

# Order Aggressiveness in Limit Order Book Markets

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## Abstract

I examine the information content of a limit order book in a purely order-driven market. I analyze how the state of the limit order book affects a trader's strategy. I develop an econometric technique to study order aggressiveness and provide empirical evidence on the recent theoretical models on limit order book markets. My results show that patient traders become more aggressive when the own (opposite) side book is thicker (thinner), the spread wider, and the temporary volatility increases. Also, I find that the buy and the sell sides of the book affect the order submission differently.

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The critical part in the limit order trading process is how the agent makes the decision to trade. However, even though interest in limit order trading has grown rapidly in recent years, research in market microstructure has focused primarily on the consequences, rather than the determinants, of a trader's decision *per se*. In fact, most researchers study topics such as the measurement of the transaction cost components or the price formation process.

This study investigates a trader's decision to submit orders. I examine the relationship between the state of the limit order book of a pure, order-driven market and the subsequent trading aggressiveness of the trader's order choices.

My empirical analysis is based on order and transaction data from the Swiss Stock Exchange (SWX), which is a pure, order-driven electronic stock market without market makers. In a quote-driven market, the designated market makers supply liquidity continuously, quoting bid and ask quotes. In an order-driven market, public orders provide liquidity. The Euronext and the Swiss Stock Exchange are among the most successful examples of this microstructure. Indeed, Virt-X, the new pan-European stock market for European blue chips, is based on the SWX technological platform.

In this paper I analyze empirically the order flow and submission in a pure order-driven market. I investigate how the thickness of the limit order book is associated with the incoming trader's decision, the link between spread size and order submission, how a trader's order aggressiveness responds to a higher transient price volatility, whether the speed of the order submission process has some bearing on the subsequent order placement, and whether the trader's willingness to buy and sell responds symmetrically to changes in the limit order book. I provide empirical evidence for the main theoretical models on limit-order markets and the agent's choice between market or limit orders.

The paper proceeds as follows. In Section 1, I describe the main features of the market structure of SWX and my data set. I also perform a preliminary analysis of the order flow. In Section 2, I discuss the research questions that I investigate empirically. Section 3 presents the empirical findings. Section 4 concludes.

## 1. DESCRIPTION OF THE MARKET AND DATA SET

In August 1996, the SWX launched the first electronic trading in Swiss stocks, bonds, and derivatives. This was the first stock market to have a fully integrated trading system that covered the entire spectrum from trade order through to settlement (SWX, 1996). Trading occurs continuously during the trading day via a computerized order book. Two call auctions establish the opening and the closing price at 10 a.m. and 4.30 p.m., respectively.

To enter an order, investors first place their exchange orders with their bank.<sup>1</sup> The order is then fed into the bank's order processing system by the investment consultant, forwarded to the trader in the trading system, and from there transmitted to the exchange system. The exchange system acknowledges receipt of the order with a time stamp and checks its technical validity. There are no market makers or floor traders with special obligations, such as maintaining a fair and orderly market or with differential access to trading opportunities in the market<sup>2</sup>.

The electronic book ranks orders in price-time priority. Traders can place four types of orders: a market order, a limit order, a hidden order<sup>3</sup>, and a fill-or-kill order<sup>4</sup>. Prices are discrete and the tick size changes depend on the price.

There are six ranges of stock prices that define the minimum tick size from a lowest tick of 0.01 in Swiss francs (CHF) to a highest tick of five CHF. The tick size depends on six stock value ranges, which go from CHF 0.01 to 9.99, from ten to 99.95, from 100 to 249.75, from 250 to 499.50, from 500 to 4999 and, from 5000 and up. The related tick sizes are 0.01, 0.05, 0.25, 0.5, one and five.

My data set, which is similar to the TAQ data set (NYSE), contains the history of trades and quotes of 15 stocks quoted on the Swiss Exchange. The sample period covers March and April of 1997. None of the 15 firms experiences any extraordinary change or transformation during the estimation period. For each stock, the tick-by-tick data set reports the transaction data (time stamp, price, and volume in number of shares) and the order flow (time stamp, prevailing quotes, and depth in shares). Thus, the data set provides information on market orders and the best buy and sell limit orders (limit orders at and within the previous quotes), but does not provide data outside the prevailing spread. Also, in my sample I do not consider the opening and closing data. I note that the whole order book is public and available in real time.

During 1997, the SWX was the sixth largest international stock exchange, in terms of both turnover in shares and market capitalization. The turnover and market capitalization were 9.8% and the 6.5%, respectively, of those on the New York Stock Exchange (SWX, 1997). The 15 stocks in my sample correspond to more than 94% and 73% of the total market values of the Swiss Market Index (SMI) and the Swiss Performance Index (SPI), respectively.

Table 1 shows summary statistics of the limit order book across the sample period. I observe that these stocks are very liquid, especially given that the ratio between the actual spread and the minimum tick size is less than two. These results support the previous works on cross-exchange comparisons that show lower trading costs provided by limit order books

(Bessembinder and Kaufman, 1997; and de Jong, Nijman, and Röell, 1995) and Angel's (1997) international comparison showing that the SWX is one of the markets with the lowest transaction costs.

Table 2 shows the unconditional frequency of order submissions ranked by order aggressiveness. To categorize order aggressiveness, I apply the method proposed in Biais, Hillion, and Spatt (1995). I define the most aggressive order as a market order that demands more trading volume than is available at the prevailing quote. The second type of aggressive order is a market order that demands less volume than the quoted depth. The third and fourth order types are limit orders within and at the prevailing quotes, respectively. The least aggressive category is an order cancellation.

Table 2 shows that the majority of the submitted orders comprises small market orders. This result is consistent with the evidence from the Paris Bourse (Biais, Hillion, and Spatt, 1995) and the Toronto Stock Exchange (Griffiths et al., 2000). Table 2 also suggests that buyers more frequently submit limit orders within the quotes. This evidence could be due to the bull market that characterizes the sample period. However, Biais, Hillion, and Spatt (1995) and Griffiths et al. (2000) also find this evidence.

Figure 1 plots the intraday patterns of the components of the order book. The difference between the depth of the buy and the sell sides is clear. Buyers submit a large number of limit orders soon after the opening, but the number of limit orders decreases around noon. In contrast, sellers take one hour before providing the same depth level, but then maintain a more stable liquidity provision over the trading day.

I note that the U.S. markets have a remarkable influence on the afternoon trading of the SWX. This influence becomes evident around 2 p.m. Zurich time. This time corresponds to the

early movements of the U.S. markets such as the opening of the U.S. futures market. It also corresponds to the disclosure time of the main U.S. economic information (Becker, Finnerty, and Friedman, 1995).

Uncertainty in the afternoon trading is also influenced by the U.S. opening at 3:30 p.m. Zurich time, and the subsequent process of price discovery. Consistent with Lee, Mucklow, and Ready (1993) and Kavajecz (1999), I observe that during expected moments of trading uncertainty, limit order traders reduce the market depth and widen the bid-ask spread.

## 2. ORDER SUBMISSION STRATEGIES HYPOTHESES

I test seven hypotheses about order submission strategies. Table 3 summarizes these hypotheses.

