Order Submission: the Choice between Limit and Market Order

Ingrid Lo* and Stephen Sapp†
University of Western Ontario
April, 2003

Abstract

Most financial markets allow investors to submit both market and limit orders but it is not always clear why agents choose one over the other. In this study we empirically investigate which factors appear to influence the submission of limit and market orders using data on orders submitted to the Reuters 2000-2 system. To determine the impact of various factors on the order submission process we use an asymmetric autoregressive conditional duration (ACD) model to determine the time between successive market orders and limit orders after controlling for many market microstructure factors believed to influence dealers’ quoting behavior over the trading day. We find that (1) the ACD process of market orders and limit orders is not symmetric so the timing of the arrival of next trade is affected by the type of order; (2) the lagged average volume, a proxy for market depth, affects the expected duration just of market order but not limit orders; and (3) time dummies for peak trading hours affect expected duration even after adjusting for the well-known time-of-day seasonalities—the periods before and after the opening of the New York market act as proxies for market depth and significantly shrink the expected duration of market orders as the New York market increases its involvement in the market.

1 Introduction

In most financial markets, traders can choose between submitting a market order for immediate execution or a limit order that specifies a price for execution and may take longer to execute. This provides traders with several alternatives to accomplish their goal of maximizing the expected

*Email: lo_ingrid@hotmail.com
†Email: ssapp@ivey.uwo.ca
value of terminal wealth. Consequently, the choice between these types of order depends on both
the trader’s preferences and the market’s price generating process. As the market changes over
the trading day and as traders’ preferences between immediacy of trades and the cost of trading
changes, we expect to see changes in the traders’ propensity to submit the different types of orders.

We focus on the impact of various factors on the market order and limit order submission process
and therefore on the overall price formation process. As discussed in papers such as Dacrogna et
al (2001), there are many microstructure factors which are hypothesized to influence this decision
and thus the frequency with which each type of order is submitted. We investigate this question in
the context of the foreign exchange market for several reasons. One of the most significant reasons
is that it allows us to use a unique data set which contains detailed information on how the supply
and demand for assets develops over the trading day and thus how these changes influence the
traders’ quote submitting process.

The foreign exchange market is also interesting in its own right because macroeconomic models
have performed poorly at explaining exchange rate movements. In a seminal paper by Meese and
Rogoff (1983) they tested the predictive ability of a wide variety of structural exchange rate models
and found that no existing structural model could reliably out predict a simple random walk. This
striking negative result persists today despite many attempts using more complex structural models
and more advanced econometric techniques (for a nice survey see Faust, Rogers and Wright (2001)).
As a result of these findings a new area of research has started which considers microstructure
influences on exchange rates (for a survey see Lyons (2002)). Similar to their counterparts in equities
markets, these models recognize that asset prices are determined by the cumulative supply and
demand for the asset from individual traders. By improving our understanding of the factors that
influence dealers choice between submitting different types of orders, we hope to better understand
the key determinants of the supply and demand of currencies (or assets in general) and thus what
influences their prices.

This paper aims to investigate how the choice of type of order affects the price formation
process through analysis of the quote arrival process in the foreign exchange brokerage market. In
the foreign exchange market there are two markets in which transactions occur: the broker market
and the interdealer market. The broker market has more transparent information flow than the
direct interdealer market because the price, type of order and quantity submitted are observable
by all market participants whereas they are not in the interdealer market. The main difference between the two types of orders is the execution timing - market orders are more "urgent" in that the trader is willing to pay a premium to execute the order immediately whereas limit orders are more like price insurance or a means of testing market current and future market conditions. Consequently it is possible that the arrival of each type of order carries different information (e.g. market orders may carry more information about the underlying state of the market due to the "urgency" of execution).

There is little empirical work examining the effect of these two types of order on prices. Since prices are based on information arrival and the submission of the different types of orders may reveal new information to the market, the arrival process of these different types of quotes may provide valuable insight into the price formation process in asset markets. The most relevant studies in the foreign exchange market have concentrated on the value of information in trading volume (e.g. Evans (2002), and Evans and Lyons(2002)) or have used indicative quotes and thus have not been able to distinguish between the types of quotes(Engle and Russel (1997)) or focused on only one type of order (e.g. Melvin and Wen(2003) focused on limit orders). In this paper we demonstrate that the information on type of order placed is important and ignoring it may lead to misspecification of the trade arrival process.

Two other features distinguish this paper from previous studies in foreign exchange market. The first is that our technique permits the modelling of irregularly spaced data. Most studies in the foreign exchange market simply aggregate the information over set intervals and investigate the characteristics of this data. Despite the obvious loss of information by such aggregation, this is how most studies deal with the irregular arrival of high frequency data. Our method follows that of Engle and Russel (1998) to avoid this and therefore is more consistent with the underlying process (Muller et al (1993) and Dacrogna et al (2001)). Two papers taking a similar approach are Engle and Russel (1997) and Melvin and Wen (2003).

The second feature of this study is the use of firm quotes. The majority of high frequency studies of the foreign exchange market use indicative quote data because it is publicly available and studies such as Goodhart, Ito and Payne (1996) and Daniellson and Payne (2001) suggest that indicative quote data is a reasonable proxy for actual foreign exchange transaction data. Extending these studies, Lyons (1995), Yao (1998), Evans (1999) and Evans and Lyons (2002) use actual transaction
level data and demonstrate the impact that some transaction-level microstructure factors may have on the price formation process. We build on this literature to determine whether information on trades such as the volume traded, the depth of the market based on submitted limit orders and other features impact the price formation process. By using transaction data there is no approximation error in the timing of trade and the measurement of other variables (as there is in studies using indicative quotes).

For our investigation we consider three models. In the first model, we use the asymmetric Autoregressive Conditional Duration (ACD) model developed by Bauwens and Giot (2000). We assume the arrival process for prices depends on the type of orders. The aim is to examine whether the state variable, the type of order, affects the timing of the next quote (trade). We find that, conditional on the type of order, the expected duration until the arrival of the next quote (or trade) is dependent on the previous type of order that was submitted. Thus ignoring the type of order may lead to a misspecification of the arrival process of prices and estimation would no longer be consistent.

