Determinants of Order Choice on the New York Stock Exchange

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Abstract

Using New York Stock Exchange order data, we examine the determinants of order strategy. We consider order type (market and limit), order side, the choice between automatic executions and the auction process, order pricing aggressiveness, order cancellation, and the passage of time without order activity. Our multinomial logit specification and new statistical test of impulse sensitivities allow us to comprehensively test order-submission theory. We find that: 1.) both order activity and inactivity are clustered; 2.) wider (narrower) spreads increase the probability of limit (marketable) orders; 3.) larger quoted depth elicits competition to supply liquidity; 4.) positive (negative) market returns produce more buy (sell) orders; 5.) positive serial correlation exists in order type; 6.) favorable (unfavorable) private information increases the likelihood of buy (sell) orders; and, 7.) limit orders are more likely late in the trading day. Our results become richer when we consider orders' pricing aggressiveness.

Keywords: Limit order, market order, liquidity, order flow.

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Section 1: Introduction

Characterizing a trader's order submission strategy can provide insights into fundamental issues of how security markets function. Order arrivals play an important role in the supply of and demand for liquidity on the New York Stock Exchange (NYSE). Typically, we assume that market orders demand liquidity and that limit orders supply liquidity. Although specialists and floor brokers provide liquidity, public limit orders are a critical part of the NYSE's displayed liquidity. Kavajecz (1999) finds that public limit orders are represented in 64% of NYSE specialists' quotes. Recent NYSE initiatives, such as Direct+ and OpenBook, have increased public limit orders' importance. If we can characterize market conditions under which traders demand liquidity and those under which (and at what prices) they supply liquidity, then we can better appreciate the price formation process – markets' most important role. In addition, a trader's order submission strategy affects execution quality. The Securities and Exchange Commission has given order execution quality substantial recent attention (e.g., SEC 2001b). Understanding when a trader submits a particular order might be a step toward designing an optimal order submission strategy. We use NYSE order data in the decimal pricing environment to document traders' electronic order submission in a representative sample of 148 securities.

Extant theoretical work describes a trader's choice between market and limit orders. Cohen, Maier, Schwartz, and Whitcomb (1981), Harris (1998), and Foucault (1999) suggest that market orders become more attractive and limit orders less attractive as the quoted bid-ask spread narrows. Parlour (1998) posits that the current depth on each side of the quote and the most recent change in that depth influence the market-limit choice. Specifically, she argues that the likelihood of observing a limit order on a given side of the book is inversely (directly) related to the depth on that side (opposite side) of the book. Foucault (1999) predicts that the fraction of limit orders in the order flow increases in security-price volatility. Hollifield, Miller, and Sandas (1999) postulate that a security's own price and the market index level affect traders' strategies. Several models suggest that the time remaining in the trading day impacts order choice. For example, Harris (1998) and Hollifield, Miller, and Sandas (1999) argue that informed traders become more aggressive as the end of the day approaches.

We use NYSE system order data to estimate a multinomial logit model of order choice based on extant theoretical work. Our analysis estimates the likelihood of observing a no order activity time interval (similar to the no-trade interval in Easley, Kiefer and O'Hara, 1997), an order's cancellation, and the arrival of an order of a particular type, on a specific side of the market, and with a given pricing aggressiveness. That is, in addition to distinguishing between market and limit orders, we distinguish between buy and sell orders, between orders using the NYSE's automatic execution system and orders using the traditional auction process, and among four pricing-aggressiveness categories for limit orders. The market that we investigate, the NYSE, differs from the markets studied by most prior studies. Except for Smith (2000), who uses Nasdaq data, and Bae, Jang, and Park (2002) and Beber and Caglio (2002), who use decade-old TORQ data, extant work examines markets that can be characterized as electronic limit order book markets. In an electronic limit order book, orders are displayed immediately. This was not necessarily true on the NYSE during our sample period, where only floor traders (specialists and, maybe, floor brokers) could see the orders in real time.

Consistently with previous studies, we find that market orders are less likely when the quoted spread is wide. In addition, we find that marketable limit orders (those limit orders that can execute immediately given their limit prices and the quoted prices) are less likely with wide spreads. Non-marketable limit orders are more likely with wide spreads. Quoted depths on both sides of the market affect the likelihood of certain types of order arrival. Specifically, we find that large depth on the bid (ask) side of the market is associated with more frequent limit buy (sell) orders having limit prices equaling or bettering the existing bid (offer) price and more frequent market buy (sell) orders.

Both order activity and inactivity are clustered. High-volume and high-volatility periods are followed by decreases in the likelihood of observing no order activity. To the extent that trading volume and price volatility proxy for the arrival of information, our results are consistent with Easley, Kiefer, and O'Hara (1997) who posit that low trading activity is related to the lack of valuation-relevant information. We find evidence that an increase in volatility in the previous five minutes increases the likelihood of a limit order's arrival relative to a marketable order's arrival. A positive own return on a security in the prior five-minute time interval increases the probability of observing marketable buy orders. The market return in the prior five minutes is inversely (directly) related to the probability of observing a buy (sell) order. Consistently with Biais, Hillion, and Spatt (1995), we find *positive* serial correlation in order type, rejecting the theoretical predictions of Parlour (1998).