*Hypothesis 1:* The thicker the book on the buy (sell) side, the stronger the order aggressiveness of the incoming buyer (seller).

*Hypothesis 2:* The thicker the book on the sell (buy) side, the weaker the order aggressiveness of the incoming buyer (seller).

In Parlour (1998), the execution probability depends on the size of the book and on the agent's belief about further order arrivals. Therefore, an incoming buyer submits a market order when the buy side of the order book is thick. Also, a rational incoming buyer anticipates that a thick book on the sell side is associated with a smaller execution probability for a sell limit order. This so-called crowding-out effect is symmetric and holds for the seller's decision.

In Handa et al. (2000), the thickness of the buy and sell sides of the book is a straightforward proxy of the proportion of high and low-valuation traders. A higher proportion of high-value (low-value) investors raises the buy (sell) competition, making the execution probability of a limit buy (sell) order more uncertain and a buy (sell) market order more attractive<sup>5</sup>.

Empirically, I expect that the coefficients resulting from the ordered probit regression will indicate (1) a positive relation between buyer's (seller's) order aggressiveness and the thickness of the buy (sell) side of the book, and (2) a negative relation between the length of the queue on the sell (buy) side with the trading aggressiveness of the incoming buyer (seller).

*Hypothesis 3:* The wider the spread, the weaker the order aggressiveness.

*Hypothesis 4:* The higher the volatility, the weaker the order aggressiveness.

Foucault (1999) shows that when the volatility increases, limit order traders demand a larger compensation for the risk of being picked off. Thus, the sell (buy) limit order traders increase (decrease) their reservation prices and market order trading becomes more costly. According to Foucault (1999), I expect a positive relation among price volatility, spread size, and the submission of passive orders.

Handa et al. (2000)<sup>6</sup> show that a variation in the proportion of high- and low-value investors alters both the spread size and trading aggressiveness. For instance, a higher proportion of buyers has two main consequences. The higher buyers' aggressiveness yields an overbidding quotation. The sellers' competition in supplying liquidity engenders an undercutting strategy. As a result, disequilibrium between supply and demand lessens the bid-ask spread. Accordingly, I expect to observe a smaller reservation bid-ask spread associated with higher order aggressiveness.

Handa and Schwartz (1996) emphasize that the rationale for an order-driven market is the co-existence of traders who are both eager and patient. Eager traders transact, since they have superior information or liquidity needs. If there are liquidity shocks, the temporary deviation between the quoted and true price provides a profit opportunity for limit order traders.

*Hypothesis 5:* The faster the process of order submission, the less aggressive the incoming order.

Much of the microstructure literature refers to a high trade frequency over a given time. In contrast, I define a fast market by focusing on the amount of time that elapses between consecutive orders. A fast rate of order submission implies a high rate of order arrivals, but not necessarily intense trading. Easley and O'Hara (1992) show that nontrading moments are informative. In the spirit of Easley and O'Hara, the liquidity provider associates a low rate of trades with a low risk of information asymmetry, and thus quotes a thinner spread. Therefore, I expect to observe faster quotation processes associated with more passive orders.

There can be other reasons supporting a negative relationship between trading aggressiveness and rate of order submission. First, Harris (1994) shows that a trading environment based on time priority and a discrete pricing grid provides both a first-mover advantage and competition in supplying liquidity. Second, Admati and Pfleiderer (1988) show that discretionary liquidity traders are better off clustering their trades in specific times.

*Hypothesis 6:* There is symmetry between buyer's and seller's order submissions.

All the models considered above assume symmetry between buyers and sellers. Even though this is a convenient assumption made for tractability, symmetry has several economic implications. Buys and sells have the same probability of being informative and being driven by

retail or institutional traders<sup>7</sup>. If the symmetry assumption holds, then I expect that the coefficients resulting from the probit analysis will be equal for the two sides of the book.

*Hypothesis 7:* Changes in the order book affect the limit and market order trading in opposite ways.

I expect that the changes in the order book marginally affect limit and market order traders in opposite ways<sup>8</sup>. I expect an opposite attitude between “eager traders” who are trading market orders and “patient traders” who are placing limit orders. I expect that the marginal probability of a buy limit (market) order submission will be positive (negative) in response to (1) one more order pending on the buy side, (2) one less order pending on the sell side, (3) one less tick in the spread size, (4) a decrease in transitory volatility, (5) or one less second in the speed of order submission. I expect symmetric results for the sellers.

### 3. EMPIRICAL FINDINGS

#### A. Empirical model

My empirical investigation is an ordered probit technique with a related analysis of the marginal probabilities. Thus, I follow Hausman, Lo, and Mackinlay (1992), who use ordered probit to deal with price discreteness. However, this method has only recently been used for qualitative dependent variables (e.g., Al-Suhaibani and Kryzanowski, 2000; Griffiths, Smith, Turnbull, and White, 2000; and Hollifield, Miller, Sândas, and Slive, 2001).

My empirical model refers to publicly visible information disseminated via an electronic open limit order book at any given moment of the trading day. The information in the order limit

book documents the state of the market and depicts the transient market dynamics. In this environment, many economic agents face the decision problem of order submission conditional on the state of the market. The traders have five choices: a large market order, a small market order, a limit order within the previous quotes, a limit order at the previous quotes, or withdrawing an existing order. The choice among these alternatives captures the trading aggressiveness. Thus, order aggressiveness is an implicit and continuous variable that depends on the trader's unobservable information set, the portfolio allocation, and personal preferences.

Because schedules of liquidity supply slope upward, costs incurred by large trades are *ceteris paribus* larger than those incurred by small trades. In equilibrium, eager traders choose larger orders. This observation explains why I can interpret a large trade as more aggressive than a small trade. The intuitive explanation for ranking a limit order within the quotes as being more aggressive than a limit order at the quotes is that the former demands immediacy.

The independent variables are the depth on the buy and sell sides, the quoted spread, and the order wait processing time. To prevent cross-correlation disturbances and multivariate biases, I analyze the transient volatility in a separate regression<sup>9</sup>.

In what follows, I refer to transaction time, not to clock time. I measure the buy (sell) depth at time  $t$  as the pending volume in number of shares at the highest (lowest) bid (ask). The proxy for the order wait at  $t$  is the average of the time elapsed between the last three subsequent order arrivals (see S andas, 2001). The bid-ask spread is the quoted spread, i.e., the difference between the lowest ask and the highest bid. I calculate the transient volatility at  $t$  recursively as the standard deviation of the most recent 20 continuously compounded midquote returns, i.e., from the return at time  $t-20$  to  $t$ <sup>10</sup>. Table 3 summarizes this notation.

I perform the analysis for the buy and the sell sides separately. Doing so means that for any one stock, I break up the entire time series of the order flow into two subsamples. Each of these subsamples contains the five order types submitted on one side of the book at time  $t$ , and the data of the state of the book immediately before, i.e., at  $t-1$ .

