more limited dealer coverage or only consider actual transactions, they provide useful benchmarks for our sample.

[11] Note: we use the final hour of the trading day as our base case and thus do not have a dummy variable for the period from 16:00 to 17:00.

Figure 1: Trading Activity for Currency Pairs

a) This graph presents the number of orders submitted in each half hour time bin using the data from the Reuters D-2002 electronic brokerage system for the Deutsche Mark- US dollar exchange rate for the week of October 6-10, 1997.



b) This graph presents the number of orders submitted in each half hour time bin using the data from the Reuters D-2002 electronic brokerage system for the Canadian dollar - US dollar exchange rate for the period from May 1 to June 30, 2005.

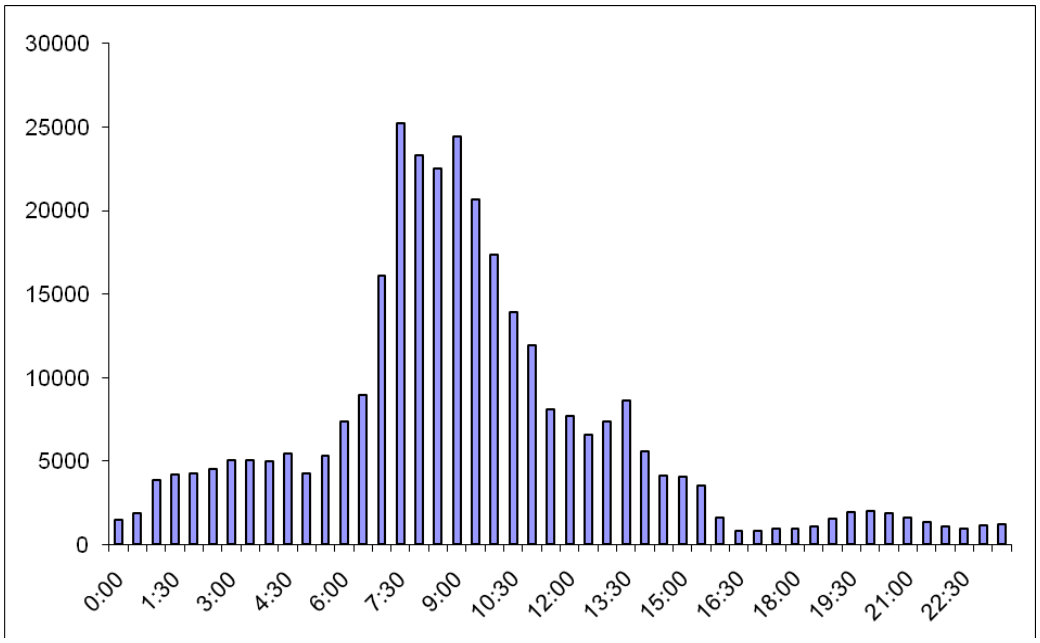


Table I: Order Aggressiveness and Quantity

The table presents the proportion of orders submitted and cancelled in terms of order aggressiveness and quantity. Order aggressiveness is divided into four order aggressiveness categories: market orders, limit orders improving the best price, limit orders at the best price, limit orders behind the best 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.

a) The data is for the Deutsch Mark – US dollar exchange rate from the Reuters D-2000-2 electronic brokerage system for the week of October 6-10, 1997.

	proportion of aggressiveness	Proportion of quantity in each category		
		qn=1	qn=2	qn >=3
All Orders				
market order	0.17	0.55	0.24	0.20
limit order better than best quotes	0.24	0.39	0.29	0.32
limit order at the best quotes	0.25	0.48	0.26	0.25
limit order behind best quotes	0.33	0.60	0.21	0.19
Ask				
market order	0.18	0.56	0.24	0.20
limit order better than best quotes	0.25	0.40	0.28	0.32
limit order at the best quotes	0.25	0.48	0.26	0.26
limit order behind best quotes	0.32	0.61	0.21	0.19
Bid				
market order	0.17	0.54	0.24	0.19
limit order better than best quotes	0.24	0.38	0.30	0.32
limit order at the best quotes	0.25	0.48	0.26	0.25
limit order behind best quotes	0.33	0.59	0.21	0.19

b) The data is from the Reuters D-2002 electronic brokerage system for the Canadian dollar - US dollar exchange rate for the period from May 1 to June 30, 2005.