In the second model, we incorporate microstructure variables such as the volume traded and the frequency of quote submission into the autoregressive component of our ACD model for both types of orders. The aim is to examine how these microstructure variables interact with the state variable in affecting the arrival time of the next quote (or trade). The major finding in this model is that the average volume, a proxy of market depth, shortens the expected duration of market orders - the time between successive market orders.

In the third model, we study a model which accounts for systematic intraday seasonalities. The peak trading hours can impose asymmetric effects on market orders and limit orders. We found that time dummies for peak trading hours affect expected duration of market orders even after adjusting for the intraday seasonalities The periods before and after the opening of the New York market act as proxies for market depth and significantly shrink the expected duration of market orders as the New York market increases its involvement in the market.

The paper develops as follows. Section two describes the asymmetric ACD models used. Section three discusses the data set. Section four presents the results from the empirical analysis and the final section concludes.
2 Model

Our paper focus on examining the impact of whether a quote was a market order or a limit order on the duration of trade through the asymmetric log-ACD model. Duration is defined as the time elapsed between trades. In this framework, the market order and the limit order are allowed to influence the timing of the arrival of the next trade. The arrival of trades forms a price process through duration specification. Specifically, let $x_i$ be the duration between two trades at times $t_{i-1}$ and $t_i$ such that $x_i = t_i - t_{i-1}$ and let $y_i$ be the state variable i.e. whether a quote was a market order or a limit order. The duration $x_i$ is a mixing process such that

$$x_i = E[x_i | y_i, H_{i-1}] \varepsilon_i$$  \hspace{1cm} (1)

in which the $\varepsilon_i$ are IID random variables with positive support. The expected duration $E[x_i | y_i, H_{i-1}]$ is a function of the state, $y_i$, and the information set $H_{i-1}$ available at time $t_{i-1}$. In this study, the expected duration $E[x_i | y_i, H_{i-1}]$ takes the following form

$$E[x_i | y_i, H_{i-1}] = \Psi_i(y_i) = \exp(\psi_i(y_i))$$  \hspace{1cm} (2)

and $\psi_i(y_i)$ takes the form of an autoregressive process, which we will specify in the next section.

The likelihood function used is the Weibull distribution, which follows the of work Engle and Russel (1997, 1998) and Bauwens and Giot (2002). Other studies such as Melvin and Wen (2003) used the Burr distribution, because it is more general than the Weibull distribution. However, the estimation of the asymmetric model more than doubles the number of parameters of the symmetric model estimated in Melvin and Wen. Further compounding this is our investigation of microstructure models requiring the addition of other variables to the model. The correspondingly large number of parameters makes the Burr distribution too complex.

Three models are examined. The first one is a basic model, in which the autoregressive process on both market order and limit order depends on the previous random errors and the type of orders. The second model incorporates market microstructure variables such as quote intensity and average volume traded. The final model incorporates time effects of the peak trading hours.
2.1 Basic Model

The basic model studied in this section follows that of Bauwens and Giot (2000). Specifically, let $X_i$ be the raw duration between two trades at times $t_{i-1}$ and $t_i$ such that $X_i = t_i - t_{i-1}$. To remove intraday seasonality in $X_i$, we follow the method proposed by Engle and Russel (1998) in which the adjusted duration, $x_i$, is used in estimation and is given by

$$x_i = \frac{X_i}{\phi(i)}$$

where $\phi(i)$ is the time-of-day effect. The time-of-day effect is formed by first dividing each day into 48 half hour bins and averaging the durations within each bin. Next we specify the state variable $y_i$, which is the type of order. Let $y_i = 1$ if the quote is a limit order and $y_i = -1$ if the quote is a market order. The joint density function of $x_i$ and $y_i$ is given by

$$f(x_i, y_i \mid F_{i-1}) = \begin{cases} 
\gamma_{lmt} \left( \frac{x_i}{\Psi_i^+} \right)^\gamma_{lmt-1} I_i^+ e \left( \frac{x_i}{\Psi_i^+} \right)^\gamma_{lmt} & \text{if } y_i = 1 \\
\gamma_{mkt} \left( \frac{x_i}{\Psi_i^-} \right)^\gamma_{mkt-1} I_i^- e \left( \frac{x_i}{\Psi_i^-} \right)^\gamma_{mkt} & \text{if } y_i = -1
\end{cases}$$

with $\Psi_i^+ = \exp(\psi_i^+)$ and $\Psi_i^- = \exp(\psi_i^-)$. The autoregressive process conditional on a limit order, $\psi_i^+$ is given by

$$\psi_i^+ = \left( w_1 + \alpha_1 \varepsilon_i^{lmt-1} \right) I_{i-1}^+ + \left( w_2 + \alpha_2 \varepsilon_i^{lmt-1} \right) I_{i-1}^- + \beta_{lmt} \psi_{i-1}^+$$

with $x_i = \exp(\psi_i^+)\varepsilon_i^+$ and $I_{i-1}^+$ is an indicator function which is equal to 1 if $y_i = 1$ and 0 otherwise. Similarly, the autoregressive process conditional on a market order, $\psi_i^-$, is given by

$$\psi_i^- = \left( w_3 + \alpha_3 \varepsilon_i^{mkt-1} \right) I_{i-1}^+ + \left( w_4 + \alpha_4 \varepsilon_i^{mkt-1} \right) I_{i-1}^- + \beta_{mkt} \psi_{i-1}^-$$

with $x_i = \exp(\psi_i^-)\varepsilon_i^-$ and $I_{i-1}^-$ is an indicator function which is equal to 1 if $y_i = 1$ and 0 otherwise.

