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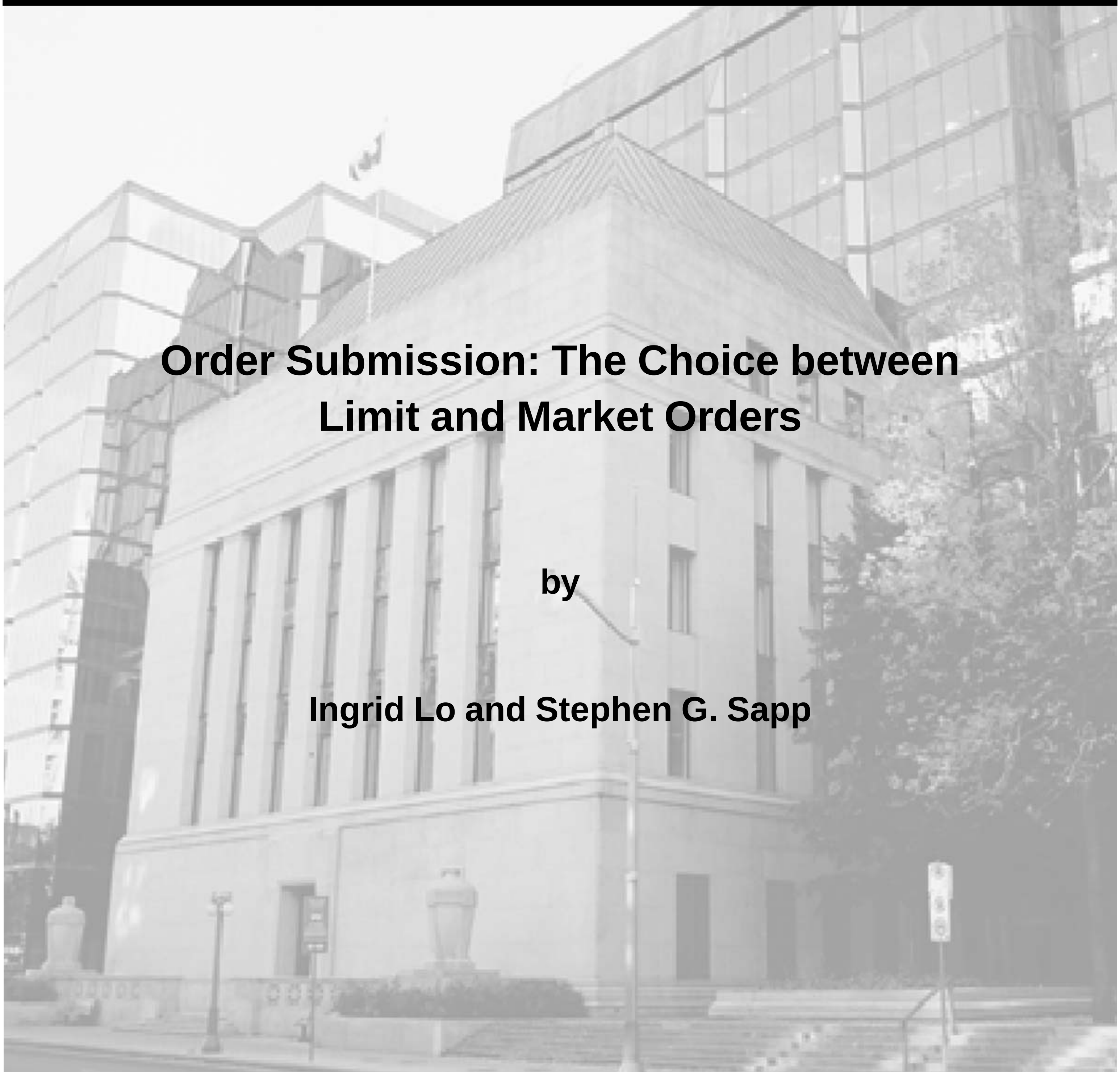

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Abstract

Most financial markets allow investors to submit both limit and market orders, but it is not always clear what affects the choice of order type. The authors empirically investigate how the time between order submissions, changes in the state of the order book, and price uncertainty influence the rate of submission of limit and market orders. The authors measure the expected time (duration) between the submissions of orders of each type using an asymmetric autoregressive conditional duration model. They find that the execution of market orders, as well as changes in the level of price uncertainty and market depth, impact the submissions of both best limit orders and market orders. After correcting for these factors, the authors also find differences in behaviour around market openings, closings, and unexpected events that may be related to changes in information flows at these times. In general, traders use more market (limit) orders at times when execution risk for limit orders is highest or the risk of unexpected price movements is highest.

JEL classification: D4, G1
Bank classification: Exchange rate; Financial institution; Market structure and pricing

Résumé

Sur la plupart des marchés financiers, les investisseurs peuvent placer aussi bien des ordres à cours limité que des ordres au mieux, mais les raisons de leur choix ne sont pas toujours claires. Les auteurs cherchent à établir empiriquement comment la durée séparant les ordres passés, l'état du carnet d'ordres et l'incertitude des prix influent sur le rythme auquel se succèdent les ordres à cours limité et les ordres au mieux. Ils ont recours à un modèle de durée conditionnelle autorégressive asymétrique pour mesurer le laps de temps susceptible de s'écouler entre les ordres de chaque type. Ils constatent que le nombre d'ordres au mieux exécutés, tout comme les variations du degré d'incertitude des prix et de profondeur du marché, a une incidence sur les flux des deux types d'ordres. Une fois ces facteurs pris en compte, les auteurs observent aussi des différences de comportement en début et en fin de séance, ainsi qu'en présence d'événements inattendus qui sont peut-être liés à l'arrivée d'informations sur le marché. En règle générale, les opérateurs font davantage appel à l'ordre au mieux quand le risque d'exécution des ordres à cours limité est élevé et à l'ordre à cours limité quand le risque de variations de prix inattendues est grand.

Classification : D4, G1
Classification de la Banque : Taux de change; Institutions financières; Structure de marché et fixation des prix

1. Introduction

In most financial markets, traders can choose between submitting a market order for immediate execution at the best available price or a limit order that specifies a price for execution but may take longer to execute.[1] Over the trading day, this provides traders with various means of accomplishing their objectives by submitting different types of orders. At each point in time, traders must decide whether to submit an order, which type of order to submit, and the price at which they are willing to transact. Since these decisions depend on the traders' expectations, preferences, and market conditions, we expect to see corresponding changes in traders' propensity to submit the different types of orders over the trading day. A key consideration in the trader's choice of order type is how the speed at which market conditions change influences the trade-off between the immediacy of trade (or execution risk) and the cost (or price risk) of trading.

In this study, we empirically investigate the role played by the time between order submissions and the impact of changes in the state of order book and price uncertainty on traders' order submission decisions (the order type and the time between consecutive orders, and the duration of orders). From a theoretical perspective, the importance of the duration of order submissions is discussed in studies by Diamond and Verrecchia (1987) and Easley and O'Hara (1992), which suggest that the time between trades reveals important information about the future value of the asset. The functional role for time implied by the models used in these studies has been empirically investigated by several authors, including Engle and Russell (1997, 1998) and Cho and Nelling (2000). Our approach extends the existing studies by jointly investigating the order choice and the time between submissions, rather than examining only the decision regarding limit order choice (e.g., Cho and Nelling 2000) or examining only order submissions without distinguishing between market and limit orders (e.g., Engle and Russell 1997, 1998). We believe there is valuable information in both the duration of order submissions and the type of the previous orders submitted. This is captured using the

[1] As a result, limit (market) orders protect against price (execution) risk, but at the expense of increasing the execution (price) risk faced by investors.

asymmetric autoregressive conditional duration (ACD) model developed by Bauwens and Giot (2000), which is an extension of the univariate duration framework of Engle and Russell (1998). Consequently, our ACD model more completely captures the endogeneity between these key aspects of the order submission decision.

Most similar to our study are Hasbrouck (1999), Hollifield et al. (2002), and Ellul et al. (2003). Each of these studies considers the factors that influence the order submission decision. Our paper differs from these earlier studies in two respects. First, we explicitly model the information carried by duration since the last order. By modelling both the order type decision and the duration of the submission, our analysis can more clearly determine how past orders impact the submission of different types of orders over the trading day, and we can investigate differences in behaviour across "fast" markets, "slow" markets, and "normal" markets. As Hasbrouck (1999) suggests: "a fast market is not merely a normal market that is speeded up, but one in which the relationships between component events differ." Second, none of these studies completely characterizes the impact of the state of the order book, especially the information carried by the cancellation of limit orders *both at the best and off-best quotes*. Ellul et al. examine only the submission and cancellation of the last type of order. Hasbrouck (1999) performs a descriptive analysis of the arrival processes of the two types of orders. Hollifield et al. (2002) explicitly estimate the trade-off between the execution risk, adverse-selection risk, and price risk of submitting the two order types. There is no cancellation in their model. We extend these studies by examining the impact of submission of limit orders and the cancellation of limit orders both at the best and at the off-best quotes within a time interval. Thus, we more completely characterize the impact of the state of the order book.