	proportion of aggressiveness	Proportion of quantity in each category		
		qn=1	qn=2	qn >=3
All Orders				
market order	0.24	0.45	0.23	0.32
limit order better than best quotes	0.50	0.52	0.24	0.24
limit order at the best quotes	0.16	0.58	0.23	0.19
limit order behind best quotes	0.09	0.47	0.23	0.30
Ask				
market order	0.25	0.45	0.24	0.31
limit order better than best quotes	0.46	0.53	0.24	0.23
limit order at the best quotes	0.21	0.55	0.24	0.21
limit order behind best quotes	0.08	0.48	0.23	0.29
Bid				
market order	0.23	0.44	0.22	0.33
limit order better than best quotes	0.56	0.52	0.24	0.24
limit order at the best quotes	0.11	0.63	0.20	0.16
limit order behind best quotes	0.10	0.46	0.22	0.31

Table II: Intra-day Proportion of Orders by Order aggressiveness and Quantity Category

The table shows the proportion of orders submitted falling into each order aggressiveness category and the proportion of quantity at each hourly interval. Orders aggressiveness are divided into four order aggressiveness categories: market orders, limit orders improving the best price, limit orders at the best price, limit orders behind the best 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.

a) The data is for the Deutsch Mark – US dollar exchange rate from the Reuters D-2000-2 electronic brokerage system for the week of October 6-10, 1997.

hr	market order	limit orders better than best quotes	limit orders at the best quotes	limit orders behind the best quotes	qn=1	qn=2	qn >=3
6:00	0.19	0.31	0.24	0.26	0.55	0.26	0.19
7:00	0.20	0.23	0.24	0.33	0.55	0.22	0.23
8:00	0.19	0.21	0.25	0.35	0.54	0.22	0.23
9:00	0.18	0.22	0.26	0.33	0.54	0.21	0.24
10:00	0.17	0.25	0.26	0.32	0.55	0.21	0.23
11:00	0.17	0.24	0.24	0.34	0.53	0.22	0.25
12:00	0.17	0.23	0.26	0.34	0.48	0.26	0.26
13:00	0.17	0.21	0.27	0.35	0.48	0.27	0.25
14:00	0.16	0.25	0.27	0.33	0.46	0.28	0.26
15:00	0.15	0.32	0.24	0.30	0.47	0.33	0.20
16:00	0.15	0.42	0.18	0.25	0.50	0.36	0.14
17:00	0.15	0.46	0.17	0.23	0.52	0.31	0.17

b) The data is from the Reuters D-2002 electronic brokerage system for the Canadian dollar - US dollar exchange rate for the period from May 1 to June 30, 2005.

hr	market order	limit orders better than best quotes	limit orders at the best quotes	limit orders behind the best quotes	qn=1	qn=2	qn >=3
6:00	0.26	0.56	0.10	0.07	0.56	0.22	0.22
7:00	0.26	0.53	0.14	0.07	0.53	0.24	0.23
8:00	0.24	0.51	0.16	0.09	0.53	0.23	0.24
9:00	0.22	0.50	0.17	0.10	0.49	0.23	0.27
10:00	0.23	0.52	0.16	0.09	0.51	0.23	0.26
11:00	0.24	0.51	0.17	0.08	0.51	0.24	0.25
12:00	0.26	0.48	0.17	0.09	0.48	0.24	0.28
13:00	0.25	0.50	0.15	0.10	0.49	0.23	0.28
14:00	0.25	0.45	0.21	0.08	0.48	0.24	0.28
15:00	0.27	0.49	0.17	0.07	0.53	0.22	0.24
16:00	0.30	0.46	0.17	0.07	0.54	0.24	0.22
17:00	0.26	0.51	0.15	0.08	0.54	0.26	0.19

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. Volatility is defined as the realized volatility over the 30 minutes before order *i* is submitted. 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

a) The data is for the Deutsch Mark – US dollar exchange rate from the Reuters D-2000-2 electronic brokerage system for the week of October 6-10, 1997.