Equation (5) and equation (6) can be interpreted in an analogous fashion to GARCH(1,1) model in the sense that the dependent variable is a function of its lagged value and lagged random error. Another feature of the model is that the effect of the transition between states (limit order and market order) on duration is captured via the intercept, $w$, and the coefficient on the previous random error, $\alpha$. The values of both $w$ and $\alpha$ depend on whether the previous trade is a market order or a limit order. This setting allows us to test whether the expected duration, $\exp(\psi_i^+)$ and $\exp(\psi_i^-)$, is dependent upon the state variable—the type of order. If the expected duration until the next order, $\exp(\psi_i^+)$ or $\exp(\psi_i^-)$, does not depend on the type of the previous order, then $w_1 = w_2, w_3 = w_4, \alpha_1 = \alpha_2$ and $\alpha_3 = \alpha_4$ hold.
2.2 Model with Microstructure Variables

We extend the model by introducing microstructure effects. Some factors influencing the choice between submitting limit or market orders have been discussed in papers such as Demsetz (1968), Cohen and al. (1981), Ho and Stoll (1983) and surveyed in O’Hara (1985) or more recently Madah-van (2000). The common factors influencing this choice are measures of current market liquidity, dealers’ inventory considerations and the possible presence of asymmetric information. The variables we use to control for some of these factors are lagged quote intensity and lagged average transacted volume traded. These variables could theoretically contain information valued by market participants and thus affect the duration of the trade arrival process. The quote intensity measures the rate at which information arrives at the market. It is defined as the number of quotes between \( t - 1 \) and \( t \). That is

\[
qint_t = nq_t - nq_{t-1}
\]

where \( nq_t \) is the cumulative number of quotes till time \( t \). The quote intensity is then adjusted by the time-of-day effect as in the case of adjusting raw duration between trades. The average volume transacted is a measure of market depth. It is defined as the quantity traded between \( t - 1 \) and \( t \) divided by the number of transactions during that time. That is,

\[
vol_t = \frac{vt - vt-1}{ntrd_t - ntrd_{t-1}}
\]

where \( vt \) is the cumulative transacted volume and \( ntrd \) is the cumulative number of transactions till time \( t \). As in the case of adjusting raw trade duration, the average volume is then scaled by the time-of-day effect to remove the intraday seasonality. By incorporating lagged quote intensity and lagged traded volume into the joint process of trades arrival and types of order, we can examine how the two types of order react to these variables.

The autoregressive process conditional on a limit order, \( \psi_t^+ \), with the microstructure variables is given by

\[
\psi_t^+ = \left( w_1 + \alpha_1 \epsilon_t^+ \right) I_t^+ + \left( w_2 + \alpha_2 \epsilon_t^+ \right) I_t^- + \beta lmt \psi_{t-1}^+ + \zeta lmt qint_{t-1} + \zeta lmt vol_{t-1}
\]

In estimating the model, the trade arrival process is thinned such that the change in price from one observation to the next is greater than a constant, \( c \). As a result, the number of transactions between two observations can be greater than 1.
where $\zeta_{qint}^{\text{lim}}$ is the coefficient of $qint$ given that the trade is a limit order. The average trade’s coefficient is $\zeta_{vol}^{\text{lim}}$. These coefficients give us information on whether the microstructure variables affect the expected duration conditional on the submitted order being a limit order, $\exp(\psi_i^+)$. Similarly, the autoregressive process conditional on a market order is given by

$$
\psi_i^- = \left( w_3 + \alpha_3 \varepsilon_{i-1} \right) I_{i-1}^- + \left( w_4 + \alpha_4 \varepsilon_{i-1} \right) I_{i-1}^- + \beta_{\text{mkt}}^- \psi_{i-1}^- + \zeta_{\text{mkt}}^- qint_{i-1} + \zeta_{\text{vol}}^- vol_{i-1} \tag{10}
$$

where $\zeta_{qint}^{\text{mkt}}$ and $\zeta_{vol}^{\text{mkt}}$ are the coefficients of quote intensity and average volume when the trade is a market order.

### 2.3 Model with Time Effects

As with all financial markets, there are clear trading patterns in the trading intensity of the foreign exchange market. The peak trading hours for foreign exchange can roughly be divided into three periods. This can be clearly seen in Figure 1. Trading first peaks from 8:00a.m. to 10:00a.m. as market opens in London. Then trading drops slightly from 10:30a.m. to before 12:30. As the New York market opens at around 1:00p.m., trade intensity goes up again.

Theoretically speaking, the standard practice of adjusting duration by expected duration should remove the influence of intraday seasonalities in foreign exchange trading. However, is the hour-of-day effect symmetric for market orders and limit orders? More specifically, we want to study whether the opening of the London and the New York market has symmetric effect on the conditional expected duration of market orders and limit orders. The successful filling of an incoming market order depends very much on the market depth. Traders who need a transaction immediately would use the electronic brokerage system if the market is deep enough to fill their orders successfully. Thus the opening the New York market, which deepens the existing market by introducing more possibilities of trade, should shorten the expected duration of the market order.

Qualitative variables are used to capture the effect of peak trading hours. Each day is divided into forty-eight 30-minutes time bins. Three time dummies are placed, one for each interval of peak trading hours. The dummy takes a value of 1 if a trade occurs in the respective peak trading hour and 0 otherwise. More specifically,

$$
t_1 = 1 \text{ if the transaction occurs between 8:00 to 10:00 (GMT), } t_1 = 0 \text{ otherwise}
$$

$$
t_2 = 1 \text{ if the transaction occurs between 10:00 to 12:30 (GMT), } t_2 = 0 \text{ otherwise}
$$
The autoregressive process for the limit order, $\psi_i^+$, with the time dummies incorporated is given by

$$
\psi_i^+ = \left( w_1 + \alpha_1 \epsilon_{i-1}^+ \right) I_{i-1}^+ + \left( w_2 + \alpha_2 \epsilon_{i-1}^+ \right) I_{i-1}^- + \beta_{lmt}^1 \psi_{i-1}^+ + \theta_{lmt}^1 t_1 + \theta_{lmt}^2 t_2 + \theta_{lmt}^3 t_3
$$

(11)

where $t_1$, $t_2$ and $t_3$ are the qualitative variables which stands for the opening of the London market, the time period before the opening of the New York market and the opening of the New York market. Their coefficients under limit order are given by $\theta_{lmt}^1$, $\theta_{lmt}^2$ and $\theta_{lmt}^3$. Similarly, the autoregressive process of the market order with time dummies is given by

$$
\psi_i^- = \left( w_3 + \alpha_3 \epsilon_{i-1}^- \right) I_{i-1}^+ + \left( w_4 + \alpha_4 \epsilon_{i-1}^- \right) I_{i-1}^- + \beta_{mkt}^1 \psi_{i-1}^- + \theta_{mkt}^1 t_1 + \theta_{mkt}^2 t_2 + \theta_{mkt}^3 t_3
$$

(12)

where $\theta_{mkt}^1$, $\theta_{mkt}^2$ and $\theta_{mkt}^3$ are the coefficients of the time dummies when the transaction is a market order.