We investigate the order submission process in the context of the foreign exchange market using Deutsche Mark/U.S. dollar orders submitted on the Reuters 2000-2 electronic brokerage system. Since the system operates 24 hours a day, it allows us to investigate a wide variety of time-of-day effects and announcement effects that are difficult to study using data from equity markets, which the previous studies have used. We should note that the order book we examine is not completely open.

Only the best quote and the most recent transaction are observable; therefore, including the off-best quotes allows us to determine the extent to which traders get valuable information from other sources.

Our results provide several interesting insights into traders' decisions regarding order submission. Examining the impact of order type, we find that market orders (i.e., transactions) prompt the submission of both market orders and best limit orders. We find evidence of trades/market orders clustering but also inducing a cross-autocorrelation on the submission of limit orders. When we examine the arrival of ask orders and bid orders separately, we find that there is an increase in the number of limit orders submitted to the ask side of the market following an increase in the execution of bid-initiated market orders. We find that an unanticipated change in duration delays limit orders more than market orders. Assuming that unanticipated changes in the duration of orders is related to the arrival of information, we find that limit orders are more sensitive to information carried by duration than market orders, to avoid being picked off.

We find that the information obtained from changes in the submission and cancellation of off-best orders prompts the submission of both market and best limit orders. The fact that some of this information is not directly observable by traders suggests that they must have other information sources that are correlated with our measures for the off-best orders (e.g., the traders' private customer base). The submission of best limit orders and market orders is more rapid following the submission of off-best orders on the same side of the market than it is for the opposite side of the market.

Regarding the impact of withdrawing liquidity from the market, we find that the cancellation of limit orders at the best price and off-best price has very different effects on the submission of market orders. Cancellations at the best price delay the submission of market orders, because the cancellation at the best price widens the spread and withdraws depth at the best price, making market orders more costly. Conversely, cancellation at the off-best prices prompts the submission of market orders. Since the cancellation of orders at the off-best prices does not affect the best price and the depth at the best price, the cancellation does not directly raise the cost of submitting market orders. Rather, cancellation at the off-best price indicates that the trade-off between execution risk, adverse-selection risk, and price risk changes could be correlated with a change in the valuation of the asset. Thus, market orders become more active. Finally, we find that even after adjusting for intraday seasonalities and other factors, the opening and the closing of the markets still have a fundamental impact on the choice of order type, which is consistent with the findings of Bloomfield, O'Hara, and Saar (2005).

This paper is organized as follows. Section 2 describes the data set: the Reuters D2000-2 electronic brokerage system. Section 3 describes the asymmetric ACD model and the hypotheses tested. Section 4 provides the results of the basic model, and section 5 extends the basic model by examining the bid side and the ask side of the market. Section 6 offers some conclusions.

2. Data

The data we use are for the Deutsche Mark/U.S. dollar exchange rate and are taken from the Reuters D2000-2 system. The D2000-2 is an electronic order book. Subscribers can see the best bid and best ask orders, the size supplied under those orders, and the recent transaction record. Although we can observe best and off-best orders being submitted and cancelled in the limit order book, market participants do not. They observe only the best orders and executed orders. They do, however, observe similar information from other sources; e.g., the Reuters' EFX page as well as their own customer order flow. The data set covers the trading activity in the electronic broker market from the evening of 5 October 1997 to midnight on 10 October 1997. The data set includes the price at which the submitter stands ready to buy or sell the currency, the exact time at which the order arrived, whether it is a limit order or market order, whether the order is initiated at the bid side or ask side, the entry and exit time of the order, and the quantity to be traded. Although these data cover only the electronic broker market and not the interdealer market, the best order and their associated quantity submitted are observable by all market participants, whereas this information is not observable in the interdealer market.[2] In the interdealer market, traders contact other traders directly to arrange the transaction price and quantity. As a result, little is known about the interdealer trades (notable exceptions being Lyons 1995, and Evans and Lyons 2002a, b).

We use the foreign exchange market because it is the largest financial market in the world, with trade occurring 24 hours a day. This limits problems caused by illiquid trading, information asymmetries, and errors in the measurement of microstructure characteristics. The foreign exchange market also allows us to study how the supply and demand for a highly liquid asset develop as liquidity increases and decreases with the opening and closing of markets. Overall, our data set consists of 130,526 submitted orders. Of the submitted orders, about 26 per cent are market orders and 74 per cent are limit orders.[3] The proportions of the two order types vary through the day, as shown in Figure 1. Market orders and marketable limit orders are used mainly during active trading hours, probably because the increased liquidity at those times means that the orders have a greater likelihood of being fully filled with lower price risk.

To limit the impact of periods of thin trading on our results, we focus on the order submission activities from 6:00 to 18:00 Greenwich Mean Time (GMT). During this period, we study the arrival of the best limit orders and market orders. Best limit orders are the orders with the highest bid price and the lowest ask price standing in the market. Our data set consists of 20,512 best limit orders and 30,758 market orders submitted. We focus our analysis on the best limit orders for three reasons. First, the best orders are the orders, along with the most recent transaction, that are observable on the Reuters screen. Second, they have priority in trading. They are the prices at which investors stand

[2] The relative importance of the electronic broker market is also increasing over time. In 1997, about 30 per cent of all U.K. and U.S. trading volume and 37 per cent of all Japanese trading volume was conducted using electronic brokers (BIS 1999), and by 2001 this had increased to over 67 per cent, 54 per cent, and 48 per cent, respectively (BIS 2002).

[3] We treat marketable limit orders as market orders. Marketable limit orders are limit orders where the quoted price is better than or equal to the best quotes existing in the market. This ensures almost immediate execution.

ready to trade in the market; our analysis therefore considers the factors that influence current trades and current prices. Third, some limit orders are submitted at a price far away from the best price (these are referred to as "off-best limit orders"). These limit orders represent information on future market conditions or dealers' concerns about future market conditions, but do not necessarily provide information on the current value of the asset (the current price) and current market conditions.

Because our model examines how the spread and the state of the order book affect the arrival of best limit orders and market orders, we provide summary statistics for the submitted orders, the best orders, their durations, and the spread from 6:00 to 18:00 in Table 1. Although our analysis focuses on the best orders, their characteristics are very similar to the overall orders submitted—the average is almost identical. The main difference is that the best orders are not as sensitive to outliers—the minimum (maximum) overall price is 1.7003 (1.8070), but for the best orders the range is much smaller: 1.7332 (1.7699). The average time between orders is about 1.7 seconds and, not surprisingly, the time between best orders is longer at around 4.2 seconds. Even though more than half of the orders are submitted within one second of the previous order, the longest duration between orders is almost 3 minutes. The best bid-ask spread varies from the smallest possible spread, 0.0001,[4] up to 0.0054. Table 2 shows the correlation between the spread and our variables related to the changes in the state of the order book.

We can clearly see some of the differences in these variables through the trading day in Table 3 and Figures 1 and 2. We divide the day into 48 half-hour time bins and report the sample mean of the variables within each time bin. Qualitatively, Figures 1 and 2 illustrate the most important seasonal changes in the foreign exchange market over the trading day. During the active trading hours (e.g., 6:00 to 18:00), we can see that dealers submit proportionately more market orders than otherwise, and that orders are submitted most frequently around the opening hours of the European and New York markets. These results suggest significant seasonalities in the order submission process.

[4] This is the smallest possible spread, since prices in the foreign exchange market are quoted to four decimal places.

Table 3 shows the frequency of best limit and market order submissions, off-best limit order submissions, best and off-best limit order cancellations, and the mean of the spread and durations during the active trading hours. Consistent with earlier studies, we find that there are more limit orders than market orders. On the New York Stock Exchange (NYSE), Harris and Hasbrouck (1996) document that 54 per cent of SuperDot orders are limit orders, and Ross, Shapiro, and Smith (1996) report that, overall, the limit orders account for 65 per cent (75 per cent) of all executed orders (executed shares). The duration between orders is shortest at the opening hours of both markets and longest as the markets close. All of our variables have similarly distinctive seasonal patterns: they increase as the London and New York markets open, with a slight drop afterward and a significant decline around the closing hours.

The changes in the time between the submissions of orders during the trading day may also contain valuable information regarding investors' beliefs, market depth, and the price formation process. The ACD model allows us to formally examine the dependence of the order type decision and the duration on different microstructure factors while controlling for the significant intraday seasonalities. This is an advancement over other studies using aggregated data because they consider the order submission decision at specific intervals and thus are unable to capture many of the dynamic aspects of these relationships.

3. Model and Hypotheses

3.1 Basic model

Our empirical model is chosen to examine the dynamics of traders' order submission strategies. Since orders are submitted at irregular intervals and market conditions change continuously, we investigate the potentially important information in both the order submission times and market conditions. Although there is evidence in work by Engle and Russell (1998) to suggest that trades are intertemporally correlated, there has been little work to investigate the information contained in the arrival rates of limit and market orders and how they depend on market characteristics. In this paper, we examine the actual arrival times of orders to investigate the dynamic impact of changes in such microstructure aspects of the market as price uncertainty and the state of the order book on the time between the submissions of different types of orders. We treat the arrival time of market or limit orders as a point process where the arrival times of the different types of orders are a function of our set of market characteristics.