	Mean	Std Dev	Max	Median	Min
volatility	0.077	0.071	0.579	0.053	0.003
spread times 1000	0.221	0.227	5.5	0.2	0
Same side depth (volume) at the best quote	4.136	3.755	52	3	1
Same side depth (volume) at the behind best quote	35.817	13.082	112	34	3
Opposite side depth (volume) at the best quote	4.048	3.635	52	3	1
Opposite side depth (volume) at the behind best quote	34.982	12.665	107	33	3
Number of same side market orders for the last 10 quote	0.914	1.150	8	1	0
Number of same side limit orders at or better than the best quotes for the last 10 quote	1.769	3.270	120	1	0
Quantity of same side market orders for the last 10 quote	1.057	1.429	8	0	0
Quantity of same side limit orders at or better than the best quotes for the last 10 quote	2.089	4.168	165	0	0

b) The data is for the Canadian dollar – US dollar exchange rate from the Reuters D-2000-2 electronic brokerage system from May 1 to June 30, 2005.

	Mean	Std Dev	Max	Median	Min
volatility	0.062	0.073	1.744	0.037	0
spread times 1000	0.454	0.526	10	0.3	0
Same side depth (volume) at the best quote	3.367	5.228	200	2	0
Same side depth (volume) at the behind best quote	14.643	24.172	206	6	0
Opposite side depth (volume) at the best quote	3.182	5.139	130	2	0
Opposite side depth (volume) at the behind best quote	13.004	23.970	206	5	0
Number of same side market orders for the last 10 quote	1.352	1.242	10	1	0
Number of same side limit orders at or better than the best quotes for the last 10 quote	3.081	5.878	600	2	0
Quantity of same side market orders for the last 10 quote	2.495	1.960	9	3	0
Quantity of same side limit orders at or better than the best quotes for the last 10 quote	5.595	9.001	400	4	0

Table IV: Correlations for Variables Used in Exclusion Restriction

This table shows the cross-autocorrelation of quotes submitted (quantity) at different order aggressiveness categories with the number (quantity) of quotes submitted at behind the best quote on the same side of the market during the previous five minutes interval. The data is for the Deutsch Mark – US dollar exchange rate from the Reuters D-2000-2 electronic brokerage system for the week of October 6-10, 1997 and the Canadian dollar from May 1 to June 30, 2005.

	DM		C$	
	price	quantity	price	quantity
Same side depth at best quote	0.048	0.107	0.072	0.125
Same side depth behind the best quote	0.142	0.094	0.087	0.067
Opposite side depth at best quote	0.071	0.047	0.009	0.033
Opposite side depth behind the best quote	0.103	0.072	-0.017	-0.012
spread	-0.130	-0.077	-0.043	-0.030
volatility	0.154	0.098	0.351	0.226
Number of same side market orders for the last 10 quotes	0.112		-0.009	
Number of same side market orders for the last 10 quotes		0.315		0.245
Number of same side limit orders better than or equal to the best quotes for the last 10 quotes	-0.005		0.004	
Number of same side limit orders better than or equal to the best quotes for the last 10 quotes		0.240		0.318