3 Data

The data we use comes from Reuters D2000-2 system. The data set covers trading activity in the electronic broker market from the evening of 5th of October to mid night on the 10th of October 1997. The quotes in the data set are firm quotes, the price at which the submitter would be willing to buy or sell a set quantity of the currency. The quote is time-stamped when it arrives. In addition to the quote, we can also extract information on whether the quote is limit order or market order, whether the quote is bid side or ask side initiated, the entry and exit time of the quote, and the quantity traded.

There are 130,526 quotes and 63,617 trades in total. The summary statistics of quote, trade and their duration (defined as time elapsed between quote/trade) is given in the Table 1. The duration is measured in seconds. The statistics for quotes and prices are quite close to each other. On the other hand, quote arrives more frequently than trade on average. Also, the variation of duration of trade is much larger than quote. Figure 1 shows the sample average of number of quotes and prices with a day divided into 48 time bins. Before 7:00 (GMT), and after 20:00 (GMT), quote intensity and trade intensity are very low. During the opening hours of the London market, a dual peak occurs in quote intensity and trade intensity. The market is most active from 8:00 to
10:00 (GMT), dips from 10:30 to 12:30, and becomes active again around 13:00. Figure 2 shows the average waiting time until the next quote/trade. The average duration is quite long before the opening of the London market. The average duration then shortens considerably, for both quote and trade, after 7:00 (GMT) and remains so for a couple of hours after the closing of the London market. It is because the New York market is still open at that time. The average duration is longest after the closing of the New York market at 21:00 (GMT).

Of all the quotes, about one sixth are market orders and the rest are limit orders. The summary statistics of the execution time or the exit time of the two types of orders are given in Table 2. The average period of time that a market order stays in the market is much shorter, 0.07 seconds, than a limit order, 171.27 seconds since a market order is executed immediately. Figure 4 shows the sample average of the number of quotes, market orders and limit orders. However, this paper does not study the timing of orders being completed. Rather, we focus on the arrival process of orders, which according to Easley and O’Hara (1992), conveys information to market participants about the underlying state. Table 3 shows the summary statistics of the durations for the two types of orders. Duration is defined as the time elapsed between two successive orders. The average duration of a market order is much longer and the variation of a market order is much higher than those of the limit order. The mean duration of a market order is four times bigger than that of a limit order. The variation of a market order is nearly 20 times bigger than that of a limit order.

Figure 4 shows a comparison of the average number of quotes, limit orders and market orders. The intensity of limit orders closely follows that of quotes, since it makes up around 5/6 of all quotes. The dual peaks pattern is evident in limit orders as well. On the other hand, the intensity of market orders is a much dampened version of the limit order. Figure 4 shows the average duration until the next quote/limit order/market order. The pattern of duration closely resembles the pattern we have discussed on quote and trade. The waiting time for the arrival of market orders is much longer than that of the limit orders, especially before the opening of the London market and after the closing of New York market. The average duration of market orders becomes much shorter when the markets are open. These results suggest that the factors influencing the decision whether to submit a limit or market order are different. As a consequence, we formally investigate the impact of various factors on this choice in the next section.
4 Results

The observations from the 5th of October are used as the initial observations in our analysis. Hereafter, we define “the arrival process of price” or “the price process” as the arrival process of trades such that the cumulative price change between trades is, hereafter the threshold, at least 0.0001. There are 24732 observation in the thinned data set. The practice of thinning the marked point process of trade is commonly adopted in dealing with irregularly spaced data. Examples are Bauwens and Giot (2000), Engle and Russel (1997) and Engle and Russel (1998). As discussed in Bauwens and Giot (2001), there are a couple of reasons of thinning the trade process. The first reason is that a thinned trade process, as shown in Engle and Russel (1998), is closely related to the instantaneous volatility. The issue of instantaneous volatility will be examined in the basic model below. The second reason is that a thinned trade process allowed microstructure variables to be more meaningfully defined so that individual outliers do not drive estimation results. Take average volume as an example. For the unthinned trade process, the average volume at time $t$ is just the volume traded at time $t$. For the thinned price process, trades are spaced by the cumulative price change and the number of trades occurring between observations can be larger than zero. Thus the average volume is the sample mean of the volume traded between observations, not just the volume traded at time $t$.

The summary statistics of the thinned trade process—the price (defined as the quote which trade occurs), the duration (defined as the time elapsed between trades) and the volume traded—are given in Table 4. The statistics of prices after thinning is close to the original trade process. This is because the range of changes in price is relatively narrow and thus thinning does not affect the price statistics. The mean of the duration of the thinned trade process is longer and the variation is bigger than the original price process. Figure 5 shows the average frequency of trades and thinned trades. The pattern of frequency of the thinned trade process closely resembles that of the original trade process. Figure 6 shows the average duration of the thinned trade process. Since the change in price between two observations must be at least 0.0001, the average duration of the thinned trade process is longer than original price process.
4.1 Basic Model

Table 5 shows the results of the basic model. The major results can be summarized as follows,

- First we investigate if market orders and limit orders have the same effect on the arrival of the next trade. A market order and a limit order have the same effect on the arrival of the next trade if all the parameters of their autoregressive process are the same. If the two types of order have the same autoregressive process, then the density function can be simplified to the symmetric log-ACD model. The null hypothesis is given by

\[ H_0 : w_1 = w_2 = w_3 = w_4, \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4, \beta_{lmt} = \beta_{mkt} \text{ and } \gamma_{lmt} = \gamma_{mkt} \] (13)

The hypothesis is tested via the likelihood ratio test. The constrained model is a model with the above restrictions imposed. The test statistics follows \( \chi^2 \) distribution with 8 degrees of freedom. The test statistics is equal to 6534. This is highly significant and the hypothesis is rejected at all significance level. This indicates that the conditional expected duration is different for the two types of order. Using a symmetric model would therefore lead to misspecification.