Not surprisingly, order activity exhibits a U-shaped intraday pattern. As the close of trading approaches, we find that the likelihood of non-marketable limit orders increase and the likelihood of order cancellations and marketable order arrivals do not increase. These findings are inconsistent with sellers becoming more aggressive late in the trading day and consistent with Bloomfield, O'Hara, and Saar (2002), who provide experimental evidence that informed traders provide liquidity late in the day.

To assess the *economic significance* of an explanatory variable's impact on order choice, we calculate what we refer to as an impulse sensitivity. An impulse sensitivity is the change in the estimated probability of the dependent variable caused by a one standard deviation shock in the explanatory variable. To determine the *statistical significance* of the direction of change in the estimated probability, we must test the statistical significance of the impulse sensitivity, *not* the statistical significance of the multinomial logit coefficient. To the best of our knowledge, there is no technique in the prior literature to perform such as test. We develop a test of the statistical significance of an impulse sensitivity.

The paper is organized as follows. Section 2 presents a literature review and states our hypotheses. Section 3 describes the data we obtain from the NYSE. In Section 4, we explain the empirical methodology. Section 5 presents our results. Section 6 concludes. The appendix describes our new test of the statistical significance of an impulse sensitivity.

Section 2: Literature Review and Hypotheses

Spread. Harris (1998) finds that wider spreads increase the cost of demanding liquidity and increase the reward to providing liquidity. This causes the marginal investor to switch from taking liquidity via market orders to supplying it with limit orders. Alternatively, Focault (1999) finds that an increase in market volatility makes liquidity demanders less patient, which allows limit order submitters to widen their spread in order to extract greater rents. So, there is a positive relation between spreads and limit orders and a negative relation between spreads and market orders. Biais, Hillion and Spatt (1995), Hollifield, Miller and Sandas (1999), Bae, Jang and Park (2002), and Ranaldo (2002) find evidence consistent with this claim. Extant empirical work (e.g., Harris 1998 and Smith 2000) also finds that the *percentage* spread is directly related to the likelihood of limit orders and inversely related to the likelihood of market orders. No one to our knowledge, however, tests this hypothesis differentiating between marketable limit orders and non-marketable limit orders.

Spread Hypothesis: In the mix of order types, narrow (wide) spreads are associated with more frequent marketable (non-marketable) orders.[1]

Depth. Parlor (1998), Beber and Caglio (2002), and Ranaldo (2000) analyze the effect of the quote's depth on the order submission decision. Because we can differentiate between buy and sell orders, we investigate whether both sides of the quote seem to affect order choice or if only one side of the quote appears to matter to traders. We anticipate that the likelihood of limit buy (sell) orders with limit prices equal to or less (greater) than the bid (ask) price is inversely related to bid (ask) depth and that the likelihood of aggressive buy (sell) orders is directly related to the bid (ask) depth. Conversely, a greater bid (offer) depth is directly related to the likelihood of a limit sell (buy) order with a limit price equal to or worse then the quote and inversely related to a seller's (buyer's) aggressiveness. Furthermore, if traders believe that unequal quoted depth on the bid and offer sides of the book is instructive about short-term price movements, then we also should see more market orders on the same side of the market (i.e., market buys with large quoted bid depth and market sells with large quoted ask depth) and more limit orders on the opposite side of the market when depth is large on one side of the book.

Depth Hypothesis: Larger quoted size is associated with fewer (more) same-side (opposite-side) limit orders with limit prices equal to or worse than the quoted price and more (fewer) aggressively-priced same-side (opposite-side) orders.

Unbalanced Depth Hypothesis: Quoted depth that is not equal on both sides of the market is associated with more market orders on the side of the book with greater quoted depth and more limit orders on the side of the book with less quoted depth.

Volatility. Foucault (1999) suggests a model of a dynamic limit order market where variation in asset valuation across agents leads to a winner's curse problem for traders. With

[1] All hypotheses are stated as the alternative.

increased volatility, limit orders are placed at less competitive prices as a compensation for the adverse selection risk. Volatility also makes market orders less profitable. In equilibrium, the proportion of limit orders increases when return volatility is high. Although Foucault examines the cross-section of securities, his prediction can be extended to the time-series realm if traders can predict volatility (say, via a GARCH model). Handa and Schwartz (1996) also predict that investors submit more limit orders when volatility rises. Smith (2000), Ahn, Bae, and Chan (2001), Danielsson and Payne (2002), Hollifield, Miller, Sandas and Slive (2002), and Ranaldo (2002) find evidence consistent with a direct relation between security price volatility and limit order arrival frequency. Hasbrouck and Saar (2002), however, find the opposite.

In addition, increased volatility in the stock price might be a result of the arrival of valuation-relevant information. If this is the case, then we anticipate that no trading activity is less likely immediately following volatile periods.

Volatility Hypothesis: Higher return volatility is associated with more frequent limit orders and less frequent periods of no trading activity.

Market Return and Own Return. Hollifield, Miller and Sandas (1999) use the market index level as a common-value proxy. Positive (negative) returns suggest the arrival of favorable (unfavorable) information. Controlling for security return, the arrival of public information is suggestive about traders' direction of trade (buy versus sell). Hollifield *et al* (2002) also suggest that the trader's private valuation of the stock influences order choice. Traders with extreme valuations (extreme demands for liquidity) are more aggressive in their order strategy because they lose more than traders with moderate valuations if their order does not execute. Thus, at a given point in time, traders with extreme valuations can determine price. This suggests that a security's prior return indicates when traders with extreme valuations have taken positions.