Table V: Order Submission – Basic Model

The results from the simultaneous estimation of the basic model:

$$I_t^* = \gamma_1 \hat{q}n^*{}_t + \beta_{sameside}^{best} Depth_{sameside,t}^{best} + \beta_{oppside}^{best} Depth_{oppside,t}^{best} + \beta_{sameside}^{market,past} Number_{sameside,t}^{market,past} + \beta_{sameside}^{best,past} Number_{sameside,t}^{best} + \beta^{vlty} Vlty_t + \beta^{sprd} Sprd_t + \beta^{TimeofDay} D_t^{TimeofDay} + \varepsilon_t$$

$$qn^*{}_t = a + \gamma_2 \hat{I}_t^* + b_{sameside}^{best} Depth_{sameside,t}^{best} + b_{oppside}^{best} Depth_{oppside,t}^{best} + b_{sameside}^{market,past} Number_{sameside,t}^{market,past} + b_{sameside}^{best,past} Number_{sameside,t}^{best} + b^{vlty} Vlty_t + b^{sprd} Sprd_t + b^{TimeofDay} D_t^{TimeofDay} + e_t$$

where $Depth_{sameside}^{best}$ is depth at the best price on the same side of the market that the order is submitted, $Depth_{oppside}^{best}$ is depth on the opposite side of the market that the order is submitted. *Vlty* is the realized volatility as defined in the previous section. *Sprd* is the bid-ask spread.

a) Order Aggressiveness for the Deutsche Mark – US dollar

Coefficient for order submission			**Coefficient for heteroscedastic standard error**		
Parameter	Estimate	P-value	Parameter	Estimate	P-value
Intercept	1.344	<.0001			
Qn_hat	-0.311	<.0001	quantity of same side market orders for the last 10 quotes	0.318	<.0001
Number of same side market orders for the last 10 quotes	-0.047	<.0001	quantity of same side limit orders better than or equal to the best quotes for the last 10 quotes	0.075	<.0001
Number of same side limit orders better than or equal to the best quotes for the last 10 quotes	0.116	<.0001	spread	-0.285	<.0001
spread	-0.022	<.0001	volatility	0.110	<.0001
volatility	0.047	<.0001	Same side depth standing at the best quote	-0.186	<.0001
Same side depth standing at the best quote	-0.009	0.002	Opposite side depth standing at the best quote	0.047	<.0001
Opposite side depth standing at the best quote	-0.029	<.0001			
dummy for 7:00	0.105	<.0001			
dummy for 8:00	0.201	<.0001			
dummy for 9:00	0.159	<.0001			
dummy for 10:00	0.122	<.0001			
dummy for 11:00	0.159	<.0001			
dummy for 12:00	0.278	<.0001			
dummy for 13:00	0.312	<.0001			
dummy for 14:00	0.268	<.0001			
dummy for 15:00	0.077	0.005			
dummy for 16:00	-0.147	<.0001			

b) Quantity for the Deutsche Mark – US dollar

Coefficient for quantity

Parameter	Estimate	P-value
Intercept	-0.207	0.0003
Aggressiveness_hat	0.046	0.2679
Number of same side market orders for the last 10 quotes	0.199	<.0001
Number of same side limit orders better than or equal to the best quotes for the last 10 quotes	0.174	<.0001
spread	-0.023	0.045
volatility	-0.025	0.026
Same side depth standing at the best quote	0.144	<.0001
Opposite side depth standing at the best quote	-0.005	0.693
dummy for 7:00	0.022	0.727
dummy for 8:00	0.159	0.011
dummy for 9:00	0.096	0.142
dummy for 10:00	0.088	0.195
dummy for 11:00	0.159	0.015
dummy for 12:00	0.409	<.0001
dummy for 13:00	0.429	<.0001
dummy for 14:00	0.512	<.0001
dummy for 15:00	0.276	0.0001
dummy for 16:00	0.015	0.873