- Next we investigate whether expected duration depends on the previous state i.e. whether the trade was a market order or a limit order. Precisely we investigate whether the autoregressive processes of the expected duration conditional on limit orders, \( \psi_i^- \), and on market orders, \( \psi_i^+ \), depend on the previous type of order. The effect of state transition is the same if the transition parameters are equal to each other. That is

\[ H_0 : w_1 = w_2, w_3 = w_4, \alpha_1 = \alpha_2 \text{ and } \alpha_3 = \alpha_4 \] (14)

This forms the null hypothesis in testing. The likelihood ratio test statistic takes a value of 36, which means that the null is rejected. This indicates that the conditional expected duration of trade is dependent of the previous type of order.

- We also examine the persistence of the dynamics of the expected duration for the two types of order. The t-statistics of both \( \beta_{lmt} \) and \( \beta_{mkt} \) are both significant and above 0.9. This indicates the presence of strong autoregressive effects. We next investigate whether the autoregressive effects in expected duration are the same for market orders and limit orders. The
null hypothesis is

\[ H_0: \beta_{\text{limt}} = \beta_{\text{limt}} \]  

The likelihood ratio test has a test statistics of 2.4 and cannot be rejected at conventional levels of significance. We can conclude that the degree of autocorrelation is the same for both types of process.

- We are also interested in the Weibull parameters, \( \gamma_{\text{limt}} \) and \( \gamma_{\text{mkt}} \), because it is related to the hazard of the trade process, \( x_i \). We first check whether the Weibull parameters are smaller than 1. A Weibull parameter smaller than 1 means that the hazard is decreasing. Both of their t-statistics are significant and the estimated coefficients are statistically less than 1. As a result, conditional on the present state \( y_i \), the hazard function of \( x_i \) is decreasing. The implication is that the longer the period without a price change, the less likely a trade will occur instantaneously. Next, we investigate whether limit orders and market orders have the same Weibull parameters. The issue is important because if

\[ \gamma_{\text{limt}} = \gamma_{\text{mkt}} = \gamma \]  

then, as shown in Bauwens and Giot (2000), the marginal distribution of \( x_i \) follows Weibull distribution with parameters \( \gamma \) and \( [(\Psi_i^+)\gamma + (\Psi_i^-)^{-1}\gamma]^{1/\gamma} \). The hazard of \( x_i \) is given by

\[ h(x_i | F_{i-1}) = \gamma [(\Psi_i^+)\gamma + (\Psi_i^-)^{-1}\gamma]^{1/\gamma}(x_i[(\Psi_i^+)\gamma + (\Psi_i^-)^{-1}\gamma]^{1/\gamma})^{\gamma-1} \]  

The likelihood ratio test, with equation (16) as the null hypothesis, has a test statistics of 0.4 and is not rejected at all significance level. Thus the Weibull parameters are the same for both market orders and limit orders.

- We now examine the instantaneous volatility implied by the asymmetric ACD model. Engle and Russel (1997) showed that the instantaneous volatility is related to the threshold of price change, \( c \), by the following equation,

\[ \sigma^2 = \frac{c^2}{E[x_i^2 | F_{i-1}]} \]  

We compare the instantaneous volatility of the symmetric model and the asymmetric model. The equality of \( \gamma_{\text{limt}} \) and \( \gamma_{\text{mkt}} \) simplifies analysis of the asymmetric ACD model. Back out
from equation (17), the conditional expectation of $x_i$ under the asymmetric ACD model, $E[x_i \mid F_{i-1}]$, is given by

$$E[x_i \mid F_{i-1}] = [(\Psi_i^+) - \gamma + (\Psi_i^-)^{-\gamma}]^{1/\gamma}$$

(19)

The value of $\gamma$ in the asymmetric model is set to 0.77. This is because the null hypothesis

$$\gamma^{lmt} = \gamma^{mkt} = 0.77$$

(20)

cannot be rejected at 5% significance level. For the symmetric ACD model, the conditional expectation of $x_i$ is given by

$$E[x_i \mid F_{i-1}] = \Psi_i = \exp(\omega + \alpha \varepsilon_{i-1} + \beta x_{i-1})$$

(21)

Table 6 shows the estimates of the symmetric model. The unit of $\sigma$ of both models are adjusted from per second to the percent of annual standard deviation. Table 7 shows comparison of the statistics of $\sigma$ of both models. Both the mean and the variance of the instantaneous volatility of the asymmetric ACD model is 12% higher than the symmetric ACD model. Figure 7 shows the average volatility of a trading day. The average volatility is high between 13:00 (GMT) and 19:00 (GMT) for both models. The average volatility of the asymmetric model is uniformly higher than that of the symmetric model. Thus if the arrival process of price is estimated via the symmetric ACD model instead of the asymmetric ACD model, we will underestimate the instantaneous volatility.

4.2 Model with Microstructure Variables

Table 8 shows the results with the microstructure variables. The major results of the model are as follows,

- We first investigate whether the microstructure variables explain the expected duration of the price process given the type of order. This can be achieved through examining the t-statistic of the coefficients on the market microstructure variables. For limit orders, the coefficient for quote intensity, $\zeta^{lmt}_{qint}$ has the expected sign— it is negative. Also the t-statistics is significant at 5% level. The result indicates that for limit orders, the intensity of quote decreases the expected duration of the price process given that a limit order is submitted. However, the...
coefficient for average volume, $\zeta_{\text{vol}}^{\text{lmt}}$, of the limit order is not statistically different from zero. From the result, it seems that the market depth is not an important factor for the expected duration of price process conditional on a limit order being submitted. One possible reason is that for limit orders, the timing of the execution of trade is of secondary importance so market depth, which reflects the volume of trade the market is able to execute, is not a significant factor for limit order.