My procedure is as follows: I let  $y_t^{*d}$  be the unobservable continuous variable denoting the order aggressiveness in  $t$ . The partition of the state space allows for mapping order aggressiveness into  $n$  discrete values. Hence,  $y_{n,t}^d$  is the discrete dependent variable in which  $n=1,\dots,5$  indicates the order type and  $d$ , for  $d=B,S$  the side of the book.  $\alpha_i^d$  is the coefficient related to the regressor  $x_{i,t}^d$  where  $i=1,\dots, \ell$ .

Equations (1) and (2) show the ordered probit regression:

$$y_t^{*d} = \sum_{i=1}^{\ell} \alpha_i^d x_{i,t-1}^d + \varepsilon_t^d \quad (1)$$

$$y_{n,t}^d = \begin{cases} 1 & \text{if } -\infty < y_t^{*d} \leq \gamma_1^d \\ m & \text{if } \gamma_{m-1}^d < y_t^{*d} \leq \gamma_m^d \\ 5 & \text{if } \gamma_4^d < y_t^{*d} < \infty \end{cases} \quad \text{for } m = 2,3,4. \quad (2)$$

Equation (1) gives the probit regression for the  $d$  side of the order book in which  $\varepsilon_t^d$  is the independent but *not* identically distributed residuals. Equation (2) shows the state-space partition in which  $\gamma_1^d$  to  $\gamma_4^d$  are the related thresholds.

Table 4 reports the estimates of the ordered probit regressions for one stock and the average estimates for the entire sample. I chose Roche as the representative stock because of its irrelevant price change over the sample period (see Table 1).

Using the results obtained from the ordered probit regression, I can extend my analysis by estimating the cumulative probabilities that any of the five events will occur and estimate the

probability that a specific order type is likely to be submitted. Based on regressions (1) and (2), I estimate the cumulative probabilities as follows:

$$\begin{aligned}
\Pr[y_{i,t}^d = 1] &= \Phi(\hat{\gamma}_1^d - E[x_{i,t}^d] \hat{\alpha}_i^d) \\
\Pr[y_{i,t}^d = m] &= \Phi(\hat{\gamma}_m^d - E[x_{i,t}^d] \hat{\alpha}_i^d) - \Phi(\hat{\gamma}_{m-1}^d - E[x_{i,t}^d] \hat{\alpha}_i^d) \text{ for } m = 2,3,4. \\
\Pr[y_{i,t}^d = 5] &= 1 - \Phi(\hat{\gamma}_4^d - E[x_{i,t}^d] \hat{\alpha}_i^d)
\end{aligned} \tag{3}$$

where  $\Phi(\cdot)$  is the cumulative normal distribution.

I use the unconditional mean of each independent variable over the entire sample as the estimate of  $E[x_i^d]$  and the estimate of each of the thresholds, i.e.,  $\hat{\gamma}_i^d$ . Table 6 shows the cumulative probability changes due to a gradual increase of the spread size. By way of comparison, the table also shows the actual frequencies of order submissions immediately after a given spread size.

I continue my analysis by calculating the marginal effects induced by an incremental variation in one of the order flow components. For instance, I estimate how the probabilities of order placement choices change marginally when the spread size increases by one tick. To do this, I differentiate the probabilities in Equation (3) for one of the independent variables regressed in Equation (1). I find the following marginal probabilities:

$$\begin{aligned}
\frac{\delta \Pr[y_{i,t}^d = 1]}{\delta x_i^d} &= \phi(\hat{\gamma}_1^d - E[x_{i,t}^d] \hat{\alpha}_i^d) (-\hat{\alpha}_i^d) \\
\frac{\delta \Pr[y_{i,t}^d = m]}{\delta x_i^d} &= [\phi(\hat{\gamma}_m^d - E[x_{i,t}^d] \hat{\alpha}_i^d) - \phi(\hat{\gamma}_{m-1}^d - E[x_{i,t}^d] \hat{\alpha}_i^d)] (-\hat{\alpha}_i^d) \text{ for } m = 2,3,4. \\
\frac{\delta \Pr[y_{i,t}^d = 5]}{\delta x_i^d} &= \phi(\hat{\gamma}_4^d - E[x_{i,t}^d] \hat{\alpha}_i^d) (-\hat{\alpha}_i^d)
\end{aligned} \tag{4}$$

In Equation (4),  $\phi(\cdot)$  is the density normal distribution, and  $\hat{\alpha}_i^d$  for  $i=1,..5$  represents the estimated coefficients resulting from Equations (1) and (2).  $E[x_i^d]$  is the regressor's unconditional mean, as before. Table 7 shows the results of the marginal analysis.

My model permits me to perform sensitivity analyses. Following the same logic as in Equations (3) and (4), I can estimate the cumulative and density probabilities for any order-type submission if, all else equal, one component of the limit order book changes. Table 6 shows the changes in probability to a spread increase of one and two ticks. Figures 2 plots the projections of the event probabilities for the Roche stock according to spread size changes.

## B. Main Results

My main results are as follows:

- The outstanding volume in the limit order book is a proxy for the execution probability and influences the trader's choice. Orders are more (less) aggressive when the order queue on the incoming (opposite) trader's side of the book is larger.
- The slower the process of order submission, the less likely the submission of aggressive orders.
- Temporary volatility and a wider spread imply weaker trading aggressiveness.
- Buyers' and sellers' trading behaviors are not perfectly symmetrical.
- The marginal analysis reveals that market order traders and limit order traders have opposite reactions to changes in the order flow components, and that those reactions are monotonic with the order aggressiveness.

### C. Market Depth

The estimates in Table 4 partially support the hypothesis that a thick book strengthens order aggressiveness. From the buyer's point of view, the thicker (thinner) the book on the buy (sell) side, the more aggressive the buy order submission. Table 7 shows that the marginal probability of a buy limit order (market buy order) placement responds negatively (positively) to one more volume pending on the buy side. Thus, these results support the idea that the thickness of the book significantly expresses the traders' execution probability.

Further support for hypothesis 1 and 2 comes from Table 2, which reports that the use of market orders is more frequent when the pending volume on the same side as the incoming trader exceeds the pending volume on the opposite side. These results support the evidence that the market depth in a given moment is negatively correlated with the successive market order submission<sup>11</sup>.

### D. Order Book Symmetry

In the microstructure literature, there is little evidence on whether the thickness of the two book sides affects the sellers' and buyers' decisions symmetrically<sup>12</sup>. The results in Table 4 present evidence against symmetry. In fact, the coefficient that relates the incoming trader aggressiveness and the thickness of the book shows that buyers are more concerned about the opposite side of the book, while sellers are more concerned about their own side. Table 7 shows that incoming buyers (sellers) have higher marginal reactions to depth variations in the sell (buy) side. These results may suggest that traders who are willing to purchase adjust their order submissions to the available liquidity supply more promptly than do traders who are willing to sell.

I provide two main explanations for these differences between buyers' and sellers' behaviors: (1) the market performance during the sample period, and (2) buyers and sellers behave differently because of liquidity and institutional trading.