Market Return Hypothesis: Controlling for security price, an increase (decrease) in the market index level is associated with more (fewer) buy orders and fewer (more) sell orders.

Own Return Hypothesis: An increase (decrease) in the stock's price, controlling for the market index level, increases the likelihood that extreme positive (negative) private valuations set the price suggesting an increase in the likelihood of selling (buying).

Time-of- day. The economics literature identifies a "deadline effect," where agreements are more likely to be reached at the last minute. For example, Roth *et al* (1988) conduct experiments testing for bargaining patterns through time and find that many agreements occur just before the deadline. This suggests that traders become more aggressive as the close of trading approaches. In contrast, Bloomfield, O'Hara and Saar (2002) use an experimental asset market to model traders' behavior in an electronic limit order book. They find that liquidity provision evolves during the trading day. Informed traders demand liquidity early in the trading session by submitting orders that hit existing limit orders but become suppliers of liquidity by submitting more limit orders towards the end of the trading day.

Time of Day Hypothesis: As the close of the trading day approaches, the distribution of order types changes.

Last Event. Parlour (1998) develops a model of a transparent limit order book with symmetric information. She assumes that limit orders have one limit price and that time priority is strictly enforced.[2] The probability of executing a limit order depends on the book's state and the trader's patience. Parlour notes that the arrival of a limit buy (sell) order lengthens the queue at the bid (ask) side of the book. This reduces the attractiveness of submitting another limit order

[2] Time priority requires that orders with equivalent limit prices fill on a first-come first-served basis. Strict time priority seems unnecessary for her result. If the arrival (execution) of an order on one side of the market decreases (increases) the likelihood of execution for an order remaining in that queue, then Parlour's predictions hold. Thus, we believe that Parlour's predictions remain relevant for the NYSE, a market without strict time priority.

of the same kind. Hence, we should observe nonrandom patterns of order submission where the probability of a limit buy (sell) is maximized after the occurrence of a market sell (buy).

Last Event Hypothesis: The probability of a limit buy (sell) is lowest if the immediately preceding event was also a limit buy (sell).

We simultaneously test these hypotheses using a multinomial logit model and electronic order data from the New York Stock Exchange.

Section 3: Data

We obtain system order data from the NYSE. Because of the volume of data, we select a sample of NYSE-listed equity securities. Initially, we choose the 50 most actively traded NYSE stocks during the 20 trading days prior to January 29, 2001. We also randomly select 25 stocks from each of four Volume-Price groups. To pick the 100-stock random sample, we rank NYSE-listed securities on share trading volume and, separately, on average NYSE trade price during the 20 trading days prior to January 29, 2001. Each security is placed into one of four categories after comparing its share price to median NYSE share price and its trading volume to median NYSE volume. These groups (of unequal numbers of stocks) are a high-volume:high-price group, a high-volume:low-price group, a low-volume:high-price group, and, a low-volume:low-price group. Within each group, we arrange securities alphabetically (by symbol) and choose every Nth security, where N is chosen to select 25 securities from that group. Because two of the 50 stocks with the highest trading volume also are randomly chosen as part of the high volume groups, our final sample has 148 securities.

We use the NYSE's System Order Database (SOD) and its companion quote file (SODQ) to provide an audit trail of system (SuperDOT) orders arriving during the week of April, 30 to

May 4, 2001.[3] SOD contains order and execution information for NYSE system orders. Order data include security, order type, a buy-sell indicator, order size, order date and time, limit price (if applicable), and the identity of the member firm submitting the order. Execution data include the trade's date and time, the execution price, the number of shares executing, and (if relevant) cancellation information. SODQ contains the NYSE quote and the best non-NYSE quote at the time an order arrives and at trade time. All records (orders, executions, and cancellations) are time-stamped to the second. System orders represent about 93% of reported NYSE orders and 47% of reported NYSE share volume.[4] Specifically, these data do not include most of the orders routed to the specialists' trading posts via floor brokers. Thus, we study only a subset of NYSE order strategies; those resulting in electronic submission of orders. Generally, these are the smaller, more easily executed orders. Our sample includes over 5.1 million events (i.e., order submissions, order cancellations, or no activity time intervals). We exclude orders arriving when the National Best Bid (NBB) price exceeds the National Best Offer (NBO) price or when the NBB or NBO size is zero.[5]

Table 1 provides some descriptive statistics for these and other variables.

[Insert Table 1.]

The mean order size is 1,232 shares. Although this is relatively small, we have large orders, as suggested by the maximum order size of 900,000 shares. On average, our sample stocks have 2.24 million shares trading per day, which is a .106% turnover rate. This undoubtedly exceeds the typical NYSE stock because our sample includes the 50 most actively traded NYSE stocks.

[3] We have data for April, May, and June for the 148 sample stocks. The large number of order submissions and cancellations makes sampling necessary. We choose this week for our sample period because it appears "typical" of the entire time period in terms of market return and order mix. We obtain similar results using April 3 or June 27. Traders might split orders among multiple execution venues. This suggests that we might not fully characterize order submission strategies. For our sample securities, 83% of the trade volume and 86% of the share volume recorded in the Trade and Quote data occur on the NYSE during our sample period.