- The situation reverses for market orders. The coefficient for average volume, $\zeta_{\text{vol}}^{\text{mkt}}$, is negative and highly significant. It indicates that the lagged average volume traded decreases the expected duration between trades for market orders. However, although the coefficient for trade intensity, $\zeta_{\text{qint}}^{\text{mkt}}$, is negative, it is not significant at 5% significance level. The intuition of the result is that the immediacy of trade is important for market orders. As the volume transacted increases, the probability that an order being filled immediately rises. Thus volume transacted is important information for traders who need to trade immediately and it shortens the expected duration the price process conditional on a market order.

- Quote intensity and average volume impose asymmetric effect on the two types of order. The hypothesis of symmetric effect can be tested via the hypothesis that

$$\zeta_{\text{qint}}^{\text{lmt}} = \zeta_{\text{qint}}^{\text{mkt}} \text{ and } \zeta_{\text{vol}}^{\text{lmt}} = \zeta_{\text{vol}}^{\text{mkt}}$$

The likelihood ratio test follows $\chi^2$ distribution with 2 degrees of freedom. The statistics yields a value of 13.88, which is rejected at all significance level. It suggests that the microstructure variables takes on different effect on the two types of order.

- The model, as in the case of the basic model, exhibit strong autoregressive process for both types of orders.

4.3 Model with Time Effects

Table 9 shows the model with time effects. Several features of the results are interesting

- We first examine whether time effect still exist after removing the intraday seasonality. The existence of time effect can be tested through the hypothesis

$$\theta_{1}^{\text{lmt}} = \theta_{2}^{\text{lmt}} = \theta_{3}^{\text{lmt}} = \theta_{1}^{\text{mkt}} = \theta_{2}^{\text{mkt}} = \theta_{3}^{\text{mkt}} = 0$$
The likelihood test statistics has a value 31.6, which rejects the null hypothesis. Time effects exist even after scaling the data to remove the time-of-day effect. This means the peak trading hours, like the microstructure variables, carries information about the arrival of next trade even after adjustment of time-of-day effect.

- We next investigate the influence of each time dummies for the two types of orders. For the market orders, the time effects for the hours before and after the opening of New York market are present and also statistically smaller then zero. These time periods corresponds to the increase, or expectation of an increase, in market depth and thus facilitate the execution of market order. Thus confirming with our conjecture, the opening of the New York market shortens the price process’s expected duration conditional on a market order. These two time qualitative variables, like the average volume between durations, proxy for market depth.

- For the autoregressive process of the limit order, the time effects are evident only for the opening of London market and the time before the opening of the New York market. Their t-statistics are significantly different from zero. The estimated coefficient corresponding to the opening of the New York market is very small and is not different from zero statistically.

5 Conclusion

We examine the impact of various factors on the market order and limit order submission process and investigate this question in the context of the foreign exchange market. We use the asymmetric ACD model to analyze the irregularly spaced data. The data set features firm quotes. The first finding is that, conditional on the type of order, the expected duration until the arrival of the next quote (or trade) is dependent on the previous type of order that was submitted. The second finding is that the average volume, a proxy of market depth, shortens the expected duration of market orders. The last finding is that time dummies for peak trading hours affect expected duration of market orders even after adjusting for the intraday seasonalities. The periods before and after the opening of the New York market act as proxies for market depth and significantly shrink the expected duration of market orders as the New York market increases its involvement in the market.

The findings in this paper suggests that ignoring the type of order leads to a misspecification of
the arrival process of prices. As a result, estimation would no longer be consistent and the implied volatility would be underestimated. We also find that the submission of market order reacts to the market depth, as a more liquid market enhances the likelihood of filling the order. For further research, the model can be extended by incorporating price change explicitly, as in Engle and Russel (1998b). Also, more general distribution assumption can be adopted for the random error.
References:


Lyons, R., Tests of Microstructural Hypotheses in the Foreign Exchange Market, *Journal of 


2000

Table 1: Summary Statistics of Quote and Trade

This table provides summary statistics describing the quote and trade from the Reuters D-2002 electronic brokerage system for the week of October 6-10, 1997. Duration is the time between the arrival of quotes and trade. For duration, the units of measurement are in seconds.

<table>
<thead>
<tr>
<th></th>
<th>quote duration</th>
<th>trade duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>1.7516</td>
<td>3.3514</td>
</tr>
<tr>
<td>variance</td>
<td>0.0001</td>
<td>1197.2685</td>
</tr>
<tr>
<td>max</td>
<td>2</td>
<td>5367.57</td>
</tr>
<tr>
<td>min</td>
<td>1.7003</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>0.0001</td>
<td>9763.5261</td>
</tr>
<tr>
<td></td>
<td>1.7318</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 2: Summary Statistics of how Long Market Order and Limit Order Stays in Market

This table provides summary statistics describing how long the quote and price stays in the market. Mean is average the amount of time (measures in seconds) an order stays in the market. Variance, max. and min. is defined on the amount of an order stays in the market as well.

<table>
<thead>
<tr>
<th></th>
<th>market order</th>
<th>limit order</th>
</tr>
</thead>
<tbody>
<tr>
<td>number of observations</td>
<td>21783</td>
<td>108752</td>
</tr>
<tr>
<td>mean</td>
<td>0.072255</td>
<td>171.2736</td>
</tr>
<tr>
<td>variance</td>
<td>0.00234</td>
<td>960364.3</td>
</tr>
<tr>
<td>max</td>
<td>3.04</td>
<td>48160.23</td>
</tr>
<tr>
<td>min</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Table 3: Summary Statistics of Market Order and Limit Order

This table provides summary statistics describing the market order and limit order from the Reuters D-2002 electronic brokerage system for the week of October 6-10, 1997. Duration is the time between the arrival of market order and limit order. For duration, the units of measurement are in seconds.