*Market Performance.* I argue that the asymmetry between the buyers' and sellers' behaviors could be primarily due to the positive market performance over the sample period. I verify this argument by analyzing the buyers' and the sellers' order submissions during up and down markets. To do this, I divide the trading day into 13 half-hour periods. I identify the intraday market movements by comparing the midquote price at the beginning and at the end of these periods. The dummy variable  $d_{p,i} = 1$  ( $d_{p,i} = 0$ ), in which  $p = 1, \dots, 13$  refers to the intraday periods, indicates that the market moves up (down). I call the upward (downward) price movement a bull (bear) market. Thus, Equation 1 becomes:

$$y_t^{*d} = \sum_{i=1}^I \alpha_i^d X_{i,t-1}^d d_{p,i} + \varepsilon_t^d \quad (5)$$

Table 5 further supports differences in the buyers' and sellers' trading behaviors. In particular, Table 5 shows that:

- A thick book in the buy (sell) side is associated with a higher buyer (seller) aggressiveness in a bull (bear) market, since the competition in demanding (providing) assets (liquidity) decreases the execution probability.
- The sell (buy) side of the book is less significant for the incoming buyer (seller) during bear (bull) markets. That is, the direction of the market movement determines how important the opposite side of the book is.

- The volatility and the buyers' aggressiveness are positively related when the market is moving up, and negatively related when the market goes down. The opposite relation holds for the sellers. Order aggressiveness and price volatility generally move together.
- The link between the spread size and the buyers' (sellers') aggressiveness is more relevant in bear (bull) markets. The direction of the price pressure generally determines uncertainty on the counterpart side of the market.

*Liquidity and Institutional Trading.* Griffiths et al. (2000) argue that buyers have more information motives to trade. Saar (2001) shows that institutional trading on the buy side of the book is more likely to be information-motivated. If a higher proportion of information-motivated trading is a characteristic of the buy side of the book, then I expect to observe systematic differences in trading behaviors between buyers and sellers. I test these differences empirically through two variables, the bid-ask spread and order autocorrelation.

Table 2 shows that the average spread size for an incoming seller is always slightly larger than it is for an incoming buyer. The table also reports that an incoming seller faces a wider spread regardless of the order type she or he submits. These results might indicate that sellers have a higher risk of transacting against an informed trader.

To take a straightforward approach to comparing the buyers' and sellers' order autocorrelations, in table 8 I test the 12 predictions derived from the Parlour model (1998)<sup>13</sup>. I find that for any kind of combination, the orders submitted by buyers always have a higher probability of continuation than do those placed by sellers. Biais et al. (1995) and Hamao and Hasbrouck (1995) also find order persistence, and suggest that the order continuation might depend on information motives.

The evidence of a higher spread and a lower autocorrelation for sell orders suggests that agents trading on the sell side of the book more frequently act as liquidity suppliers. The dynamic analysis in Table 6 and Figures 2 suggests that sellers take the role of liquidity suppliers even in presence of high market uncertainty.

#### E. Spread and Volatility

The empirical findings in Table 2 and 4 support Hypotheses 3 and 4 that transient volatility encourages (discourages) limit (market) order trading, and that when the spread size widens, the aggressive order submission is less likely. Also, this effect is more marked for the sellers. Further support comes from the dynamic analysis showing that the higher the market uncertainty, the higher the quotation of limit orders (see Table 6).

The results in Table 4 support the Foucault model (1999), which shows that an increase in volatility determines an enlargement of the limit order traders' reservation spreads. These results support those of Handa and Schwartz (1996) and Harris and Hasbrouck (1996), who show that short-run volatility due to liquidity events provides a profit opportunity for liquidity traders. My findings are also in line with Hollifield et al. (2001), who show that the probability of successive market orders decreases with the spread size. Ahn, Bae, and Chan (2001) and Chung, Van Ness, and Van Ness (1999) also find that limit order submission is more likely after a period of intraday volatility.

#### F. The Order Processing Wait

Hypothesis 5 states that a fast quotation process indicates the submission of less aggressive orders. Table 4 shows that fast order submissions are driven by more passive orders.

Also, Biais et al. (1995) find that the average time that elapses between subsequent orders is lowest when the spread is wide. Both results suggest that traders actively monitor the book and exploit temporary opportunities associated with a wider spread size.

My results are also in line with the empirical findings in Lo, MacKinlay, and Zhang (1997) and Engle and Lunde (1999). In fact, Lo et al. (1997) find that the two determinants of order aggressiveness, i.e., the order size and the limit order price, increase the expected time-to-execution. Engle and Lunde (1999) find that quote arrivals are more frequent in the absence of rapid price revisions, but fast trading is likely to be related to slow order placement.

#### H. Eager and patient traders

As in Glosten (1994), I define eager and patient traders as market and limit order submitters, respectively. However, an eager trader does not necessarily mean an information-motivated trader. Eager and patient traders may have very different reasons for trading. In the Chakravarty and Holden (1995) model, informed traders can submit market or limit orders. By extending the trader's choices, Chakravarty and Holden show the complexity of the optimal trading strategy. An informed trader may optimally choose any combination of market and limit orders.

The marginal analysis in table 7 shows that the behaviors of limit and market order traders are opposite. In fact, a change in the order book is associated with a positive marginal probability for eager traders and a negative marginal reaction for patient traders, and vice versa. This switching occurs between traders who place limit orders within the quotes and traders who submit small market orders, i.e., the most and the least aggressive category of patient and eager traders.

Table 7 warrants two other comments. First, that the marginal reactions are monotonically related to order aggressiveness. Second, that the cumulative and marginal probabilities are sensitive to the market conditions. The sensitivity analysis depicted in Figure 2 and in Table 6 shows that the submission probabilities depend critically on the state of the market.

#### 4. CONCLUSION

I investigate the relationship between trading aggressiveness and order flow in a pure, order-driven market. Using a unique data set from the Swiss stock exchange, my study shows that the state of the order book has a dynamic effect on a trader's quotation decisions.

The paper shows that:

- The thickness of the limit order book is a proxy for the execution probability of an incoming trader. The thickness on the same side of an incoming trader strengthens her/his trading aggressiveness, but the thickness on the opposite side weakens her/his trading aggressiveness.
- Fast order submission is driven more by passive orders.
- Transient volatility and a wider spread encourage limit order placement and discourage market order submission. Furthermore, price return volatility and the trader's aggressiveness move in the same direction.
- Market order traders and limit order traders have an opposite reaction to changes in market conditions.

These results demonstrate that both sides of the book are important in determining an agent's order choice, and that traders actively react to changes in the execution probability. Thus, I show that a limit order book market runs on a continuous adjustment process between the

liquidity demanders and suppliers. This mechanism relies on the motives that underlie aggressive trading. On one hand, a positive order volume imbalance signals the prevalence of demanders. This imbalance engenders an upward price pressure, a positive transitory volatility, and a tighter spread. Under these market conditions, buyers (sellers) face a smaller (higher) execution probability and raise (lessen) their order aggressiveness. On the other hand, the equilibrium between demand and supply is associated with weak trading aggressiveness, a balanced order book, smoothed price fluctuations, and a slackened spread.