To focus on the impact of order type on the elapsed time between orders (duration), we use the asymmetric log-ACD model. The asymmetric model is essentially a competing risk model that allows us to explicitly characterize potential differences in the order submission processes for market and limit orders. In this model, the arrival processes of limit orders and market orders can have different reactions to the previous type of order submitted, the time since the last order was submitted, and our microstructure variables. In this framework, the conditional duration of the two types of orders is dependent on past information. The asymmetric ACD model is characterized by two states: market orders and limit orders. Let x_{t_i} be the time elapsed since the last order, $x_{t_i} = t_i - t_{i-1}$, where t_i denotes the arrival time of the *i*th order. To economize the notation, we will use $t - j$ to denote t_{i-j}, *j = 0, 1, ..., I.* In a competing risk model, the observed duration is the smallest duration between the two states. The realized state contributes to the likelihood function through its density, and the state that is not realized, or truncated, contributes to the likelihood function through the survivor function. More specifically, the asymmetric ACD model specifies that, conditional upon the state $y_t = \{lmt, mkt\}$, the observed duration, x_t, is a mixing process such that

$$x_t = E[x_t | y_t, H_{t-1}]\varepsilon^{y_t}, \quad y_t = \{lmt, mkt\}, \tag{1}$$

where the expected duration $E[x_t|y_t, H_{t-1}]$ is a function of whether the order at time t was a market or limit order (the state denoted by y_t), the information set available at time t_{i-1} (H_{t-1}), and the innovation

ε^{y_t} is an independent, indentically distributed random variable with positive support. Because we are using the log-ACD model, the expected duration takes the following form:

$$E[x_t | y_t, H_{t-1}] = \Psi_t(y_t) = \exp(\psi_t(y_t)), \quad y_t = \{lmt, mkt\}, \tag{2}$$

where $\psi_t(y_t)$ is an autoregressive process of the order type y_t. To estimate this model, we need to assume a distribution for ε^{y_t}. The likelihood function we use is the Weibull distribution, as in Engle and Russell (1997, 1998) and Bauwens and Giot (2001). Some other studies using the ACD model have used the Burr distribution, because it is more general than the Weibull distribution (e.g., Melvin and Wen 2003). Nevertheless, we use the Weibull distribution because it is simpler for large models. Our asymmetric models are larger than those used in many previous studies, because we allow the order submission process to differ across order types. This requires each order type to have its own autoregressive process and therefore doubles the number of parameters to be estimated relative to the symmetric model. Further compounding the identification problem is our investigation of the influence of microstructure factors. The correspondingly large number of parameters makes the Burr distribution too complex for our study. The joint likelihood of the asymmetric ACD model is given by,

$$f(x_t, y_t \mid \Phi_t) = \left[\frac{\gamma^{lmt}}{\Psi_t^{lmt}}\left(\frac{x_t}{\Psi_t^{lmt}}\right)^{\gamma_t^{lmt}-1}\right]^{I_t^{lmt}} e^{\left(\frac{x_t}{\Psi_t^{lmt}}\right)^{\gamma^{lmt}}} \left[\frac{\gamma^{mkt}}{\Psi_t^{mkt}}\left(\frac{x_t}{\Psi_t^{mkt}}\right)^{\gamma^{mkt_t}-1}\right]^{I_t^{mkt}} e^{\left(\frac{x_t}{\Psi_t^{mkt}}\right)^{\gamma^{mkt}}}, \tag{3}$$

where $\Psi_t^{lmt} = \exp(\psi_t^{lmt})$ and $\Psi_t^{mkt} = \exp(\psi_t^{mkt})$. The autoregressive process conditional on a limit order, ψ_t^{lmt}, is given by

$$\psi_t^{lmt} = \left(\omega_1 + \alpha_1 \varepsilon_{t-1}^{lmt}\right) I_{t-1}^{lmt} + \left(\omega_2 + \alpha_2 \varepsilon_{t-1}^{lmt}\right) I_{t-1}^{mkt} + \beta^{lmt} \psi_{t-1}^{lmt} + \xi^{lmt}{}' z_{t-1} + \theta^{lmt} d_t, \tag{4}$$

where $x_t = \exp(\psi_t^{lmt})\varepsilon_t^{lmt}$ and I_{t-1}^{lmt} is an indicator function that is equal to 1 if $y_{t-1}= lmt$, and 0 otherwise. We include a set of explanatory variables, z_t, measuring changes in the supply of liquidity in the order book and the spread. More specifically, we examine

- the number of best limit orders cancelled from the ask side and the bid side of the market from *t*-2 to *t*-1
- the number of off-best limit orders cancelled from the ask side and the bid side of the market from *t*-2 to *t*-1
- the number of off-best limit orders submitted on the bid and the ask side of the market from *t*-2 to *t*-1
- the best bid-ask spread at *t*-1

The ξ^{lmt} are the coefficients on these factors. In addition, we include five time dummies, d_t. We incorporate time dummies to capture the effects of the opening of the London market (d_1) and the New York market (d_2), the closing of both markets (d_3), and two dummies to capture the effect of the period before (d_4) and after (d_5) the Bundesbank announcement.[5] The θ^{lmt} are the corresponding coefficients on the time dummies.

Similarly, the autoregressive process conditional on the current order being a market order, ψ_t^{mkt}, is given by

$$\psi_t^{lmt} = \left(\omega_1 + \alpha_1 \varepsilon_{t-1}^{lmt}\right) I_{t-1}^{lmt} + \left(\omega_2 + \alpha_2 \varepsilon_{t-1}^{lmt}\right) I_{t-1}^{mkt} + \beta^{lmt} \psi_{t-1}^{lmt} + \xi^{mkt}{}' z_{t-1} + \theta^{mkt} d_t , \qquad (5)$$

where $x_t = \exp(\psi_t^{mkt})\varepsilon_t^{mkt}$ and I_{t-1}^{mkt} is an indicator function equal to 1 if $y_{t-1} = mkt$, and 0 otherwise. The coefficients for the microstructure variables and time dummies in the market order autoregressive process are defined similarly to those for limit orders.

The durations and other variables we use in this paper are scaled to remove the well-known time-of-day effects found in microstructure data. In our variables, we assume that there is a dynamic stochastic part and a deterministic part. The dynamic part changes as market conditions change, and the deterministic part considers patterns such as intraday seasonalities. Since we are most interested in the first component, we scale our data to remove the systematic intraday seasonalities. The method we

[5] We provide more formal definitions of these variables in sections 3.2.4 and 3.2.5.

use follows Engle and Russell (1998) by comparing the current value with the average value for that value at that time of day. For example, let X_t be the raw duration between orders, so that $X_{t_i} = t_i - t_{i-1}$. Since durations are known to vary over the day, we remove the intraday seasonalities in X_t by calculating the adjusted duration, x_t, as proposed by Engle and Russell (1998):

$$x_t = \frac{X_t}{\phi(t)} \,, \tag{6}$$

where $\phi(t)$ is the time-of-day effect formed by dividing each day into 48 half-hour bins, averaging the durations within each bin, and then smoothing the average durations with a cubic spline. The choice of 30-minute time bins follows that in Bauwens and Giot (2000).

3.2 Hypotheses

We examine how changes in price uncertainty and changes in the state of the order book affect the arrival of best limit orders and market orders. As Cao, Hansch, and Wang (2004) point out, the state of the order book carries important information about the asset and impacts the price discovery process. Our study extends upon their work in that, instead of looking at the depth of the limit order book, we examine the factors that account for the changes in its depth: both the cancellation and submission of limit orders. In addition, because the order book in our case is only partially open, we examine whether information unobservable to traders, the cancellation and submission of behind best orders, impacts the order submission process. Building on the existing market microstructure literature, we develop a number of hypotheses regarding the impact of our set of market characteristics on the order submission decision.

3.2.1 How does the previous type of order affect the duration and order type?

Various empirical studies show that trades cluster. We examine how the previous type of order affects the arrival time of the subsequent order and the order type by examining the *T* and " coefficients. Equations (4) and (5) can be interpreted in an analogous fashion to a GARCH(1,1) model, in that the dependent variable is a function of its lagged value and a lagged random-error term. The effect of the transition between states on duration is captured via the intercept, *T*, and the coefficient on the previous random error, ". The values of *T* therefore represent the effect of the previous order type on the current order type submitted. For example, ω_1 and ω_3 are the impact of previous limit orders on the expected duration of limit orders and market orders, respectively. A negative value of ω_1 (ω_2) means that, following a limit (market) order, traders more rapidly submit limit orders (i.e., the duration decreases). The "'s are the autoregressive conditional heteroscedasticity (ARCH) effects of the lagged disturbance from the previous order on the expected duration. If "$_1$ and "$_2$, for example, are different, the impact of the size of the disturbance from the last limit order on the expected duration for current limit orders depends on the lagged order type.