[4] See SEC (2001a), page 5.

[5] The National Best Bid (Ask) price is the higher (lower) of the NYSE bid (ask) and the best non-NYSE bid (ask).

The average NYSE bid (offer) depth is 2,760 (3,701) shares. For the sample stocks (again, oriented to the more actively traded NYSE stocks), the spread averages 0.15% of the stock's $43.80 average "price," i.e., bid-ask spread midpoint. We do, however, have some observations where the spread is a large fraction of the stock's price. The average time of an event is 153.76 five-minute intervals past midnight, or approximately 12:48. The average five-minute own- and market-return are positive during the sample period. The own-return has more cross-sectional volatility than the market return. The private information variable (measured as the change in the quote midpoint between order arrival time and that day's closing) averages 0.27%.

Section 4: Methodology

4.1 Variables

We analyze the likelihood of observing particular events – the submission of different order types and order cancellations. In addition, because the trader can choose to do nothing, we design a role for clock time passing with no activity. Specifically, we define a no activity event as a stock-specific time interval passing without an order submission or cancellation. The no-activity time interval is defined as either: (1) the median time between successive order events, or (2) five minutes, whichever is less. There is considerable variation across stocks in their no-activity time intervals. The eight most active stocks have a no-activity time interval of one second. The 50 least active stocks have a median time between events exceeding five minutes and, thus, receive a no activity time interval of five minutes. Easley, Kiefer, and O'Hara (1997) use a similar no-activity event to model and estimate the passage of clock time without activity.

Beginning with the first trade of each day, we compute the time between successive pairs of order submissions/cancellations. If the elapsed time exceeds the no-activity interval, then we insert the appropriate number of no-activity events. For example, suppose that a stock has a median time between order activity events of 20 seconds and that orders arrive at 9:30:00, 9:30:05, and 9:30:50. There are fewer than 20 seconds between the first and second order, so a no-activity event is NOT inserted. Between the second and third order, we insert no-activity events at 9:30:25 and 9:30:45. The 4:00:00 closing is taken as the end of the trading day.

We distinguish four order types: Market Buy, Market Sell, Limit Buy and Limit Sell. We see in Table 1 that these order types account for 57% of the events (= .1250 + .1266 + .1641 + .1546). Thus, a cancellation or no-activity event occurs 43% of the time. The fact that limit orders are more frequent than market orders is consistent with extant literature finding that limit orders are more frequent than market orders on the NYSE (e.g., Harris and Hasbrouck, 1996). A simple count of the dependent variables provides a similar mix of events: no-activity events are 32.5% of the observations, cancellations are 14.8%, limit buy orders are 18.0%, limit sell orders are 17.1%, and market buys and sells orders are 8.8% each.

Our analysis differentiates among four types of limit orders: behind-the-quote, at-the-quote, inside-the-quote, and marketable. We place each limit order into one of the categories by comparing the limit price to NYSE quoted prices. Behind-the-quote buy (sell) orders have limit prices less (more) than the NYSE bid (ask) price. At-the-quote buy (sell) orders have limit prices equal to the NYSE bid (ask) price. Inside-the-quote orders have limit prices between the NYSE bid price and the NYSE ask price. Finally, buy (sell) marketable limit orders have limit prices greater (less) than or equal to the NYSE ask (bid) price.[6] Behind-the quote limit orders are the least aggressive and market orders are the most aggressive. We distinguish between the cancellations of buy and sell orders. To identify the model, one event must be designated as the base case. We arbitrarily designate the no-activity event as our base case.

[6] Peterson and Sirri (2002) provide a more detailed discussion of marketable limit orders.

Based on extant theoretical and empirical work on order submission strategy, we identify 17 explanatory variables. We define these variables below.

1. Percentage spread is measured as the NYSE bid-ask spread divided by the average of the bid and ask prices at the time the order is submitted; [7]

2. Relative NYSE Bid size is the size (in hundreds of shares) associated with the NYSE's bid price at the time of the event divided by the number of shares outstanding (in millions);

3. Relative NYSE Ask size is the size (in hundreds of shares) associated with the NYSE's ask price at the time of the event divided by the number of shares outstanding (in millions);

4. Relative volume is the natural logarithm of the number of shares traded in the five-minute interval prior to the event divided by the number of shares outstanding;

5. Own return is the percent change in the stock's midpoint (i.e., the average of the best bid and best ask prices) in the five-minute interval before the event;

6. Own return squared is the stock's own return squared;

7. Market return is the percentage change in the quoted spread's midpoint for the exchange traded fund mimicking the S&P500 (SPY) in the five-minute interval prior to the event;

8. Time is the time of day of the event expressed as the number of five-minute intervals since midnight (e.g., 9:30:00am to 9:34:59am is interval 114);

9. Time from noon squared is the deviation of the event's time interval from the mid-day time interval (153) squared;

10. Last event market buy takes the value of 1 if the previous event was a buy market order and 0 otherwise;

11. Last event market sell takes the value of 1 if the previous event was a sell market order and 0 otherwise;

12. Last event limit buy takes the value of 1 if the previous event was a limit buy order and zero otherwise;

13. Last event limit sell takes the value of 1 if the previous event was a limit sell order and zero otherwise;

14. Last event cancel buy takes the value of 1 if previous event was cancellation of a buy order and 0 otherwise;

[7] We obtain similar results if we use both dollar spread and price (or inverse price) in the regressions.