My analysis provides insights on the systematic differences between the buy and sell sides of the order book. Prior to the submission of any type of sell orders, the book always shows a larger spread and a thicker sell side. Also, buy orders are more autocorrelated than are sell orders. After controlling for these results, I find that poorer information and a higher proportion of institutional trading might characterize seller's trading.

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Table 1. The Main Statistics of the Limit Order Book

This table reports the main sample statistics averaged over the sample period. *Order wait* is the elapsed time in seconds between one order and the next. *Buy (sell) depth* is the number of shares available at the highest (lowest) bid (ask) quote. *Buy and Sell depth in value* refer to the buy and sell depth in value (in thousands of Swiss francs, CHF). *Midquote* is the mid-price in CHF. The *%P change* is the percentage stock price change over the sample period. The *actual spread* is the difference between the prevailing ask and bid quotes in CHF. The *relative spread* is the actual spread divided by the midquote times 100. The *spread over tick* represents the ratio between actual spread and tick size. The *volatility* is the standard deviation of the last 20 midquote returns times 1,000.

STOCK	Order Wait	Buy Depth	Buy Depth in Value	Sell Depth	Sell Depth in Value	Midquote	%P Change	Actual Spread	Relative Spread	Spread over Tick	Volatility
Novartis	14.0	479.0	868.6	576.0	1047.0	1813.9	10.9	1.533	0.085	1.533	0.250
Roche	15.4	55.3	668.5	61.2	742.1	12110.4	0.3	10.480	0.087	2.096	0.250
Nestlé	18.4	444.2	751.9	529.5	898.6	1696.1	12.4	1.536	0.091	1.536	0.270
UBSn	21.5	665.6	871.1	872.8	1148.8	1305.0	9.8	1.549	0.119	1.549	0.350
CS	24.2	7857.3	1301.3	9109.4	1510.7	165.7	0.6	0.323	0.195	1.290	0.510
Ciba	25.8	4295.8	514.2	7188.5	868.2	119.9	0.9	0.328	0.274	1.313	0.590
SwissRe	32.1	330.1	508.1	381.2	588.7	1542.7	10.2	1.650	0.107	1.650	0.310
ABB	35.7	274.5	477.4	284.3	495.1	1737.6	3.9	2.023	0.117	2.023	0.310
Wint.	37.1	486.2	490.9	556.5	565.8	1013.0	6.5	1.864	0.184	1.864	0.520
SBV	37.9	2856.4	870.0	3404.6	1042.3	303.5	7.8	0.646	0.213	1.292	0.540
Zurich	45.6	1228.1	557.0	1406.7	639.2	454.7	8.5	0.774	0.170	1.549	0.480
Alus.	58.1	322.2	388.9	382.4	462.0	1208.1	5.0	1.894	0.157	1.894	0.480
Clariant	59.5	329.6	251.4	371.7	288.5	761.3	16.4	1.991	0.265	1.991	0.750
UBSb	79.6	252.2	247.2	295.7	290.6	974.8	9.4	2.449	0.253	2.449	0.710
SMH	121.2	1049.4	202.7	1047.8	202.7	193.9	-1.0	0.615	0.318	2.459	0.910
Mean	41.7	1395.1	597.9	1764.6	719.4	1693.4	6.8	1.977	0.176	1.766	0.482

Table 2. Statistics of Order Submissions

The left-hand side of this table shows the unconditional frequencies of the different order submissions, which I define according to the Biais et al. (1995) method. The “*Absolute Freq.*” and “*Relative Freq.*” columns show the absolute and relative frequency of the five order submissions. The right-hand side of this table shows the state of the order book before an order submission. *Buy (Sell) Depth* means the buy (sell) the depth in number of shares, *Spread* is the actual spread in CHF, *Wait* is the time in seconds that elapses between the order at t and t-1, and *Volat.* is the standard deviation of the last 20 midquote returns times 1,000. BUYER (SELLER) refers to the buyer’s (seller’s) order submissions.

BUYER	Order Type	Absolute Freq.	Relative Freq.	Buy Depth	Sell Depth	Spread	Wait	Volat.	
Large Buy	1	20410	6.5	1510.5	1393.4	1.609	41.6	0.470	
Small Buy	2	91008	28.8	1348.6	1786.3	1.680	45.61	0.450	
Bid Within	3	24286	7.7	1886.8	2013.3	3.071	38.1	0.510	
Bid At	4	25984	8.2	986.7	1948.3	1.994	33.71	0.460	
Cancellation	5	11475	3.6	1445.3	1672.2	1.890	34.44	0.470	
Total		173163	54.9						
				Mean	1354.5	1795.6	1.946	41.42	0.472

SELLER	Order Type	Absolute Freq.	Relative Freq.	Sell Depth	Buy Depth	Spread	Wait	Volat.	
Large Sell	1	18678	5.9	1862.9	1051.8	1.658	45.03	0.470	
Small Sell	2	66631	21.1	1680.4	1429.3	1.737	45.87	0.460	
Ask Within	3	22611	7.2	2258.1	1591.6	3.083	37.26	0.510	
Ask At	4	24544	7.8	1272.4	1500.6	2.022	35.17	0.460	
Cancellation	5	9946	3.2	1775.2	1370.8	1.926	32.83	0.480	
Total		142410	45.1						
				Mean	1687.1	1417.3	2.029	41.74	0.476

**Table 3. Definitions of Explanatory Variables and Hypotheses to Test**

This table provides the abbreviation and description for each explanatory variable analyzed in this paper. The table also shows the seven hypotheses and the underpinning models tested thereafter.

**Abbreviation Variables**

<i>samevol</i>	Pending volume in number of shares divided by 10,000 at the best quote on the same side of the market as the incoming trader
<i>opvol</i>	Pending volume in number of shares divided by 10,000 at the best quote on the opposite side of the market with respect to the incoming trader
<i>spread</i>	Quoted spread as the difference between the lowest ask and the highest bid quotes
<i>wait</i>	Average waiting time in seconds between the last 3 subsequent orders, divided by 100
<i>volat</i>	Transitory return volatility as the standard deviation of the last 20 midquote returns

**Hypotheses Prediction**

Hypothesis 1	<i>samevol</i> positively related to order aggressiveness
Hypothesis 2	<i>opvol</i> negatively related to order aggressiveness
Hypothesis 3	<i>spread</i> negatively related to order aggressiveness
Hypothesis 4	<i>volat</i> negatively related to order aggressiveness
Hypothesis 5	<i>wait</i> is positively related to order aggressiveness
Hypothesis 6	symmetry between buyer's and seller's order submissions
Hypothesis 7	limit and market order traders have opposite behaviors

**Related literature**

Handa et al. (2000), Parlour (1998)
Handa et al. (2000), Parlour (1998)
Foucault (1999), Handa et al. (2000)
Foucault (1999), Handa and Schwartz (1996)
Easley and O'Hara (1992)

Table 4. Ordered Probit Regressions

This table shows the estimates of the ordered probit regressions. The dependent variable is order aggressiveness ranked from the most to the least aggressive order submission. Hence, a negative estimated coefficient means that the explanatory variable is positively related to order aggressiveness. The regressors are the depth on the same side of the incoming trader (*samevol*) and the depth on the opposite side (*opvol*), the spread (*spread*), and the order wait (*wait*). I analyze the price volatility (*volat*) in a separate regression.  $\gamma_i$ , for  $i=1$  to 4, which refers to the probit thresholds. The right (left) side the table shows the average sample value of the estimated coefficients (Roche stock). BUYER (SELLER) refers to the buyer's (seller's) order submissions. t-stat means the  $t$ -statistic and Sig. 1% refers to the number of coefficients significant at the 1% level.