Coefficient for heteroscedastic standard error

Parameter	Estimate	P-value
sigma	2.822	<.0001
quantity of same side market orders for the last 10 quotes	-0.01401	<.0001
quantity of same side limit orders better than or equal to the best quotes for the last 10 quotes	-0.00977	<.0001
spread	-0.041	<.0001
volatility	0.019	0.008
Same side depth standing at the best quote	0.045	<.0001
Opposite side depth standing at the best quote	0.026	0.001

c) Order Aggressiveness for the Canadian dollar – US dollar

Coefficient for order submission			**Coefficient for heteroscedastic standard error**		
Parameter	Estimate	P-value	Parameter	Estimate	P-value
Intercept	0.792	<.0001			
Qn_hat	-0.050	<.0001	quantity of same side market orders for the last 10 quotes	0.0185	0.005
Number of same side market orders for the last 10 quotes	0.008	0.1037	quantity of same side limit orders better than or equal to the best quotes for the last 10 quotes	0.073	<.0001
Number of same side limit orders better than or equal to the best quotes for the last 10 quotes	-0.022	<.0001	spread	-0.152	<.0001
spread	0.010	0.0068	volatility	0.040	<.0001
volatility	0.019	<.0001	Same side depth standing at the best quote	0.030	0.001
Same side depth standing at the best quote	-0.088	<.0001	Opposite side depth standing at the best quote	-0.036	<.0001
Opposite side depth standing at the best quote	0.011	0.009			
dummy for 7:00	0.046	0.159			
dummy for 8:00	0.145	<.0001			
dummy for 9:00	0.210	<.0001			
dummy for 10:00	0.179	<.0001			
dummy for 11:00	0.125	<.0001			
dummy for 12:00	0.142	<.0001			
dummy for 13:00	0.148	<.0001			
dummy for 14:00	0.164	<.0001			
dummy for 15:00	0.076	0.029			
dummy for 16:00	0.012	0.751			

d) Quantity for the Canadian dollar – US dollar

Coefficient for quantity			**Coefficient for heteroscedastic standard error**		
Parameter	Estimate	P-value	Parameter	Estimate	P-value
Intercept	-0.677	<.0001	sigma	2.795	<.0001
Aggressiveness_hat	0.158	0.125	quantity of same side market orders for the last 10 quotes	0.007	<.0001
Number of same side market orders for the last 10 quotes	0.167	<.0001	quantity of same side limit orders better than or equal to the best quotes for the last 10 quotes	-0.002	<.0001
Number of same side limit orders better than or equal to the best quotes for the last 10 quotes	0.177	<.0001	spread	-0.042	<.0001
Spread	-0.095	<.0001	volatility	0.137	<.0001
Volatility	0.034	0.019	Same side depth standing at the best quote	0.165	<.0001
Same side depth standing at the best quote	0.206	<.0001	Opposite side depth standing at the best quote	0.285	<.0001
Opposite side depth standing at the best quote	0.248	<.0001			
dummy for 7:00	-0.152	0.077			
dummy for 8:00	-0.031	0.692			
dummy for 9:00	0.190	0.013			
dummy for 10:00	0.119	0.117			
dummy for 11:00	0.034	0.665			
dummy for 12:00	0.115	0.162			
dummy for 13:00	0.130	0.126			
dummy for 14:00	-0.012	0.888			
dummy for 15:00	-0.176	0.058			
dummy for 16:00	-0.424	<.0001			

Table VI: Order Submission – Extended Model

The results from the simultaneous estimation of the extended model:

$$I_t^* = \gamma_1 \hat{qn}^*{}_t + \beta_{sameside}^{best} Depth_{sameside,t}^{best} + \beta_{sameside}^{behindbest} Depth_{sameside,t}^{behindbest} + \beta_{oppside}^{best} Depth_{oppside,t}^{best} + \beta_{oppside}^{behindbest} Depth_{oppside,t}^{behindbest} + \\ + \beta_{sameside}^{market,past} Number_{sameside,t}^{market,past} + \beta_{sameside}^{best,past} Number_{sameside,t}^{best} + \beta^{vlty} Vlty_t + \beta^{sprd} Sprd_t + \beta^{TimeofDay} D_t^{TimeofDay} + \varepsilon_t$$