15. Last event cancel sell takes the value of 1 if the previous event was cancellation of a sell order and 0 otherwise;

16. Information is a measure of the traders' private information as proxied by the *future* change in stock value. It is calculated as [(closing NYSE quoted spread midpoint) - (order-time NYSE quoted spread midpoint)]/(order-time NYSE quoted spread midpoint); and,

17. NYSE equals National Best Bid/Offer is a binary variable equal to one if the NYSE quoted bid and offer prices equal the NBB and NBO prices and zero otherwise.

4.2 Models

We specify the following multinomial logit model for each stock i and time t over which an event can occur.

$$\text{Event type}_{i,t} = a + b_1(\textit{Percentage spread})_{i,t} + b_2(\textit{Relative NYSE bid size})_{i,t} + b_3(\textit{Relative NYSE ask size})_{i,t} + b_4(\textit{Relative volume})_{i,t-1} + b_5(\textit{Own return})_{i,t-1} + b_6(\textit{Own return squared})_{i,t-1} + b_7(\textit{Market return})_{t-1} + b_8(\textit{Time})_t + b_9(\textit{Time from noon squared})_t + b_{10}(\textit{Last event market buy})_{i,t} + b_{11}(\textit{Last event market sell})_{i,t} + b_{12}(\textit{Last event limit buy})_{i,t} + b_{13}(\textit{Last event limit sell})_{i,t} + b_{14}(\textit{Last event cancel buy})_{i,t} + b_{15}(\textit{Last event cancel sell})_{i,t} + b_{16}(\textit{Information})_{i,t} + b_{17}(\textit{NYSE equals NBBO})_{i,t} + e_{i,t} \quad (1)$$

In this specification, the subscript "t" represents a contemporaneous value. The subscript "t-1" represents an aggregate value from the preceding five-minute interval. To compute the values for these five-minute intervals, we begin with the 9:30:00-to-9:34:59 interval. We proceed to compute values for each five-minute interval throughout the day, ending with the time from 3:55:00 to 4:00:00. Thus, for example, the "t-1" interval associated with an order arriving at 9:42:30 is the 9:35:00-9:39:59 interval. We run two types of multinomial logit models with different event structures.[8]

[8] Our approach can be thought of as randomly selecting a single representative trader and assessing his/her actions. We do not model the number of traders present in the market at a particular time. Using the Belsley, Kuh, and Welsch (1980) method, we do not find a muti-collinearity problem among our explanatory variables.

Initially, we analyze a 7-way event structure. The seven events are: (1) cancellation of an existing buy order, (2) cancellation of an existing sell order, (3) the arrival of a Limit Buy order, (4) the arrival of a Limit Sell order, (5) the arrival of a Market Buy order, (6) the arrival of a Market Sell order, or (7) No Activity in a stock-specific time interval since the last event.[9] Next, we conduct a more detailed analysis using a 13-way event structure: (1) Cancellation of a buy order, (2) Cancellation of a sell order, (3) Behind-The-Quote Limit Buy, (4) At-The-Quote Limit Buy, (5) Inside-The-Quote Limit Buy, (6) Marketable Limit Buy, (7) Behind-The-Quote Limit Sell, (8) At-The-Quote Limit Sell, (9) Inside-The-Quote Limit Sell, (10) Marketable Limit Sell, (11) Market Buy, (12) Market Sell, or (13) No Activity (order arrival or cancellation) in a stock-specific time interval since the last event.

Section 5: Results

5.1 All Orders, Stock-By-Stock

We estimate equation (1) separately for each stock using all events for the stock.[10] Table 2 reports the results of the 7-way event structure estimation, which ignores limit orders' pricing aggressiveness. Table 3 provides the results of the 13-way event structure, which considers order pricing aggressiveness. Both tables report the mean estimates from the stock-by-stock analysis. In each table, Panel A reports the mean coefficient estimates from the multinomial logit regression and Panel B presents the mean impulse sensitivities. Again, an impulse sensitivity is

[9] For the 7-way event structure, the "market buy" ("market sell") event includes marketable limit buys (sells), because both types of orders are liquidity-demanding, executable orders. The "limit buy" ("limit sell") event includes only non-marketable limit orders, because these orders are the liquidity supplying. For expositional clarity, the "market order" vs. "limit order" terminology is used.

[10] For 85 of the sample stocks, we observe all order events during the sample period and find that the maximum likelihood regression converges. We aggregate the data from the remaining stocks in one regression. Thus, for our stock-by-stock analysis, we have 86 observations. Estimating equation (1) with the entire panel of data (i.e., simultaneously for all stocks) gives similar conclusions. We note that the stock-by-stock analysis, with its 86 observations, is a conservative approach to the statistical test compared to the literally millions of observations in the panel regression. Assuming only 86 observations also is conservative to reporting average test statistics from the regressions, which have thousands of observations.

the change in the probability of a dependent variable (row) caused by a one standard deviation increase in an explanatory variable (column).