ROCHE	BUYER		SELLER		SAMPLE	BUYER		SELLER	
	Coeff	t-Stat	Coeff	t-Stat		Coeff	Sig. 1%	Coeff	Sig. 1%
<i>samevol</i>	-2.760	-2.587	-3.170	-2.566	<i>samevol</i>	-0.796	11	-0.328	8
<i>opvol</i>	5.140	4.964	-3.710	-3.725	<i>opvol</i>	0.868	12	-0.061	6
<i>spread</i>	0.038	32.494	0.026	22.548	<i>spread</i>	0.403	15	0.395	15
<i>wait</i>	-0.137	-3.164	-0.233	-4.600	<i>wait</i>	-0.100	11	-0.146	13
$\gamma_1$	-0.789	-41.341	-0.802	-38.283	$\gamma_1$	-0.905	15	-0.857	15
$\gamma_2$	0.793	40.975	0.406	19.404	$\gamma_2$	0.711	15	0.577	15
$\gamma_3$	1.286	64.007	0.949	44.208	$\gamma_3$	1.162	15	1.061	15
$\gamma_4$	1.920	88.655	1.634	70.923	$\gamma_4$	1.861	15	1.822	15
ROCHE	BUYER		SELLER		SAMPLE	BUYER		SELLER	
	Coeff	t-Stat	Coeff	t-Stat		Coeff	Sig. 1%	Coeff	Sig. 1%
<i>volat</i>	250.14	4.139	361.49	5.762	<i>volat</i>	150.18	12	154.623	8
$\gamma_1$	-1.067	-58.059	-0.889	-44.993	$\gamma_1$	-1.147	15	-1.081	15
$\gamma_2$	0.452	25.847	0.284	14.950	$\gamma_2$	0.415	15	0.310	15
$\gamma_3$	0.929	51.348	0.816	41.647	$\gamma_3$	0.854	15	0.786	15
$\gamma_4$	1.571	78.244	1.506	69.206	$\gamma_4$	1.568	15	1.551	15

Table 5: Order Aggressiveness During Upward and Downward Markets

This table shows the estimates of the ordered probit regressions in which I use dummy variables to find the differences in the order submission between upward and downward markets. The dependent variable is order aggressiveness ranked from the most to the least aggressive order submission. Hence, a negative estimated coefficient means that the explanatory variable is positively related to order aggressiveness. The regressors are the depth on the same side of the incoming trader (*samevol*) and the depth on the opposite side (*opvol*), the spread (*spread*), and the order wait (*wait*). I analyze price volatility (*volat*) in a separate regression. I divide the trading day into 13 half-hour periods. I identify the intraday market movements by comparing the midquote price at the beginning and at the end of these periods. The resulting piecewise dummy variables allow me to capture the differences in the order submission during up and down markets. BUYER (SELLER) refers to the buyer's (seller's) order submissions. BULL (BEAR) refers to an upward (downward) market. On the right (left) side the table shows the average sample values of the estimated coefficients (Roche stock). *t*-Stat means the *t*-statistic and Sig. 1% refers to the number of coefficients significant at the 1% level.

	ROCHE BUYER				SAMPLE BUYER				
	BULL		BEAR		BULL		BEAR		
	Coeff	t-Stat	Coeff	t-Stat	Coeff	Sig. 1%	Coeff	Sig. 1%	
<i>samevol</i>	-8.550	-5.32	-0.521	-0.37	<i>samevol</i>	-1.893	14	-1.558	11
<i>opvol</i>	-2.890	-2.16	-8.310	-6.24	<i>opvol</i>	-0.351	4	0.199	2
<i>spread</i>	0.023	17.87	0.023	18.66	<i>spread</i>	0.207	14	0.245	15
<i>wait</i>	-0.383	-6.96	-0.590	-10.48	<i>wait</i>	-0.239	14	-0.260	15
<i>volat</i>	70.241	1.38	88.798	1.91	<i>volat</i>	-46.817	4	132.422	11
	ROCHE SELLER				SAMPLE SELLER				
	BULL		BEAR		BULL		BEAR		
	Coeff	t-Stat	Coeff	t-Stat	Coeff	Sig. 1%	Coeff	Sig. 1%	
<i>samevol</i>	-5.190	-2.96	-9.500	-5.60	<i>samevol</i>	-0.976	12	-1.243	10
<i>opvol</i>	-4.700	-2.85	-6.660	-5.81	<i>opvol</i>	-0.464	2	-1.088	5
<i>spread</i>	0.024	16.92	0.015	13.08	<i>spread</i>	0.262	15	0.193	15
<i>wait</i>	-0.609	-8.45	-0.365	-6.27	<i>wait</i>	-0.292	14	-0.273	15
<i>volat</i>	304.66	5.41	-6.678	-0.14	<i>volat</i>	167.63	11	-62.142	6

**Table 6. Actual and Simulated Cumulative Probabilities of Order Submissions Conditional on the Spread Size**

This table shows the actual frequencies (*Actual*) of the five order submissions conditional on four spread sizes before the incoming order. The spread sizes are one, two, three, and four ticks. For the Roche stock these spread sizes correspond to CHF 5, 10, 15, and 20, respectively. For any actual data, the table shows corresponding simulated data (*Simulated*), which I calculate by using the estimated coefficients from the probit regressions. On the left (right) side the table shows the average sample values (the Roche stock). The upper (lower) part of the table shows the results for the buyer's (seller's) order submissions. I denote the submission of a large (small) market order as Large (Small) MO. I denote the submission of a limit order within (at) the prevailing quotes is as LO Within (At). Cancel indicates order cancellation. The Table also provides two rows titled "*# of obs*" which report the actual data for the total number of observations.