$$qn^*{}_t = a + \gamma_2 \hat{I}_t^* + b_{sameside}^{best} Depth_{sameside,t}^{best} + b_{sameside}^{behindbest} Depth_{sameside,t}^{behindbest} + b_{oppside}^{best} Depth_{oppside,t}^{best} + b_{oppside}^{behindbest} Depth_{oppside,t}^{behindbest} \\ + b_{sameside}^{market,past} Number_{sameside,t}^{market,past} + b_{sameside}^{best,past} Number_{sameside,t}^{best} + b^{vlty} Vlty_t + b^{sprd} Sprd_t + b^{TimeofDay} D_t^{TimeofDay} + e_t$$

where $Depth_{sameside}^{best}$ is depth at the best price on the same side of the market that the order is submitted, $Depth_{oppside}^{best}$ is depth on the opposite side of the market that the order is submitted. *Vlty* is the realized volatility as defined in the previous section. *Sprd* is the bid-ask spread.

a) Order Aggressiveness for the Deutsche Mark – US dollar

Coefficient for order submission			**Coefficient for heteroscedastic standard error**		
Parameter	Estimate	P-value	Parameter	Estimate	P-value
Intercept	1.344	<.0001			
Qn_hat	-0.315	<.0001	Volume of same side market orders for the last 10 quotes	0.321	<.0001
Number of same side market orders for the last 10 quotes	-0.038	<.0001	Volume of same side limit orders better than or equal to the best quotes for the last 10 quotes	0.076	<.0001
Number of same side limit orders better than or equal to the best quotes last 10 quotes	0.116	<.0001	spread	-0.292	<.0001
spread	-0.022	<.0001	volatility	0.103	<.0001
volatility	0.044	<.0001	Same side depth standing at the best quote	-0.186	<.0001
Same side depth standing at the best quote	-0.009	0.003	Same side depth standing behind the best quote	0.024	0.002
Same side depth standing behind the best quote	0.067	<.0001	Opposite side depth standing at the best quote	0.048	<.0001
Opposite side depth standing at the best quote	-0.032	<.0001	Opposite side depth standing behind the best quote	-0.031	<.0001
Opposite side depth standing behind the best quote	-0.028	<.0001			

dummy for 7:00	0.103	<.0001
dummy for 8:00	0.202	<.0001
dummy for 9:00	0.165	<.0001
dummy for 10:00	0.130	<.0001
dummy for 11:00	0.166	<.0001
dummy for 12:00	0.283	<.0001
dummy for 13:00	0.315	<.0001
dummy for 14:00	0.276	<.0001
dummy for 15:00	0.087	0.002
dummy for 16:00	-0.148	<.0001

b) Quantity for the Deutsche Mark – US dollar

Coefficient for quantity			**Coefficient for heteroscedastic standard error**		
Parameter	Estimate	P-value	Parameter	Estimate	P-value
Intercept	-0.202	0.001	Sigma	2.820	<.0001
Aggressiveness_hat	0.0415	0.287	Volume of same side market orders for the last 10 quotes	-0.014	<.0001
Number of same side market orders for the last 10 quotes	0.199	<.0001	Volume of same side limit orders better than or equal to the best quotes for the last 10 quotes	-0.009	<.0001
Number of same side limit orders better than or equal to the best quotes for the last 10 quotes	0.174	<.0001	spread	-0.035	<.0001
spread	-0.018	0.113	volatility	0.018	0.013
volatility	-0.027	0.021	Same side depth standing at the best quote	0.047	<.0001
Same side depth standing at the best quote	0.142	<.0001	Same side depth standing behind the best quote	0.058	<.0001
Same side depth standing behind the best quote	0.021	0.069	Opposite side depth standing at the best quote	0.026	0.001
Opposite side depth standing at the best quote	-0.005	0.664	Opposite side depth standing behind the best quote	0.014	0.052
Opposite side depth standing behind the best quote	0.026	0.022			
dummy for 7:00	0.019	0.755			
dummy for 8:00	0.155	0.013			
dummy for 9:00	0.095	0.144			
dummy for 10:00	0.093	0.173			
dummy for 11:00	0.160	0.014			
dummy for 12:00	0.406	<.0001			
dummy for 13:00	0.426	<.0001			
dummy for 14:00	0.513	<.0001			
dummy for 15:00	0.275	0.001			
dummy for 16:00	0.013	0.889			