To compute the impulse sensitivities reported in Panel B, we define the benchmark probability of each event as the estimated logistic function evaluated at the mean of each of the explanatory variables. In the 7-way analysis, we estimate that the probability of no activity is 44%, the probability of a limit buy (sell) order of 18% (17%), the probability of a market buy or market sell order is 9%, and the probability of a cancelled order is 3.65%. The 13-way analysis provides similar estimates of the likelihood of cancellations and marketable orders, but estimates that limit orders are less likely (14% for buys and 16% for sells) and no-activity intervals are more likely (49.7%) than the 7-way event model. To compute the change in the probabilities (impulse sensitivities), we successively re-evaluate the estimated logistic function after adding a standard deviation to the mean of one explanatory variable without disturbing the means of the other explanatory variables. Thus, the column labeled "Percent Spread" in Panel B of Tables 2 and 3 reports the impulse sensitivity based on a one standard deviation increase in the percent spread holding all other explanatory variables constant at their mean levels.

Our hypotheses are statements about the impulse sensitivities, so we discuss and interpret the impulse sensitivities, not the coefficient estimates. In most cases, the sign of the multinomial coefficient estimate is the same as that of the impulse sensitivity, but not always. For example, in Table 2 Panel A, the Market Buy coefficient in the Last Limit Sell column is +0.575, but the Market Buy impulse sensitivity in the Last Limit Sell column of Panel B is -0.12%. What matters for the multinomial logit coefficients is their *relative size*. In this case the Market Buy coefficient is smaller than the other coefficients in the Last Limit Sell column, so the Market Buy impulse sensitivity is negative and the other non-base case impulse sensitivities are positive.

In general, whenever there are more than two events on the left-hand-side, then the sign of the impulse sensitivity may or may not be the same sign of the estimated multinomial logit coefficient.[11] Because our hypotheses are concerned with the sign of the impulse sensitivities, we wish to test if an impulse sensitivity is statistically significantly different from zero. There appears to be no established procedure to do this. The appendix derives a new econometric procedure for testing the statistical significance of an impulse sensitivity. We summarize our hypotheses regarding the expected signs of the impulse sensitivities in Panel C of Table 2.

[Insert Tables 2 and 3.]

Percentage spreads. In Table 2, we find that it is significantly less likely to observe marketable orders and no-activity intervals and significantly more likely to find non-marketable limit orders as spreads widen. This is consistent with the Spread Hypothesis. From Table 3, we see that the increased likelihood of limit orders is concentrated on inside-the-quote and, to a lesser extent, at-the-quote orders. When spreads are wide, a trader is more likely to try to narrow the spread by submitting limit orders with limit prices within the existing spread. Marketable limit orders behave more like market orders than like non-marketable limit orders as spread widens. In fact, the probability of marketable limit orders is more sensitive to changes in the spread than is the probability of market orders.

Depth. Large depth at either side of the quote is associated with an increased likelihood of non-marketable limit orders on that side of the market (i.e., more bid depth is associated with more buy limit orders and more ask depth with more sell limit orders) and a decreased likelihood of non-marketable limit orders on the opposite side of the market. This seems counter-intuitive. It appears that, as quoted depth increases, liquidity providers are more likely to join an already

[11] This is caused by the fact that the multinomial logit coefficients affect the denominator of a probability calculation, as well as the numerator.

long queue. Table 3, however, shows that the only type of same-sided, non-marketable limit order experiencing an increased likelihood as the depth rises is an inside-the-quote order. Same-sided at- and behind-the-quote limit orders actually are less likely when depth is large. This suggests that traders compete to obtain priority by bettering the quoted price when their order would otherwise be at the end of a long queue due to time priority. This is consistent with the Depth Hypothesis. In addition, the likelihood of a marketable buy (sell) order increases as depth at the bid (offer) increases. This suggests that traders buy (sell) when bid (offer) size is large, which is consistent with the Unbalanced Depth Hypothesis. Table 3 suggests that this result is primarily due to the sensitivity of marketable limit orders rather than market orders.

Trading Volume. Generally, elevated trading volume in the prior five-minute interval is associated with more contemporaneous trading activity (less frequent no-activity events). That is, order activity has positive serial correlation. This is consistent with the Volume Hypothesis. The relative magnitudes of the probability changes suggest that much of this activity is new, not replacement, orders. That is, the increased likelihood of a new limit order is greater than the increased likelihood of an order cancellation.

Own return. We find little support for the Own Return Hypothesis. Own return in the previous five-minute interval is positively correlated with the frequency of buy orders and negatively correlated with the likelihood of sell orders. Thus, there appears to be momentum trading; buying (selling) as the price increases (decreases). For limit orders we might explain this as a mechanical refilling of the bid side of the limit order book after a price increase. It is more difficult to reconcile the marketable order results to our hypothesis.

Volatility. Squaring own-return provides an estimate of the time-series price volatility. We find that volatility is associated with an increased probability of all order activities. The increase in non-marketable limit order probability in Table 2 is large relative to the increase in marketable order likelihood, which is weakly consistent with the Volatility Hypothesis.[12] Table 3 suggests that the increased likelihood of non-marketable limit orders is focused on at- and behind-the-quote orders. Thus, traders tend not to narrow spreads after volatile periods.

Market return. After controlling for the security's own return, the return on the market (S&P 500 Exchange Traded Fund) in the prior five-minute interval increases the likelihood of buy orders and decreases the likelihood of sell orders, providing support to the Market Return Hypothesis. This is consistent with the idea that a trader views the market return as a leading indicator for a security's short-term price change. The effect on non-marketable limit orders detailed in Table 3 suggests that traders become more aggressive on the bid side (increasing the likelihood of at- and inside-the-quote orders) and less aggressive on the offer side when the return on the market in the previous five minute interval is positive.