3.2.2 How is duration affected by changes in the depth of the market?

We examine how the submission and cancellation of limit orders affects the arrival time of the next order and the order type. These variables capture the state of the order book and are defined by the number of orders submitted or cancelled in the open interval between the arrivals of best orders. We use the number of orders because we believe that each order counts as a "vote" for future changes in market conditions (e.g., Lyons 1995).

The first set of variables we investigate is the number of best and off-best limit orders submitted on each side of the market. These variables measure the role of increases in the supply of liquidity. An increase in the number of off-best limit orders submitted increases market depth and thus lowers the price risk of submitting market orders—the risk of walking up (down) the order book and paying a higher price for the marginal unit is smaller. Consequently, as the market depth and liquidity increase and therefore the price risk decreases, we expect to see a more rapid submission of market orders.

The second set of variables we examine is the cancellation of best limit orders from the ask and the bid sides of the market. These cancellations withdraw liquidity from the market at the best price, thereby either widening the spread or decreasing the market depth at the best price. Thus, the price risk of submitting market orders is higher, whereas the execution risk of submitting best limit orders decreases.

The third set of variables we examine is the cancellation of orders at off-best prices. This withdraws liquidity at prices behind the best. Although this set of variables does not impact the best prices directly, it indicates that traders who were willing to bear execution risk at off-best prices are no longer willing to do so. This could reveal a change in the information set of the traders, thus carrying important information and impacting the submission of subsequent orders. Consequently, the cancellation of orders at off-best prices may convey different information than the cancellation at the best price, and traders may be more likely to submit market orders to avoid the increased execution risks at these times.

3.2.3 What about price uncertainty?

To measure price uncertainty, we use a common measure of price risk—the best bid-ask spread. We use the difference between the highest bid and the lowest ask active in the market at time *t*. A wider bid-ask spread indicates an increase in dealer uncertainty and a less liquid market. Since a widening spread means that market orders cost more and there is a larger price impact on trades, we expect to see the payoff from submitting limit orders increase and the payoff from submitting market orders decrease as the spread increases. Similarly, Easley and O'Hara (1992) propose that when the probability of trading against an informed trader decreases, dealers are willing to quote tighter spreads, leading to less price risk and thus more market order submissions. Empirically, Peterson and Sirri (2002) find more market orders are submitted when spreads tighten. Biais, Hillion, and Spatt (1995) and Ahn, Bae, and Chan (2001) find that limit order submission is impacted by market depth, price volatility, and quoted spreads. Harris (1998) finds that, as spreads widen, the cost of demanding liquidity and thus the reward for providing liquidity increases, and that more limit orders are therefore submitted. Consequently, as the spread increases, we expect the duration of limit orders to decrease and the duration of market orders to increase.

3.2.4 Does the opening and closing of markets fundamentally affect order arrival and order type?

Although we correct for intraday seasonalities, we also incorporate a set of dummy variables in our model to capture systematic changes in trading activity in the periods surrounding the opening and closing of the markets in Europe and North America. Our adjustment of duration by the expected duration discussed earlier (in equation (6)) should, theoretically, remove the influence of intraday seasonalities in foreign exchange trading, but it is possible that there is more to the time-of-day effects for market orders and limit orders; we add dummy variables to capture these potential differences. An increasing number of studies suggest that the trading behaviour of market participants in various financial markets is different at these times (for a detailed discussion in the context of the foreign exchange market, see Dacorogna et al. 2001). Across the trading day, there are times more likely than others at which traders will submit orders (e.g., lunch hour in Japan and Europe are well-known times when trading activity decreases). Models by Admati and Pfleiderer (1988), Foster and Viswanathan (1990), and Brock and Kleidon (1992) suggest that traders focus on the openings when the value of information is highest and the closings when investors are trying to close their positions or protect themselves from risks associated with overnight volatility. Bloomfield, O'Hara, and Saar (2005) use an experimental asset market to investigate traders' behaviour at these times; they find that informed traders demand liquidity early in the trading session by submitting market orders that hit existing limit orders, but that they start to supply liquidity as the day progresses. As a result, we expect to see an increase in the proportion of market (limit) orders at the start (end) of the day.

To implement this test we examine the trading patterns for our market. Consistent with other studies of the foreign exchange market, we find that the peak trading hours fall into roughly two periods (e.g., Figure 2). Trading is most active from 7:00 to 10:00[6] during early trading in Europe and

[6] All times are in GMT.

from 12:00 to 15:00 as North America becomes actively involved.[7] We also see a decline in trading activity as London and New York close between 16:00 and 18:00. These patterns may influence our results because the successful filling of an incoming order (whether a market or a limit order) depends very much on changes in the number of counterparties and the arrival of new information. For example, the opening of the New York market should deepen the existing market by introducing more possibilities of trade with new market participants. It may also increase the amount of information being incorporated into prices. Although these effects may be partially captured by changes in our microstructure variables and the scaling, recent studies suggest the possibility of fundamental changes around the opening and closing of markets; we therefore control for it.

In our model, we include three dummy variables to capture the effects of increased and declining trading activity as these markets open and close. The dummy takes on a value of 1 if a trade occurs in the respective period, and 0 otherwise:

$d_1 = 1$ if the order is submitted between 7:00 and 8:00 (GMT), $d_1 = 0$ otherwise

$d_2 = 1$ if the order is submitted between 12:00 and 13:00 (GMT), $d_2 = 0$ otherwise

$d_3 = 1$ if the order is submitted between 16:00 and 18:00 (GMT), $d_3 = 0$ otherwise

Even though several studies suggest that the time of day, especially the opening and closing of markets, influences traders' order submission strategies, few studies have investigated this possibility. If we find asymmetric effects on the submissions of the two order types, then work that does not distinguish between the two order types or adequately correct for these periods may not accurately adjust for intraday seasonalities and its estimation would no longer be efficient.

3.2.5 The effect of macroeconomic announcements on traders' decisions

To examine the potential effect of important macroeconomic announcements on the order submission decision, we study the impact of an unexpected announcement following a Bundesbank council meeting on traders' order submission decisions. On Thursday, 9 October 1997, there was a

[7] The London opening is generally viewed as around 7:00 and the New York opening around 12:00.

regularly scheduled Bundesbank council meeting. The meeting started, as scheduled, at 11:00 (GMT), but the council unexpectedly announced an increase in the German interest rates afterwards at 11:30 (GMT). Since these meetings are known to have a very significant impact on trading activity in the foreign exchange market (e.g., Andersen and Bollerslev 1998), we incorporate two dummies to capture the effect on market activities before and after the announcement:

$d_4 = 1$ if the order is submitted between 10:30 and 11:30 (GMT) on 9 October 1997, $d_4 = 0$ otherwise

$d_5 = 1$ if the order is submitted between 11:30 and 12:30 (GMT) on 9 October 1997, $d_5 = 0$ otherwise

We can therefore study the differences in the submission of limit orders and market orders before and during the meeting as well as after the announcement; both periods are well known for their importance in the price formation process. We expect to see an increase in the use of market orders following the unexpected arrival of the new price-relevant information, because traders are concerned about execution risk as the price rapidly moves to its new equilibrium level.

4. Results

To determine the factors that influence the order submission decision, we examine the results of our estimated asymmetric ACD model in Table 4. The first two columns represent the estimated coefficients and *t*-statistics for our full model (equations (3) to (5)).

4.1 The impact of the previous type of order submitted

The T-coefficients represent the impact of the order type (e.g., whether the previous order was a limit or market order) on the time until the next order is submitted (i.e., the duration). We find that the estimated coefficient for the impact of the last order that is a limit order only has a significantly positive (0.2987) impact on the duration of current limit orders, ω_1. Thus, traders are more hesitant to submit new best limit orders (i.e., limit orders that will improve the current price) when the previous best order was a limit order. Since such orders would compete with the other limit orders in the order book, this effect is consistent with the "crowding out" effect described in Parlour (1998): the time priority given to the limit orders already in the order book slows the arrival of new best orders.

Turning to the impact of previous market orders on the submission of subsequent orders, the estimated coefficients for the limit order equation and the market order equation, ω_2 and ω_4, are significantly negative (-0.0288 and -0.2209, respectively). These results indicate that when the last order was a market order, traders are more likely to submit both market orders and best limit orders. This complements the existing literature (e.g., Hasbrouck 1999), in that we find that not only do trades cluster,[8] but that their execution prompts the submission of best limit orders at the best price. Market orders erode depth at the best price, thereby lessening the competition of submitting best limit orders and increasing the profitability from supplying liquidity with limit orders.

Regarding the ARCH effects, all of the estimated α's are significantly positive. This indicates that disturbances or unexpected changes in the duration since the previous order was submitted lengthen the expected duration for the next order for all order types. More precisely, the longer the time since the last limit (market) order was submitted, the longer the time until the next best limit (market) order is submitted. Comparing the magnitudes of the estimated values for the α's for the best limit orders with those for market orders, we find that the values for the limit orders are larger in magnitude. This suggests that limit orders are more sensitive than market orders to the previous disturbance in duration. Because submitting a new best limit order means providing liquidity at the most competitive price, traders tend to be more cautious about providing liquidity when there has been an unexpected change in the lagged duration. A potential explanation for this caution is that the disturbance could indicate the presence of an information event (e.g., Easley and O'Hara 1992), making traders more hesitant to submit limit orders.