<table>
<thead>
<tr>
<th></th>
<th>market order duration</th>
<th>limit order</th>
<th>limit order duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>1.7514</td>
<td>1.7514</td>
<td>4.7540</td>
</tr>
<tr>
<td>variance</td>
<td>0.0001</td>
<td>0.0001</td>
<td>1696.3500</td>
</tr>
<tr>
<td>max</td>
<td>1.765</td>
<td>2</td>
<td>5367.5700</td>
</tr>
<tr>
<td>min</td>
<td>1.7318</td>
<td>1.7003</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Table 4: Summary Statistics of the Thinned Trade Process

This table provides summary statistics of the thinned trade, the associated volume trade and the trade duration. The trade process is thinned such that the change in price between any two successive observations is at least 0.001. Duration is the amount of time between the arrivals of trades. Volume is the transacted volume associated with the price process. Price is the quote at which FX is traded.

<table>
<thead>
<tr>
<th></th>
<th>duration</th>
<th>price</th>
<th>volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>17.3852</td>
<td>1.7505</td>
<td>1.7743</td>
</tr>
<tr>
<td>variance</td>
<td>30,821.3</td>
<td>0.0001</td>
<td>1.9416</td>
</tr>
<tr>
<td>max</td>
<td>10,472</td>
<td>1.7699</td>
<td>28</td>
</tr>
<tr>
<td>min</td>
<td>0.01</td>
<td>1.7318</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5: Asymmetric Log- ACD Model

Maximum likelihood estimates of the asymmetric log-ACD models of duration. The model estimated is as in equation (5) and equation (6) using the data from the Reuters D-2002 electronic brokerage system for the week of October 6-10, 1997.

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Std Error</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega_1$</td>
<td>-0.0201</td>
<td>0.0047</td>
<td>-4.2473</td>
</tr>
<tr>
<td>$\omega_2$</td>
<td>-0.0630</td>
<td>0.0100</td>
<td>-6.2937</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>0.0876</td>
<td>0.0046</td>
<td>18.8789</td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>0.0741</td>
<td>0.0095</td>
<td>7.8397</td>
</tr>
<tr>
<td>$\beta_{\text{int}}$</td>
<td>0.9656</td>
<td>0.0031</td>
<td>313.1685</td>
</tr>
<tr>
<td>$\gamma_{\text{int}}$</td>
<td>0.7677</td>
<td>0.0044</td>
<td>175.8330</td>
</tr>
<tr>
<td>$\omega_3$</td>
<td>-0.0478</td>
<td>0.0121</td>
<td>-3.9381</td>
</tr>
<tr>
<td>$\omega_4$</td>
<td>0.0031</td>
<td>0.0207</td>
<td>0.1472</td>
</tr>
<tr>
<td>$\alpha_3$</td>
<td>0.5421</td>
<td>0.0406</td>
<td>13.3502</td>
</tr>
<tr>
<td>$\alpha_4$</td>
<td>0.3643</td>
<td>0.0772</td>
<td>4.7171</td>
</tr>
<tr>
<td>$\beta_{\text{mkt}}$</td>
<td>0.9749</td>
<td>0.0048</td>
<td>203.8953</td>
</tr>
<tr>
<td>$\gamma_{\text{mkt}}$</td>
<td>0.7742</td>
<td>0.0076</td>
<td>101.7578</td>
</tr>
<tr>
<td>Likelihood</td>
<td>-58297.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 6: Symmetric Log-ACD Model

Maximum likelihood estimates of the symmetric log-ACD models of duration. The autoregressive equation $\psi_t$ is given by $\psi_t = \omega + \alpha \epsilon_{t-1} + \beta x_{t-1}$ and the conditional duration is given by $\exp(\psi_t)$.

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Std Error</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega$</td>
<td>-0.0280</td>
<td>-7.6033</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.1609</td>
<td>24.1328</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.9701</td>
<td>383.3858</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.7690</td>
<td>203.1524</td>
</tr>
<tr>
<td>Likelihood</td>
<td>-61564.2</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Statistics on Instantaneous Volatility

The table provides summary statistics of instantaneous volatility implied by the symmetric and asymmetric ACD model. Volatility is measured in annual standard deviation (%).

<table>
<thead>
<tr>
<th></th>
<th>Asymmetric ACD</th>
<th>Symmetric ACD</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>33.5520</td>
<td>21.3558</td>
</tr>
<tr>
<td>variance</td>
<td>53.1133</td>
<td>21.4154</td>
</tr>
<tr>
<td>max</td>
<td>61.2224</td>
<td>38.8812</td>
</tr>
<tr>
<td>min</td>
<td>10.1015</td>
<td>6.4978</td>
</tr>
</tbody>
</table>
Table 8: Asymmetric Log-ACD Model with Microstructure Variables

Maximum likelihood estimates of the asymmetric log-ACD models of duration. The model estimated is as in equation (9) and equation (10) using the data from the Reuters D-2002 electronic brokerage system for the week of October 6-10, 1997. This model corrects for some of the well-documented microstructure effects found in high-frequency studies in the foreign exchange market. The variables used are quote intensity between trades and average volume between trades.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coefficient</th>
<th>Std Error</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega_1$</td>
<td>-0.0101</td>
<td>0.0081</td>
<td>-1.2472</td>
</tr>
<tr>
<td>$\omega_2$</td>
<td>-0.0531</td>
<td>0.0120</td>
<td>-4.4110</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>0.0882</td>
<td>0.0047</td>
<td>18.7499</td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>0.0739</td>
<td>0.0095</td>
<td>7.7825</td>
</tr>
<tr>
<td>$\beta_{\text{int}}$</td>
<td>0.9651</td>
<td>0.0031</td>
<td>309.5265</td>
</tr>
<tr>
<td>$\gamma_{\text{int}}$</td>
<td>0.7678</td>
<td>0.0044</td>
<td>175.8396</td>
</tr>
<tr>
<td>$\zeta_{\text{int}, \text{tint}}$</td>
<td>-0.0512</td>
<td>0.0310</td>
<td>-1.6509</td>
</tr>
<tr>
<td>$\zeta_{\text{int}, \text{vol}}$</td>
<td>0.0184</td>
<td>0.0602</td>
<td>0.3061</td>
</tr>
<tr>
<td>$\omega_3$</td>
<td>-0.0035</td>
<td>0.0186</td>
<td>-0.1904</td>
</tr>
<tr>
<td>$\omega_4$</td>
<td>0.0520</td>
<td>0.0269</td>
<td>1.9311</td>
</tr>
<tr>
<td>$\alpha_3$</td>
<td>0.5477</td>
<td>0.0415</td>
<td>13.2071</td>
</tr>
<tr>
<td>$\alpha_4$</td>
<td>0.3629</td>
<td>0.0813</td>
<td>4.4640</td>
</tr>
<tr>
<td>$\beta_{\text{mkt}}$</td>
<td>0.9716</td>
<td>0.0051</td>
<td>192.0254</td>
</tr>
<tr>
<td>$\gamma_{\text{mkt}}$</td>
<td>0.7743</td>
<td>0.0076</td>
<td>101.7576</td>
</tr>
<tr>
<td>$\zeta_{\text{mkt}, \text{tint}}$</td>
<td>-0.0095</td>
<td>0.0062</td>
<td>-1.5381</td>
</tr>
<tr>
<td>$\zeta_{\text{mkt}, \text{vol}}$</td>
<td>-0.0387</td>
<td>0.0117</td>
<td>-3.3090</td>
</tr>
<tr>
<td>Likelihood</td>
<td>-58289.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 9: Asymmetric Log-ACD Model with Time Dummies