Time-of-day. The time-of-day is not significantly positively associated with the likelihood of cancellations or with the probability of marketable order arrivals. This is inconsistent with the hypothesis that a trader converts from limit orders to market orders during the trading day as they become less patient as the close of trading approaches (e.g., Harris, 1998). However, we find that the likelihoods of at- and inside-the-quote limit orders rise as the end of trading approaches. This is consistent with the experiment in Bloomfield, O'Hara, and Saar (2002), that finds that informed traders demand liquidity early in the day but later assume the role of market maker.

Time-from-noon Squared. The time-from-noon-squared variable is large when events occur early or late in the day. This controls for the documented (e.g., Chung, Van Ness and Van Ness, 1999) U-shaped intra-day trading pattern. In Table 2, all events' impulse sensitivities

[12] Because the likelihood of order cancellation also increases in volatility, many of the limit orders might be replacement orders. It is not obvious that Foucault (1999) makes time series predictions regarding volatility. Hasbrouck and Saar (2002) do not support the predictions of Foucault in the cross-section.

associated with an increase in *Time Squared* are positive. This suggests that all order types and cancellations are more frequent early and late in the trading day. This is consistent with a U-shaped trading pattern. Not surprisingly, the no-activity event is much less likely early or late in the trading day. Table 3 shows that the U-shaped intra-day pattern is less pronounced for at- and inside-the-quote limit orders. Combined with the time-of-day results, this suggests that traders are less aggressive with their limit prices early in the day.

Last event. As with volume, we see that most of the impulse sensitivities associated with the last event variables are positive. This suggests that trading activity is clustered – the arrival or cancellation of any type of order significantly increases the likelihood of an additional order activity and decreases the likelihood of no activity. Based on the theoretical work of Parlour (1998) and the empirical work of Bias, Hillion, and Spatt (1995), we are interested in the serial correlations of order types.

Consider marketable orders. Examining Table 2, we find that marketable buy (sell) orders are most likely to follow marketable buy (sell) orders. That is, the largest change in probability in the “Last Market Buy” (“Last Market Sell”) column is associated with marketable buy (sell) orders. These results suggest positive serial correlation for marketable orders, which is consistent with the findings in Biais, Hillion, and Spatt (1995) and Yeo (2002). In addition, this provides evidence against the Last Event Hypothesis. A marketable order takes liquidity from the limit order book and produces a shorter queue for new limit orders to stand behind. Parlor (1998) suggests that liquidity suppliers are more willing to join shorter queues. Thus, we expect that marketable orders would be followed by limit orders replenishing the extinguished liquidity (limit sells following market buys and limit buys following market sells). In fact, we find that the likelihood of limit orders arriving on the opposite side of the book from where liquidity was taken increases more after the arrival of a marketable order than the likelihood of a limit order replacing the taken liquidity.

When the previous event is a limit order, the results are equally clear. For limit buy (sell) orders, we find that the likelihood of a limit buy (sell) order increases the most. This also is inconsistent with the Last Event Hypothesis. A limit buy (sell) order adds liquidity at the bid (offer) side of the market. The fact that an additional liquidity supplier adds to that liquidity by submitting another limit buy (sell) order is not consistent with Parlour. Table 3 confirms that the arrival of a limit buy (sell) order increases the likelihood of seeing another non-marketable limit buy (sell) order for all levels of pricing aggressiveness except (including) marketable orders.

Finally, we examine the changes in probabilities after an order's cancellation. Our results are consistent with a trader canceling existing limit orders and submitting new ones. When a buy (sell) order is cancelled, the most likely subsequent event is the arrival of a new buy (sell) limit order. Table 3 indicates that the increase in likelihood of non-marketable limit orders is common across all levels of pricing aggressiveness.

We should note that our results, by implication, extend the Bias, Hillion, and Spatt (1995) "diagonal effect" to no activity intervals. The arrival or cancellation of an order significantly decreases the likelihood of a no-activity interval. Thus, if we observe no activity, the likelihood of a subsequent no-activity interval increases.

Information. Although own (market) return in the previous five-minute interval might control for private (public) information arriving in the market, we also might wish to control for private information that has not yet been reflected in the security's price. Our forward-looking, private-information proxy is the change in the spread's midpoint between an orders' arrival and day's end. The impulse sensitivities associated with buy orders are positive and the impulse sensitivities associated with sell orders are negative. This suggests that as the value of the private information variable increases (meaning that there is favorable private information) the fraction of buy orders in total order flow increases. Conversely, when the information variable suggests unfavorable information (i.e., the variable *info* is negative), the portion of sell orders in total order flow increases. Private information appears to particularly affect the likelihood of at- and inside-the-quote non-marketable limit orders and marketable orders.

NYSE at the NBBO. It is possible that traders behave differently when the NYSE quote determines (or is part of) the NBBO. For example, whether or not the NYSE is at the NBBO might affect the aggressiveness of liquidity suppliers. We find that, when the NYSE's quoted prices are at the NBBO prices, the likelihood of no activity increases. This increase in inactivity is primarily a result of a lower likelihood of the cancellation of and arrival of non-marketable limit orders. This appears to be consistent with Parlour as adding liquidity on the NYSE when the NYSE quotes already are the best in the national market suggests that the new liquidity provider will have lower time priority than those who entered the queue earlier.