4.2 The persistence of order arrivals

The estimated value for the autoregressive portion of the order submission process for limit orders, β^{lmt}, is much smaller than for market orders, β^{mkt}: 0.68 versus 0.95 in Table 4. Since

[8] Market orders follow market orders, suggesting that the conditions that motivate traders to submit market orders are persistent at certain times.

likelihood-ratio tests reject the null hypothesis that $\beta^{lmt} \geq \beta^{mkt}$ at the 5 per cent significance level, this suggests that the changes in duration are more persistent and that order arrival is more clustered for market orders than for limit orders. More precisely, the longer (shorter) the time since the arrival of the last market order, the longer (shorter) the expected time until the arrival of the next market order. Limit orders, on the other hand, appear to be more evenly distributed over the trading day.

The estimated Weibull parameters, γ, reveal the shape of the hazard function for market and limit orders. The estimated value for market orders, γ^{mkt}, is less than one (0.86) in Table 4. A Weibull parameter of less than 1 means that the hazard is decreasing; therefore, conditional on the current order being a market order, the hazard function for subsequent market orders is decreasing. More precisely, the longer the period without a market order arriving, the less likely it is that a market order will be submitted (i.e., market orders are clustered). The Weibull parameter of best limit orders, γ^{lmt}, is around one. Consequently, conditional on the current order being a limit order, the submission of best limit orders is less dependent on the time that has passed since the last best limit order was submitted. A likelihood-ratio test shows that γ^{lmt} is significantly greater than γ^{mkt}; this confirms our previous observation that market orders are more clustered at certain times of the day or during certain market conditions.

4.3 The impact of changes in price uncertainty

We next examine the effects that our microstructure variables related to price risk have on our estimated durations. We find that changes in the spread have the opposite impact on limit order submissions than on market order submissions. Further, the magnitude of the estimated coefficient on ξ^{lmt}_{spread} is roughly 6 times that on ξ^{mkt}_{spread}, as shown in Table 4. Since ξ^{lmt}_{spread} is significantly negative and ξ^{mkt}_{spread} is significantly positive, this indicates that a widening of the spread prompts the submission of limit orders while slowing the submission of market orders. Our findings support Foucault (1999), who suggests that market orders are more costly when there is a larger bid-ask spread and thus when there is larger price uncertainty; therefore, in equilibrium, a higher proportion of limit orders is submitted at these times.

4.4 The impact of changes in the depth of the order book

To study how changes in the supply of liquidity impact the duration of limit and market orders, we first consider the effect of changes in the number of off-best limit orders submitted, and thus the effect of changes in the depth of the order book. We find that an increase in the number of off-best limit orders prompts the submission of both limit and market orders. The fact that the coefficient is significantly smaller for market orders (the likelihood-ratio test for equality gives a *p*-value of less than 1 per cent) suggests that increasing the liquidity in the market increases the submission of market orders more than it does limit orders. Since the submission of more off-best limit orders means that the potential price impact of a given trade is smaller, traders are more willing to submit market orders at these times. Intuitively, when a large market order is submitted, it may have to walk up the order book to be filled. The more off-best limit orders that have been submitted, the lower the cost (or potential cost) of walking up the order book. These results are consistent with more liquidity and lower price risk increasing the submission rate of market orders.

To study the impact of the withdrawal of liquidity from the market, we examine both the cancellation of best limit orders and the cancellation of off-best limit orders. We find that an increase in the withdrawal of limit orders at the best price is associated with more active submissions of limit orders (both $\xi^{lmt}_{cancelled,best,ask}$ and $\xi^{lmt}_{cancelled,best,bid}$ are significantly negative), but slower submissions of market orders ($\xi^{mkt}_{cancelled,best,ask}$ is insignificant from zero while $\xi^{lmt}_{cancelled,best,bid}$ is significantly positive), as shown in Table 4. Since the cancellation of best limit orders implies a less competitive environment for limit orders and therefore more price risk for market orders, this creates an opportunity for traders to profit from supplying liquidity to the market, and thus traders increasingly submit limit orders (e.g., Biais, Hillion, and Spatt 1995). This raises the price risk of market orders either by widening the spread or by decreasing the depth at the best price; therefore, there is an increased risk of moving up (down) the order book to completely fill an order. As a result, we see fewer market orders being submitted.

The cancellation of orders at off-best prices has quite a different impact on the order submission decision. Cancellation of off-best bid orders prompts the submission of best limit orders, but the cancellation of off-best ask orders has nearly no effect on the submission of best limit orders. On the other hand, the cancellation of off-best orders from both sides of the market prompts the submission of market orders. One possible explanation for this pattern in our results is that the cancellation of limit orders at the off-best price discussed above conveys different information than the cancellation of limit orders at the best price. Traders who originally placed off-best limit orders were more willing to bear execution risk (they were more willing to wait) or less willing to face price risk (by submitting market orders). The cancellation of orders at the off-best price signifies that traders are no longer willing to bear the execution risk at the existing off-best prices. This could be due to the following reasons: (i) the market prices are moving against them, so the execution risk at the present off-best price is increasing and it may be more favourable to submit a best limit order or market order; (ii) the market is more confident in the value of the asset, so adverse-selection risk drops and it is more favourable to submit best limit orders; and (iii) there is more depth at the best price, so price risk drops and submitting a market order is more favourable. All three motives reveal information to other market participants regarding potential changes in the valuation of the asset; therefore, cancellation at off-best prompts submission of orders, particularly market orders.

4.5 The impact of the opening and closing of markets

Our results around the opening and closing of markets are similar to the experimental results of Bloomfield, O'Hara, and Saar (2005). We find that limit orders and market orders respond differently to the opening of markets. Even after correcting for changes in market liquidity and price uncertainty, we find that traders are more hesitant to submit limit orders at the opening of markets and more hesitant to submit market orders at the closing of markets. The coefficients corresponding to limit order submissions at the opening of the two markets, $\theta^{lmt}_{London\ open}$ and $\theta^{lmt}_{NT\ open}$, are both positive (with $\theta^{lmt}_{London\ open}$ significantly positive at the 1 per cent level and $\theta^{lmt}_{NT\ open}$ significantly positive at the 10 per cent level). Since the potential asymmetry of information between traders or differences in the interpretations of information across traders is greatest at the beginning of the trading day, this is consistent with traders being concerned that limit orders have a higher probability of being "picked-off" at those times. This is a form of the "winner's curse," as discussed in Easley and O'Hara (1992) and Glosten (1994).

At the closing of the market, on the other hand, more limit orders are used. This may be a result of trading over the day revealing information on the value of the asset so that its price converges to the full information value. Consequently, there is less risk of being picked off at the closing of the market and limit orders are submitted more readily. This is in line with the suggestion that traders submit limit orders at the end of trading to close their positions and protect themselves from "overnight" volatility. In general, the opening and closing effects are much larger for limit orders than for market orders: the coefficients $\theta^{lmt}_{London\ open}$, $\theta^{lmt}_{NY\ open}$, and θ^{lmt}_{close} are larger in both magnitude and statistical significance than their counterparts in the market order equation. Thus, it appears that the factors that influence the submission of limit orders are more sensitive to time-of-day related effects than to market orders.

4.6 The impact of macroeconomic announcements

A unique feature of our data set is that it enables us to study the effect of an important macroeconomic announcement on the order submission decision. On Thursday, 9 October 1997, the regularly scheduled biweekly Bundesbank council meeting started at 11:00 (GMT) and ended at 11:30 (GMT). Immediately following the meeting, the Bundesbank unexpectedly announced an increase in its repo rate from 3 per cent to 3.3 per cent. Since this action was unexpected, we are able to examine how the order submission decision appears to change around such events. The estimated coefficients for our dummy variable before the announcement, $\theta^{lmt}_{10:30to11:30}$ and $\theta^{mkt}_{10:30to11:30}$, are not significantly different from zero. This is consistent with comments from market participants that the announcement was unanticipated and thus order submission activity was normal (e.g., Carlson and Lo, forthcoming). After the announcement, however, there was a significant increase in the submission of both market orders and limit orders. Though the magnitude of the estimated coefficients was similar for both market and limit orders, the level of statistical significance suggests that there was a larger increase in the submissions of market orders.

Our time-of-day variables allow us to extend the existing empirical and theoretical work. After correcting for the influence of changes in liquidity, price risk, and market seasonalities, we continue to find important factors that influence the order submission decision. Around the opening of markets and following unexpected announcements, there may be significant information asymmetries that result in the more rapid submission of market orders. Traders are concerned that limit orders will be "picked off" as the price adjusts to the new information and the price attains its new equilibrium value. When the level of information asymmetry among traders decreases, however, the traders appear more willing to submit limit orders. These findings are an interesting complement to our previous results and to the existing results in the literature.