c) Order Aggressiveness for the Canadian dollar – US dollar

Coefficient for order submission			**Coefficient for heteroscedastic standard error**		
Parameter	Estimate	P-value	Parameter	Estimate	P-value
Intercept	0.745	<.0001			
Qn_hat	-0.015	<.0001	Volume of same side market orders for the last 10 quotes	0.009	0.166
Number of same side market orders for the last 10 quotes	-0.004	0.412	Volume of same side limit orders better than or equal to the best quotes for the last 10 quotes	0.076	<.0001
Number of same side limit orders better than or equal to the best quotes for the last 10 quotes	-0.033	<.0001	spread	-0.150	<.0001
Spread	0.012	0.001	volatility	0.0420	<.0001
Volatility	0.015	0.001	Same side depth standing at the best quote	0.043	<.0001
Same side depth standing at the best quote	-0.111	<.0001	Same side depth standing behind the best quote	0.165	<.0001
Same side depth standing behind the best quote	-0.009	0.144	Opposite side depth standing at the best quote	-0.025	<.0001
Opposite side depth standing at the best quote	0.002	0.643	Opposite side depth standing behind the best quote	-0.054	<.0001
Opposite side depth standing behind the best quote	-0.003	0.497			
dummy for 7:00	0.057	0.076			
dummy for 8:00	0.152	<.0001			
dummy for 9:00	0.210	<.0001			
dummy for 10:00	0.181	<.0001			
dummy for 11:00	0.127	<.0001			
dummy for 12:00	0.143	<.0001			
dummy for 13:00	0.134	<.0001			
dummy for 14:00	0.171	<.0001			
dummy for 15:00	0.085	0.015			
dummy for 16:00	0.033	0.367			

d) Quantity for the Canadian dollar – US dollar

Coefficient for quantity			**Coefficient for heteroscedastic standard error**		
Parameter	Estimate	P-value	Parameter	Estimate	P-value
Intercept	-0.668	<.0001	Sigma	2.765	<.0001
Aggressiveness_hat	0.152	0.157	Volume of same side market orders for the last 10 quotes	0.006	<.0001
Number of same side market orders for the last 10 quotes	0.166	<.0001	Volume of same side limit orders better than or equal to the best quotes for the last 10 quotes	-0.002	<.0001
Number of same side limit orders better than or equal to the best quotes for the last 10 quotes	0.176	<.0001	spread	-0.023	0.007
spread	-0.094	<.0001	volatility	0.144	<.0001
volatility	0.035	0.014	Same side depth standing at the best quote	0.171	<.0001
Same side depth standing at the best quote	0.203	<.0001	Same side depth standing behind the best quote	0.102	<.0001
Same side depth standing behind the best quote	-0.012	0.437	Opposite side depth standing at the best quote	0.284	<.0001
Opposite side depth standing at the best quote	0.236	<.0001	Opposite side depth standing behind the best quote	0.140	<.0001
Opposite side depth standing behind the best quote	0.031	0.040			
dummy for 7:00	-0.139	0.100			
dummy for 8:00	-0.017	0.828			
dummy for 9:00	0.213	0.004			
dummy for 10:00	0.138	0.066			
dummy for 11:00	0.052	0.503			
dummy for 12:00	0.136	0.094			
dummy for 13:00	0.138	0.099			
dummy for 14:00	0.003	0.969			
dummy for 15:00	-0.153	0.094			
dummy for 16:00	-0.396	<.0001			