<b>SAMPLE</b>						<b>ROCHE</b>			
<b>BUYER</b>									
Actual	Spread	1tick	2ticks	3ticks	4ticks	5	10	15	20
	Large MO	0.150	0.089	0.066	0.063	0.180	0.114	0.071	0.061
	Small MO	0.636	0.440	0.318	0.252	0.643	0.507	0.377	0.332
	LO Within	0.000	0.248	0.410	0.493	0.000	0.177	0.333	0.395
	LO At	0.141	0.159	0.152	0.147	0.112	0.137	0.140	0.149
	Cancel	0.073	0.064	0.055	0.045	0.064	0.065	0.078	0.064
	# of obs	93285	53677	16532	5825	9156	6919	2996	1504
Simulated	Spread	1tick	2ticks	3ticks	4ticks	5	10	15	20
	Large MO	0.160	0.094	0.066	0.046	0.196	0.123	0.089	0.062
	Small MO	0.663	0.512	0.455	0.391	0.668	0.540	0.503	0.455
	LO Within	0.000	0.153	0.165	0.170	0.000	0.156	0.174	0.186
	LO At	0.125	0.160	0.193	0.220	0.094	0.120	0.147	0.175
	Cancel	0.051	0.080	0.121	0.173	0.041	0.061	0.087	0.121
<b>SELLER</b>									
Actual	Spread	1tick	2ticks	3ticks	4ticks	5	10	15	20
	Large MO	0.174	0.102	0.068	0.056	0.236	0.149	0.088	0.083
	Small MO	0.591	0.382	0.271	0.232	0.538	0.393	0.291	0.265
	LO Within	0.000	0.273	0.434	0.521	0.000	0.218	0.369	0.409
	LO At	0.159	0.176	0.171	0.149	0.149	0.162	0.165	0.157
	Cancel	0.075	0.068	0.056	0.042	0.077	0.079	0.087	0.086
	# of obs	74356	44646	14786	5293	6309	5245	2533	1320
Simulated	Spread	1tick	2ticks	3ticks	4ticks	5	10	15	20
	Large MO	0.184	0.107	0.077	0.055	0.252	0.163	0.133	0.107
	Small MO	0.619	0.457	0.402	0.342	0.564	0.426	0.405	0.380
	LO Within	0.000	0.172	0.182	0.184	0.000	0.189	0.200	0.208
	LO At	0.144	0.183	0.219	0.247	0.128	0.148	0.168	0.189
	Cancel	0.053	0.081	0.121	0.172	0.057	0.073	0.093	0.117

Table 7. Marginal Reactions to a Change in the Limit Order Book

This table shows the estimates of the marginal probabilities for the five order submissions. I denote the submission of a large (small) market order as Large (Small) MO. I denote the submission of a limit order within (at) the prevailing quotes as LO Within (At). Cancel indicates order cancellation. BUYER (SELLER) refers to the buyer's (seller's) order submissions. The lower (upper) part of this table shows the results for the average sample values (Roche stock). To calculate these probabilities, I use the estimated coefficients resulting from the probit regressions, and the unconditional mean of the explanatory variables. The explanatory variables are the depth on the same side of the incoming trader (*samevol*) and the depth on the opposite side (*oppvol*), the spread (*spread*), the order wait (*wait*), and the transitory volatility (*volat*).

ROCHE	BUYER					SELLER				
	<i>Samevol</i>	<i>oppvol</i>	<i>spread</i>	<i>wait</i>	<i>volat</i>	<i>samevol</i>	<i>oppvol</i>	<i>spread</i>	<i>wait</i>	<i>volat</i>
Large MO	0.819	-1.469	-0.008	0.041	-52.762	0.939	1.102	-0.006	0.070	-89.090
Small MO	-0.003	-0.006	-0.006	-0.002	-39.715	0.021	0.024	-0.004	0.014	-52.512
LO Within	-0.032	0.060	0.004	-0.016	23.952	-0.037	-0.043	0.002	-0.027	30.585
LO At	-0.030	0.059	0.005	-0.015	36.568	-0.047	-0.054	0.004	-0.034	57.901
Cancel	-0.017	0.034	0.005	-0.008	31.958	-0.032	-0.037	0.004	-0.023	53.116
SAMPLE	BUYER					SELLER				
	<i>samevol</i>	<i>oppvol</i>	<i>spread</i>	<i>wait</i>	<i>volat</i>	<i>samevol</i>	<i>oppvol</i>	<i>spread</i>	<i>wait</i>	<i>volat</i>
Large MO	0.222	-0.228	-0.067	0.027	-30.128	0.096	0.022	-0.070	0.042	-32.620
Small MO	0.018	-0.048	-0.080	0.003	-24.638	0.015	0.006	-0.081	0.005	-26.906
LO Within	-0.085	0.098	0.026	-0.009	10.633	-0.030	-0.008	0.025	-0.015	11.166
LO At	-0.102	0.113	0.067	-0.014	23.581	-0.052	-0.009	0.075	-0.022	27.592
Cancel	-0.053	0.066	0.054	-0.007	20.553	-0.029	-0.011	0.052	-0.010	20.768

Table 8. Order Sequences

I define BMO (SMO) as a buy (sell) market order, and BLO (SLO) as a buy (sell) limit order. I do not distinguish between large and small market orders or between limit orders with a limit price within or at the previous quoted prices. The sequences 1-4 refer to the trades conditional on the preceding order submission. The sequences 5-8 refer to the sell limit orders conditional on the preceding order submission. The sequences 8-12 refer to the buy limit orders conditional on the preceding order submission. The column titled “# obs” reports the absolute frequencies and the column titled “mean” refers to relative frequencies. The column titled “Prediction” indicates the predictions in the Parlour model (1998), and the column titled “Proportion of Stocks” reports the proportion of the stocks consistent with those predictions.

Sequence		# obs	mean	Prediction	Proportion of Stocks
1	SMO <sub>t</sub>   SMO <sub>t-1</sub>	27708	0.218		
2	SMO <sub>t</sub>   BMO <sub>t-1</sub>	27280	0.215	1 > 2	8 / 15
3	BMO <sub>t</sub>   BMO <sub>t-1</sub>	45491	0.358		
4	BMO <sub>t</sub>   SMO <sub>t-1</sub>	26426	0.208	3 > 4	15 / 15
5	SLO <sub>t</sub>   SLO <sub>t-1</sub>	8029	0.187		
6	SLO <sub>t</sub>   SMO <sub>t-1</sub>	13366	0.312	5 < 6	15 / 15
7	SLO <sub>t</sub>   BLO <sub>t-1</sub>	6476	0.151	6 < 7	0 / 15
8	SLO <sub>t</sub>   BMO <sub>t-1</sub>	15037	0.350	7 < 8	15 / 15
9	BLO <sub>t</sub>   BLO <sub>t-1</sub>	8910	0.195		
10	BLO <sub>t</sub>   BMO <sub>t-1</sub>	17467	0.383	9 < 10	15 / 15
11	BLO <sub>t</sub>   SLO <sub>t-1</sub>	6294	0.138	10 < 11	0 / 15
12	BLO <sub>t</sub>   SMO <sub>t-1</sub>	12965	0.284	11 < 12	15 / 15

Figure 1. Intraday Patterns. This graph shows the standardized intraday patterns of buy volumes (BUYVOL), sell volumes (SELLVOL), and actual spread (SPREAD). The graph refers to the Swiss time, i.e., the GMT plus one hour. The trading day comprises 13 periods of 30 minutes each, from 10 a.m. until 4:30 p.m. The buy (sell) volume is the cumulated number of shares at the highest (lowest) bid (ask) quotes over intervals of 30 minutes. The spread is the average actual spread over intervals of 30 minutes. My standardization procedure subtracts the mean and dividing by the standard deviation.