5. The Ask and Bid Sides of the Market

In the previous section, we focused on the arrival process of all best limit orders and all market orders. Since we find some differences in how changes in our factors on each side of the market influence the overall order submission decisions, the question arises as to whether the arrival process of the two order types differs across the bid and the ask sides of the market. In this section, we examine how information on the same and opposite sides of the market affects the decision to submit the two order types. To accomplish this, we estimate two separate models for the arrival process of the two order types: one on the bid side and the other on the ask side of the market.

Because the previous model did not distinguish between the side of the market for the market orders and the best limit orders, we add two new variables to our model of the expected duration of best limit order and market orders: the number of best limit orders posted and the number of market orders executed on the opposite side of the market. The coefficients are indicated by $\xi_{best,\, opposite\ side}$ and $\xi_{mkt,\, opposite\ side}$, respectively, as shown in Table 5. These variables are added because the arrival of best orders and market orders on the opposite side of the market may have a different impact than when they are arriving on the same side of the market as traders submit their orders. This model allows us to examine several interesting questions:

What has the greatest influence on the supply of liquidity at the best price: the previous submission of best limit orders or market orders/transactions? An increase in the submission of best limit orders on the opposite side of the market appears to prompt the submission of best limit orders. The magnitude of the effect is more than three times as large and the statistical significance is much larger than for the impact of the execution of market orders on the opposite side of the market. The null hypothesis $\left|\xi^{lmt}_{mkt,\, opposite\ side}\right| \geq \left|\xi^{lmt}_{best,\, opposite\ side}\right|$ on both the bid and the ask equations is rejected at the 5 per cent significance level using likelihood-ratio tests. This result suggests that an increase in the supply of liquidity at the best price on the opposite side of the market prompts traders to increase the supply of liquidity more than when there is an increase in the quantity of transactions on the opposite side of the market. As a result, an increase in liquidity on one side is related to an increase on the other, and therefore to an increase in overall market depth. There is, however, a smaller effect if there was a consumption of liquidity on the other side of the market.

These results are in contrast to the impact of changes on the same side of the market. Regarding the coefficient related to the submission of best limit (market) orders on the same side of the market, ω_1 (ω_2), the results suggest that an increase in these orders tends to delay the submission of best limit orders, possibly due to the "crowding out" effect (or fear of being "picked off"). We find little impact of previous limit orders on the same side on the current market orders (ω_3), but market orders on the same side appear to result in the clustering observed in the previous section.

How do transactions cluster? Clustering depends on the side of the market. For orders being submitted on the ask side of the market, a previous market order on either the same or the opposite side prompts the submission of ask market orders. This is indicated by significantly negative estimated coefficients: ω_4 and $\xi^{mkt}_{mkt, opposite\ side}$. Consequently, sell transactions (or market orders) cluster following transactions from both sides of the market. Interestingly, for the bid side of the market, it is only previous bid market orders that prompt the submission of bid market orders—the estimated coefficient on ω_4 is significantly negative. The submission of previous ask market orders, $\xi^{mkt}_{mkt, opposite\ side}$, does not have a significant effect. The difference between the effects on bid and ask orders is consistent with previous studies, which suggests that buying and selling behaviours differ. Bid market orders appear to cluster following transactions on the same side of the market (information related to the value increasing), but selling is more sensitive to overall information arrival.

Does the submission of the behind best ask and the behind best bid limit orders have the same impact on the order submission decision? Again, such submissions depend on the side of the market. For the submission of ask orders, the likelihood-ratio test cannot reject the null hypothesis that $\xi^{lmt}_{off-best,bid} = \xi^{lmt}_{off-best,ask}$, so the behind best bid and behind best ask submissions have the same effect on ask limit order submissions. A similar finding holds for the submission of ask market orders: the null hypothesis that $\xi^{mkt}_{off-best,bid} = \xi^{mkt}_{off-best,ask}$ cannot be rejected.

For the bid side of the market, an increase in the number of off-best limit orders submitted on the bid side of the market tends to prompt the submission of both more best limit orders and market orders. The likelihood-ratio test rejects the null hypothesis that $\xi^{lmt}_{off-best,bid} \geq \xi^{lmt}_{off-best,ask}$ and that $\xi^{mkt}_{off-best,bid} \geq \xi^{mkt}_{off-best,ask}$ at the 5 per cent significance level. Thus, bid orders are more sensitive to changes in market depth related to the movement of behind best orders from the same side of the market than from the opposite side of the market.

Do cancellations at the best quoted price and cancellations at prices behind the best quoted price have the same effect? Interestingly, on the ask side of the market, the cancellation of best limit orders on the same side of the market has the opposite effect on the arrival of best limit orders than the cancellation of off-best limit orders. Following an increase in the cancellation of orders at the best price on the same side of the market, we observe an increase in the submission of limit orders, as evident in the significantly negative $\xi^{lmt}_{cancelled,best,ask}$ in the ask equation. Cancellation at off-best quoted prices on the same side of the market has the opposite effect: $\xi^{lmt}_{cancelled,off-best,ask}$ is significantly positive in the ask equation.

To investigate why the withdrawals of liquidity at best and off-best prices have opposite effects on the decision regarding ask limit order submission, we study the first-order autocorrelation between prices, volatility, and the state of the order book (Table 6). We divide the trading day into 1-minute intervals and use the frequency of the submission and cancellation of limit orders within the intervals. The price trend is defined as the difference in the mid-quote of the prices at the beginning and end of the 1-minute interval. The price trend has a value of 1 if the difference is positive, -1 if the difference is negative, and 0 if the price stays the same. We find that, following an increase in prices, the number of ask cancellations at the off-best price drops, but the cancellation at the best price rises. This suggests that the cancellation of orders at the best and off-best quotes occurs for different reasons. For example, when the price increases, the number of cancellations at the ask increases to avoid adverse selection, whereas the number of off-best cancellations drops to take advantage of the drop in execution risk. Submitting a best limit ask order when the cancellation of best orders increases leads to less competition and also less execution risk when the price is increasing. On the other hand, more ask orders are cancelled at the off-best prices when prices drop. Thus, traders submitting a best limit order at this time have to offer a lower price and, if the price drops further, the execution risk increases.

Regarding market orders, cancellations at the best and off-best prices also have different effects. We find that the cancellation of orders at the best quote on the same side of the market delays the subsequent submission of other market orders. Cancellation at the best price on the same side of the market means that traders are wary of facing adverse-selection risk at the best prices. The increased activity on the same side of the market suggests an upcoming change in the valuation of the asset. As a result, it is more risky to submit market orders at these times. On the opposite side of the market, for both the bid and ask equations, we see that the number of cancellations at off-best quotes prompts the submission of market orders. Cancellation at off-best bid prices is associated with an increase in mid-quote prices. It therefore appears that ask market orders arrive to sell as the price is inreasing. Similarly, cancellation at off-best ask is associated with a drop in mid-quoted prices, so bid orders arrive to buy at a lower price.

6. Conclusion

In this paper, we have examined the impact of price risk and changes in the supply of liquidity on the market order and best limit order submission processes in the context of the foreign exchange market. Because of the potential differences in the characteristics of the order submission process across order types and the irregular duration of order submissions, we studied the problem using the asymmetric log-ACD model. This model allowed us to jointly study the time between the time of order submission and the type of order submitted. We have found that, conditional on the type of order, the expected duration until the arrival of the next order depends on the previous type of order submitted, changes in price risk, and changes in liquidity in the market. Further, we have found that these factors have different effects on the arrival process of best limit order and market orders. As a consequence, ignoring differences in the types of orders being studied and ignoring differences in the types of orders traders submitted in the past may lead to a misspecification of the order submission process and therefore of the price formation process.

Our research extends the existing work that studies how the order submission process depends on microstructure factors, by using a technique that allows us to more completely capture relevant aspects of the order submission decision. We have found that market liquidity and price uncertainty play a significant role in the order submission decision (the duration of when to submit orders and the type of order). Specifically, we have found that increasing price uncertainty and the withdrawal of liquidity prompt the submission of limit orders, whereas increases in the supply of liquidity prompt the submission of market orders. Further, even after correcting for these factors, we continued to find differences in behaviour around market openings and closings and unexpected events: traders use more market (limit) orders at the opening (closing) of the market and more market orders after unexpected economic announcements and thus unexpected price movements.

Since many previous studies were unable to capture differences in order submission strategies across periods of changing order submission intensity, we have provided a valuable new perspective into the role played by market liquidity and price uncertainty in various aspects of the order submission decision. Unlike previous studies, we have been able to study the differences in quoting behaviour around market openings, closings, and unexpected economic announcements that compensate for the changes in order submission intensities, and have found that these differences, even after correcting for the impact of market liquidity and price uncertainty, suggest that information asymmetries and information shocks play a significant role in the order submission decision.