Maximum likelihood estimates of the asymmetric log-ACD models of duration. The model estimated is as in equation (11) and equation (12) using the data from the Reuters D-2002 electronic brokerage system for the week of October 6-10, 1997. This model compensates for the differences in quoting intensity across the trading day by inserting time dummies in the peak trading hours. Trading level is low until the market in London opens and it peaks between 8:00 to 10:00 (GMT), it decreases somewhat between 10:30 and 12:30 (GMT) and peaks with the opening of the market in New York at 13:00 (GMT).

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Std Error</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega_1$</td>
<td>-0.0166</td>
<td>0.0055</td>
<td>-3.0517</td>
</tr>
<tr>
<td>$\omega_2$</td>
<td>-0.0625</td>
<td>0.0104</td>
<td>-5.9911</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>0.0873</td>
<td>0.0048</td>
<td>18.2554</td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>0.0769</td>
<td>0.0097</td>
<td>7.9720</td>
</tr>
<tr>
<td>$\beta_{lmt}$</td>
<td>0.9627</td>
<td>0.0034</td>
<td>286.0924</td>
</tr>
<tr>
<td>$\gamma_{lmt}$</td>
<td>0.7681</td>
<td>0.0044</td>
<td>175.7491</td>
</tr>
<tr>
<td>$\theta_{lmt,1}$</td>
<td>0.0214</td>
<td>0.0091</td>
<td>2.3633</td>
</tr>
<tr>
<td>$\theta_{lmt,2}$</td>
<td>-0.0140</td>
<td>0.0071</td>
<td>-1.9747</td>
</tr>
<tr>
<td>$\theta_{lmt,3}$</td>
<td>0.0006</td>
<td>0.0077</td>
<td>0.0823</td>
</tr>
<tr>
<td>$\omega_1$</td>
<td>-0.0278</td>
<td>0.0145</td>
<td>-1.9200</td>
</tr>
<tr>
<td>$\omega_2$</td>
<td>0.0249</td>
<td>0.0234</td>
<td>1.0628</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>0.5332</td>
<td>0.0415</td>
<td>12.8379</td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>0.3737</td>
<td>0.0831</td>
<td>4.4990</td>
</tr>
<tr>
<td>$\beta_{lmt}$</td>
<td>0.9688</td>
<td>0.0055</td>
<td>177.2440</td>
</tr>
<tr>
<td>$\gamma_{lmt}$</td>
<td>0.7751</td>
<td>0.0076</td>
<td>101.6357</td>
</tr>
<tr>
<td>$\theta_{mkt,1}$</td>
<td>0.0293</td>
<td>0.0179</td>
<td>1.6330</td>
</tr>
<tr>
<td>$\theta_{mkt,2}$</td>
<td>-0.0401</td>
<td>0.0144</td>
<td>-2.7812</td>
</tr>
<tr>
<td>$\theta_{mkt,3}$</td>
<td>-0.0335</td>
<td>0.0154</td>
<td>-2.1680</td>
</tr>
</tbody>
</table>

Likelihood -58281.9
Figure 1: Frequency of Quotes and Prices (Trades)

This figure illustrates the frequency of quotes and prices (trades) submitted to the Reuters D-2002 electronic brokerage system for the week of October 6-10, 1997.
Figure 2: Duration (Arrival Process) of Quotes and Prices (Trades)

This figure illustrates the duration of quotes and prices (trades) submitted to the Reuters D-2002 electronic brokerage system for the week of October 6-10, 1997. Duration is defined as the time elapse between quotes and trades. For duration hitting 1800 seconds, it means either no trade occurs or the duration until next trade is longer than 1800 seconds.
Figure 3: Frequency of Quotes, Limit Orders and Market Orders

This figure illustrates the frequency of quotes, limit orders and market orders submitted to the Reuters D-2002 electronic brokerage system for the week of October 6-10, 1997.
Figure 4: Duration (Arrival Process) of Quotes, Limit Orders and Market Orders

This figure illustrates the duration of quotes, limit orders and market orders submitted to the Reuters D-2002 electronic brokerage system for the week of October 6-10, 1997. Duration is defined as the time elapse between quotes and trades. For duration hitting 1800 seconds, it means either no order occurs or the duration until next order is longer than 1800 seconds.
Figure 5: Frequency of Prices and Thinned Prices

This figure illustrates the frequency of prices and thinned prices.
Figure 6: Duration (Arrival Process) of Prices and Thinned Prices

This figure illustrates the duration of prices and thinned prices. Duration is defined as the time elapse between quotes and trades. For duration hitting 1800 seconds, it means either no trade occurs or the duration until next trade is longer than 1800 seconds.
Figure 7: Average Instantaneous Volatility

This figure illustrates the average instantaneous volatility in a trading day implied by the symmetric ACD model and the asymmetric ACD model.