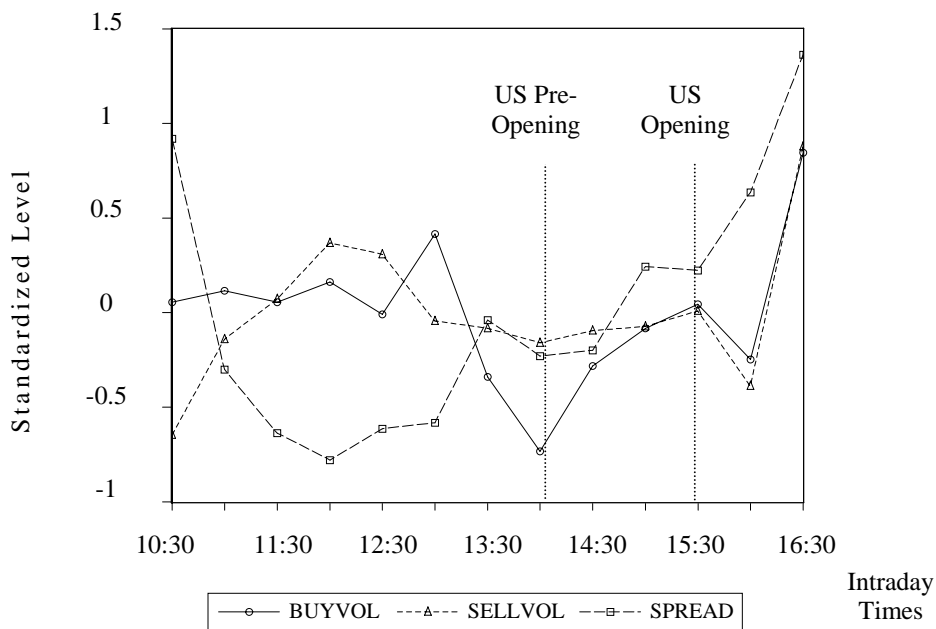
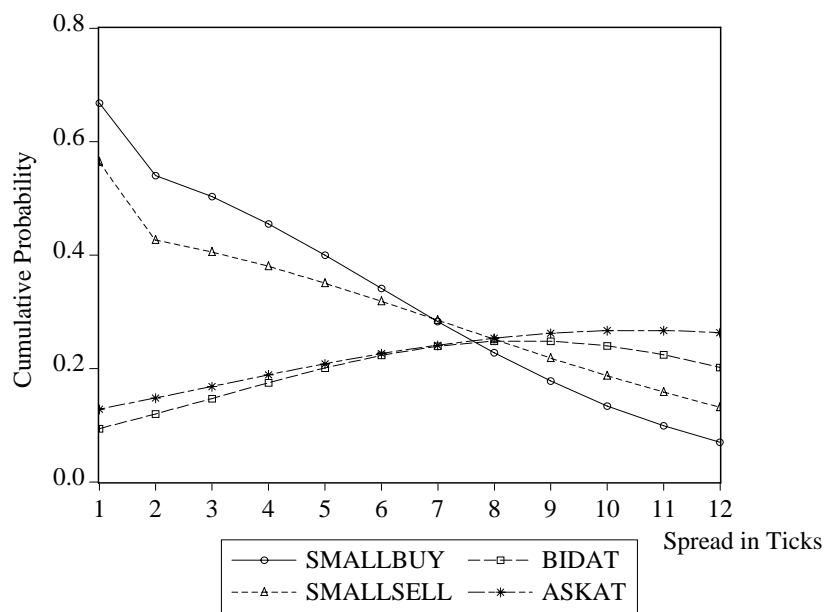


Figure 2. Sensitivity Analysis of Market and Limit Order Quotations to Spread Size Changes. This graph depicts the simulated cumulative probabilities of market and limit orders quotations for the Roche stock. First, I run the ordered probit regression. Next, I use the estimated coefficients to calculate the probability changes of the order submissions to an increasing spread size. The horizontal axis represents the spread size in ticks. The vertical axis shows the cumulative probabilities for the submission of a small buy and sell market order (*smallbuy* and *smallsell*), and the cumulative probabilities for the placement of a buy and sell limit order at the prevailing quotes (*bidat* and *askat*).



ENDNOTES:

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<sup>1</sup> Commissions are negotiable. In 1997, the banks' commission was at 80-120 CHF for an order value less than 50,000 CHF. For larger order, the commission was 0.1-0.11% of the order value.

<sup>2</sup> In this aspect, the SWX differs from the Paris Bourse that sets up special agreements with intermediaries (member firms) called animateurs. Animateurs undertake to ensure orderly trading in a given security and, more specifically, a maximum size for the bid-ask spread and a minimum depth in the limit order book (Paris Bourse, 1999). Demarchi and Foucault (1999) provide a survey of the microstructure differences among the SWX, the Paris Bourse, and other European exchange systems.

<sup>3</sup> Hidden order corresponds to an order above 200,000 CHF. The hidden order may be traded outside the market, but must be announced within a half-hour.

<sup>4</sup> Fill or kill order must be completely matched in order to create a trade, otherwise it is cancelled.

<sup>5</sup> Hollifield, Miller, and Sândas (2002) also use a rational expectations assumption to analyze the trader's optimal order submission. They find that the trader's optimal strategy depends on her/his valuation for the asset and subjective beliefs about the probability that a limit order be executed.

<sup>6</sup> In Handa et al. (2000), the spread changes may be due to several reasons. However, only a variation in the proportion of demanders and suppliers strengthens order aggressiveness and lessens the spread size.

<sup>7</sup> Saar model (2001) allows asymmetry between buys and sells.

<sup>8</sup> Hypothesis 7 can be seen as a direct implication of Parlour model (1998).

<sup>9</sup> I note that when I carry out the multivariate regression by including the transient volatility among the regressors, the coefficient for the volatility variable is significant and negative. In contrast, when transitory volatility is analyzed in a separate regression, the coefficient is significant and positive. The most obvious explanations are statistical issues such as collinearity and multivariate biases. But even after an orthogonalization test, the transient volatility in the multivariate regression keeps a negative and significant coefficient. A possible economic interpretation comes from the wider information set of the incoming trader in the multivariate case.

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<sup>10</sup> The Foucault model (1999) formally refers to the expectation on true price changes. I implicitly assume that the standard deviation over the last 20 mid-price changes reflects the expectation of the true price fluctuation. I checked the robustness of this proxy by comparing alternative measures of transient volatility. In particular, I examined the standard deviation over 30 and 50 price returns. The alternative measures of transient volatility yield very similar results.

<sup>11</sup> See Ahn, Bae, and Chan (2001); Chung, Van Ness, and Van Ness (1999); Griffiths et al. (2000); and Hollifield et al. (2001).

<sup>12</sup> The study of Hedvall, Niemeyer and Rosenqvist (1997) is a partial exception.

<sup>13</sup> The results in table 8 only partially corroborate the Parlour's predictions. The main support I find is that the continuation in the same direction of limit orders occurs less frequently than does the change in direction or any increase in order aggressiveness (e.g., a sell limit order followed by a sell or a buy market order). Contrary to the Parlour's predictions, a sequence of limit orders in opposite directions is not more likely than a market order followed by a limit order in the same direction.