Having seen how the choice of order type and trading process interact, one can start to extend the models we have examined to test a wider range of theoretical microstructure models. We have highlighted some of the areas where the order submission process is different across order types, as well as where they are similar. Further research can extend our findings to consider other hypotheses and develop new models to help explain some of these new findings.

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Table 1: Summary Statistics for Quotes, Best Quotes, Durations, and Microstructure Variables

This table lists the mean, standard deviation, maximum, minimum, and median values for several key variables using the data from the Reuters D2000-2 electronic brokerage system for the week of 6–10 October 1997 from 6:00 to 18:00. We use the quote and best quote in Deutsche Marks per U.S. dollar. The durations are measured in seconds for both the quotes and best quotes. Spreads are quoted in Deutsche Marks per U.S. dollar.

	Quote	**Quote of best limit orders and market orders**	**Duration: quote by quote**	**Duration: quote of best limit orders and market orders**	**Spread**
Mean	1.7515	1.7514	1.7303	4.2037	0.0002
Std	0.0074	0.0073	3.9658	8.0698	0.0002
Median	1.7530	1.7528	0.7900	1.9900	0.0002
Min	1.7003	1.7332	0.0100	0.01	0.0001
Max	1.8070	1.7699	208.39	254.80	0.0054

Table 2: Correlation of Microstructure Variables

This table shows the correlation matrix between the spread and the variables, capturing the state of the order book.

	Spread	No. ask off-best	No. bid off-best	No. off-best ask cancelled	No. off-best bid cancelled	No. best ask cancelled	No. best bid cancelled
Spread	1.00	-0.07	-0.05	-0.04	-0.03	0.05	0.05
No. ask off-best		1.00	0.30	0.38	0.26	0.26	0.23
No. bid off-best			1.00	0.28	0.39	0.23	0.25
No. off-best ask cancelled				1.00	0.17	0.23	0.14
No. off-best bid cancelled					1.00	0.15	0.22
No. best ask cancelled						1.00	0.13
No. best bid cancelled							1.00

Table 3: Limit Orders, Marketable Limit Orders, Market Orders, Duration between Quotes, and Microstructure Variables through the Trading Day

This table shows the frequency of limit orders, market orders, off-best limit orders, order flow, and cancelled limit orders, together with the sample mean of spread, duration, and best mid-quote duration through the active trading hours using the data from the Reuters D2000-2 electronic brokerage system for the week of 6–10 October 1997. The trading day is divided into half-hour time bins and we examine the values between 6:00 and 18:00 (GMT). The duration is measured in seconds.

	Freq. best limit orders	Freq. market orders	Freq. off-best ask limit orders submitted	Freq. off-best bid limit orders submitted	Freq. off-best ask limit orders cancelled	Freq. off-best bid limit orders cancelled	Freq. best ask limit orders cancelled	Freq. best bid limit orders cancelled	Spread	Duration of best limit orders and market orders submitted
6:00	469	411	303	327	168	193	179	176	0.00030	10.06
6:30	862	1054	976	1105	549	619	384	458	0.00021	4.81
7:00	1091	2135	1972	2052	1113	1150	602	604	0.00019	2.90
7:30	971	2016	2064	1977	1059	1105	628	602	0.00019	3.10
8:00	969	2377	2292	2752	1285	1507	693	690	0.00017	2.85
8:30	831	1868	1802	2018	1005	1099	563	520	0.00017	3.50
9:00	675	1308	1598	1466	864	817	468	453	0.00016	4.67
9:30	613	1272	1428	1248	734	711	421	457	0.00017	4.91
10:00	574	996	973	1211	596	630	412	332	0.00018	5.91
10:30	626	917	914	1051	537	644	348	388	0.00020	6.04
11:00	825	1406	1255	1625	788	893	438	468	0.00024	4.18
11:30	1125	2272	2025	2316	1186	1377	686	656	0.00032	2.80
12:00	1237	2105	2118	2380	1200	1412	750	787	0.00022	2.81
12:30	1327	2247	2583	2538	1467	1566	919	933	0.00022	2.61
13:00	1412	2900	3542	3135	2007	1913	1031	1133	0.00020	2.20
13:30	1182	1850	2224	2404	1265	1388	867	906	0.00019	3.06
14:00	1339	2040	2451	2263	1413	1370	913	949	0.00021	2.76
14:30	1232	1465	1637	1874	1008	1074	818	843	0.00023	3.44
15:00	1061	884	1151	1124	661	813	602	665	0.00029	4.70
15:30	622	400	472	597	322	388	341	365	0.00034	8.89
16:00	457	275	277	314	191	220	207	214	0.00045	12.09
16:30	334	145	136	160	93	114	142	176	0.00060	18.50
17:00	305	149	111	175	88	128	151	123	0.00087	20.50
17:30	373	122	129	170	101	143	170	161	0.00054	17.89

Table 4: Asymmetric Log-ACD Model

Maximum-likelihood estimates of the asymmetric log-ACD models of duration. The model estimated is equation (3) using the data from the Reuters D2000-2 electronic brokerage system for the week of 6–10 October 1997.

	Full model		Model with only microstructure variables		Model with only time dummies	
	coefficient	*t*-stat	coefficient	*t*-stat	coefficient	*t*-stat
ω_1	0.2987	14.05	0.2940	12.28	-0.0307	-4.35
ω_2	-0.0288	-2.14	0.0161	1.04	-0.0369	-8.75
α_1	0.3945	25.43	0.4385	25.49	0.2272	21.45
α_2	0.4857	24.93	0.5145	25.45	0.1994	17.40
β^{lmt}	0.6752	44.22	0.6263	35.81	0.9409	192.06
γ^{lmt}	1.0022	211.71	0.9978	211.47	0.9995	213.03
ξ^{lmt}_{spread}	-0.0622	-26.73	-0.0716	-27.52		
$\xi^{lmt}_{off-best,ask}$	-0.0136	-4.91	-0.0142	-4.78		
$\xi^{lmt}_{off-best,bid}$	-0.0091	-3.28	-0.0107	-3.59		
$\xi^{lmt}_{cancelled,off-best,ask}$	0.0000	0.00	0.0000	0.00		
$\xi^{lmt}_{cancelled,off-best,bid}$	-0.0174	-6.92	-0.0166	-6.15		
$\xi^{lmt}_{cancelled,best,ask}$	-0.0294	-11.88	-0.0303	-11.45		
$\xi^{lmt}_{cancelled,best,bid}$	-0.0336	-13.69	-0.0338	-12.89		
$\theta^{lmt}_{London,open}$	0.0993	9.03			0.0225	6.75
$\theta^{lmt}_{NY,open}$	0.0141	1.48			0.0022	0.83
θ^{lmt}_{close}	-0.3566	-20.97			-0.1007	-12.72
$\theta^{lmt}_{10:30\ to\ 11:30}$	-0.0153	-0.75	-0.0019	-0.08	-0.0211	-3.33
$\theta^{lmt}_{11:30\ to\ 12:30}$	-0.0506	-3.78	-0.0518	-3.53	-0.0068	-1.89
ω_3	0.0030	0.43	0.0141	2.12	0.0303	5.78
ω_4	-0.2209	-32.27	-0.2236	-33.12	-0.1391	-27.51
α_3	0.2554	25.64	0.2481	25.37	0.1476	21.57
α_4	0.2664	26.73	0.2635	26.85	0.1476	21.65
β^{mkt}	0.9486	275.07	0.9500	285.02	0.9644	360.91
γ^{mkt}	0.8618	248.14	0.8622	248.31	0.8579	248.24
ξ^{mkt}_{spread}	0.0096	10.64	0.0095	10.60		
$\xi^{mkt}_{off-best,ask}$	-0.0206	-10.72	-0.0203	-10.59		
$\xi^{mkt}_{off-best,bid}$	-0.0218	-10.85	-0.0210	-10.53		
$\xi^{mkt}_{cancelled,off-best,ask}$	-0.0104	-5.80	-0.0107	-6.01		
$\xi^{mkt}_{cancelled,off-best,bid}$	-0.0105	-5.78	-0.0107	-5.95		
$\xi^{mkt}_{cancelled,best,ask}$	0.0008	0.44	0.0003	0.17		
$\xi^{mkt}_{cancelled,best,bid}$	0.0066	3.62	0.0056	3.12		
$\theta^{mkt}_{London,open}$	-0.0073	-1.81			-0.0030	-1.22
$\theta^{mkt}_{NY,open}$	0.0005	0.14			0.0010	0.43
θ^{mkt}_{close}	0.0346	5.58			0.0176	4.46
$\theta^{mkt}_{10:30\ to\ 11:30}$	0.0040	0.50	0.0020	0.27	0.0047	0.97
$\theta^{mkt}_{11:30\ to\ 12:30}$	-0.0546	-9.89	-0.0529	-9.99	-0.0291	-8.23
Likelihood	-94004.18		-94399.26		-95156.8	

Table 5: Asymmetric Log-ACD Model for the Ask Side and the Bid Side of the Market

Maximum-likelihood estimates of the asymmetric log-ACD models of duration. The model estimated is equation (3) using the data from the Reuters D2000-2 electronic brokerage system for the week of 6–10 October 1997.

	Ask		Bid	
	coefficient	*t*-stat	coefficient	*t*-stat
ω_1	0.4249	13.83	0.4207	12.05
ω_2	0.0143	0.63	0.0621	2.61
α_1	0.4492	16.34	0.4617	16.41
α_2	0.5496	18.70	0.5282	17.57
β^{lmt}	0.5568	23.64	0.5687	22.90
γ^{lmt}	0.9115	152.68	0.9186	151.83
ξ^{lmt}_{spread}	-0.0505	-19.15	-0.0466	-19.97
$\xi^{lmt}_{best,\ opposite\ side}$	-0.0322	-8.62	-0.0277	-7.63
$\xi^{lmt}_{market,\ opposite\ side}$	-0.0082	-1.89	0.0050	0.89
$\xi^{lmt}_{off-best,ask}$	-0.0126	-2.67	-0.0096	-1.59
$\xi^{lmt}_{off-best,bid}$	-0.0098	-2.54	-0.0260	-7.31
$\xi^{lmt}_{cancelled,off-best,ask}$	0.0084	2.65	-0.0013	-0.37
$\xi^{lmt}_{cancelled,off-best,bid}$	-0.0044	-1.31	0.0023	0.70
$\xi^{lmt}_{cancelled,best,ask}$	-0.0098	-3.26	-0.0062	-1.73
$\xi^{lmt}_{cancelled,best,bid}$	-0.0050	-1.40	-0.0065	-2.19
$\theta^{lmt}_{London,open}$	0.1385	6.38	0.1160	5.66
$\theta^{lmt}_{NY,open}$	0.0434	2.27	-0.0122	-0.67
θ^{lmt}_{close}	-0.4859	-15.42	-0.5067	-15.88
$\theta^{lmt}_{10:30\ to\ 11:30}$	-0.0085	-0.21	-0.0677	-1.77
$\theta^{lmt}_{11:30\ to\ 12:30}$	-0.0396	-1.55	-0.1466	-5.50
ω_3	0.0889	6.72	0.0151	1.10
ω_4	-0.3168	-29.74	-0.2925	-28.52
α_3	0.3141	21.89	0.3333	21.63
α_4	0.3427	24.02	0.3636	24.43
β^{mkt}	0.9026	130.37	0.9052	129.85
γ^{mkt}	0.7557	175.84	0.7684	177.48
ξ^{mkt}_{spread}	0.0068	5.17	0.0087	6.39
$\xi^{mkt}_{best,\ opposite\ side}$	0.0100	3.27	0.0142	4.62
$\xi^{mkt}_{market,opposite\ side}$	-0.0168	-5.40	-0.0001	-0.03
$\xi^{mkt}_{off-best,ask}$	-0.0127	-3.63	-0.0224	-4.66
$\xi^{mkt}_{off-best,bid}$	-0.0155	-5.00	-0.0331	-12.13
$\xi^{mkt}_{cancelled,off-best,ask}$	-0.0014	-0.59	-0.0143	-5.31
$\xi^{mkt}_{cancelled,off-best,bid}$	-0.0112	-4.43	0.0006	0.22
$\xi^{mkt}_{cancelled,best,ask}$	0.0096	3.85	-0.0002	-0.08
$\xi^{mkt}_{cancelled,best,bid}$	-0.0032	-1.11	0.0147	5.96
$\theta^{mkt}_{London,open}$	-0.0129	-1.43	-0.0158	-1.78
$\theta^{mkt}_{NY,open}$	0.0028	0.36	0.0025	0.31
θ^{mkt}_{close}	0.0394	2.88	0.0953	6.46
$\theta^{mkt}_{10:30\ to\ 11:30}$	0.0327	1.76	-0.0234	-1.30
$\theta^{mkt}_{11:30\ to\ 12:30}$	-0.0959	- 8.28169	-0.0791	-6.71
Likelihood	- 44438.2612		-46244.95	

Table 6: First-Order Autocorreation between Book Variables, Price Trend, and Volatility

	No. of ask cancel *t*	No. of bid cancel *t*	No. best ask cancel *t*	No. best bid cancel *t*	No. of ask submit	No. of bid submit	No. best ask submit	No. best bid submit	No. mkt ask executed	No. mkt bid executed
Price change, *t*-1	0.0046	0.0078	0.0058	0.0063	0.0287	-0.0256	0.0114	-0.0069	-0.0117	0.0159
Volatility $_{\text{price trend>0}}$, *t*-1	0.0195	0.0348	0.0357	0.0454	0.0683	-0.0131	0.0446	0.0225	-0.0035	0.0485
Volatility $_{\text{price trend<0}}$, *t*-1	0.0283	0.0224	0.0456	0.0137	-0.0038	0.0661	0.0170	0.0444	0.0474	0.0061
Volalility $_{\text{price trend=0}}$, *t*-1	0.1033	-0.0948	-0.1266	-0.0708	-0.1071	-0.0744	-0.1001	-0.0907	-0.0627	-0.0697

Figure 1:
This graph shows the proportion of all orders submitted in each half-hour time bin that were limit orders and market orders using the data from the Reuters D2000-2 electronic brokerage system for the week of 6–10 October 1997.

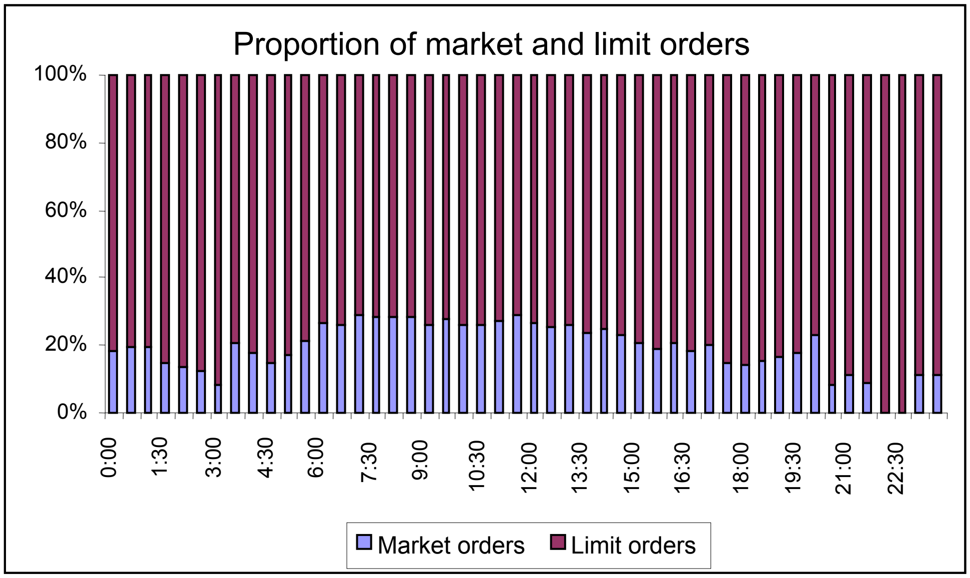
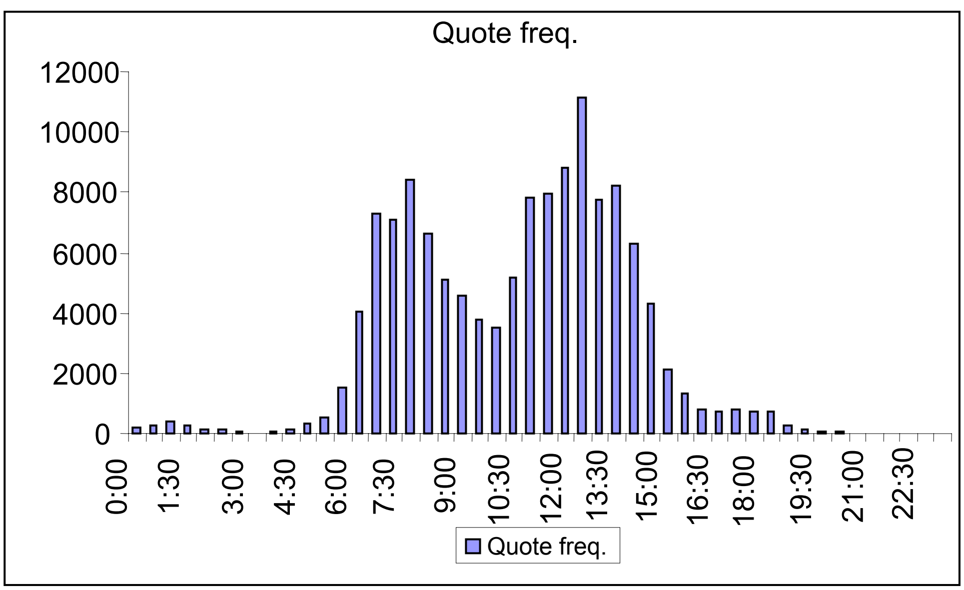


Figure 2:

This graph shows the average number of orders submitted in each half-hour time bin using the data from the Reuters D2000-2 electronic brokerage system for the week of 6–10 October 1997.



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