5.2 Robustness

We perform robustness checks on the 7-way conclusions and report the results in Table 4. We allow traders to choose between automatic and traditional floor executions of marketable orders in Panel A, allow for the possibility that traders split orders in Panel B, determine if differences in trading strategy emerge toward the close of the trading day in Panel C, and alter the definition of "last" event in Panel D. For each analysis, we re-estimate equation (1) using pooled data. That is, we do not estimate equation (1) separately for each stock. Our pooled regression has sufficient observations so that all regression coefficients and impulse sensitivities are different from zero at traditional significance levels. Therefore, we do not report significance levels. We only discuss when the conclusions differ from the results presented in the previous section. In order to save space, we report only the impulse sensitivities.

[Insert Table 4.]

Automatic Executions (Direct+) versus Traditional Auction-Process Executions

Just prior to our sample period, the NYSE began allowing traders to choose between automatic executions and the traditional, auction-process fill for marketable orders. The NYSE's Direct+ product permits small, marketable buy (sell) orders to automatically fill at the quoted offer (bid) price. The size of a Direct+ order is limited to the size of the quote it is trying to hit or 1099 shares, whichever is less. These orders are filled without price improvement. In Panel A of Table 4, we re-estimate the 7-way event model allowing for two additional order types. Thus, we have nine events: (1) cancel buy order; (2) cancel sell order; (3) Direct+ buy order; (4) Direct+ sell order; (5) limit buy order; (6) limit sell order; (7) traditional marketable buy order; (8) traditional marketable sell order; and, (9) no activity.

Most of the explanatory variables affect Direct+ orders in a similar manner to traditional marketable orders (albeit with smaller impulse sensitivities). There are, however, interesting exceptions. First, the U-shaped intra-day pattern in the likelihood of Direct+ orders is much less pronounced than the pattern in traditional marketable orders. Second, we find that traders are more likely to use Direct+ orders when the NYSE is setting or is part of the NBBO. This latter result contrasts the decreased likelihood of traditional marketable orders when the NYSE is at the NBBO. Finally, Direct+ orders are less sensitive to the spread width than traditional orders.

Order Splitting

A trader can decide to divide the original order into several, smaller orders if that appears optimal. Using the raw data we might misestimate the coefficients because we treat each order as a separate trading decision when, in fact, one decision might result in several orders. This is particularly true of the impulse sensitivities associated with the Last Event variables. We control for order splitting by developing an algorithm to identify similar successive orders submitted in close proximity to one another. Our data identify the member firm submitting the order as well as the branch office from which the order is submitted. We assume that consecutive orders originating from the same branch of the same broker on the same side of the market as the prior order are split orders. To address this potential problem, we keep the first order in a series of consecutive "identical" orders and delete the successive orders as the outcome of order splitting. We experiment with deleting from one to fifteen successive identical orders. In this paper, we report results from examining fifteen successive orders.[13]

We re-estimate the logit model after eliminating "duplicate" orders. The results are in Panel B of Table 4. Except for minor differences in some impulse sensitivities associated with quoted size and own return, there are no major departures from the results discussed above.[14] In particular, the positive serial correlation in order type is maintained.

Orders Near the Close

Cushing and Madhavan (2000) find that there is a higher demand for immediacy at the close of trading then during the day. Although our "Time" and "Time-from-noon-squared" variables address time-of-day effects on order submission strategies, we re-estimate equation (1)

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[13] Note that we are not attempting to control for all possible order splitting strategies. We simply are trying to determine whether order splitting strategies explain the positive serial correlation in order type. We also note that not all of the orders in these stocks are routed to the NYSE. Regional exchanges, NASD market makers and Electronic Communication Networks receive orders in these stocks. Traders might split orders among multiple execution venues. This also suggests that we might not fully characterize order splitting strategies.

[14] We also address potential endogeneity problems with non-reported robustness checks. For example, contemporaneous volume, quotes and volatility might be co-determined. To address this we use an instrument for the volume in the previous five-minute interval. The instrument we use is the volume in the five-minute interval prior to the previous five-minute interval (i.e., t-2). As an alternative approach to addressing the potential endogeneity problem, we re-estimate the logit model excluding the quoted spread and size variables without affecting our conclusions. We also estimate the model without our proxy for private information to eliminate "look-ahead" bias. None of these alternative specifications alters our conclusions in any meaningful manner.

using only orders submitted in the final 15 minutes of the trading day. This reduces our sample size to 227,399 events. Our results, reported in Panel C of Table 4, suggest some differences in order strategy. The impulse sensitivities associated with our quoted size variables indicate that traders appear less willing to join a queue when the end of trading is near. When bid (ask) size is large, traders are less likely to submit buy (sell) limit orders. There also is less evidence of momentum trading in the last 15 minutes of trading. Finally, the time and time squared variables suggest less trading at the end of our 15-minute interval than at the beginning.[15]

Redefine "Last" Event

Traders off the floor (the traders we study with our data) might not see the last order before making their decision. Although marketable limit and market orders generally execute quickly, specialists have 30 seconds to post at- and inside-the-quote limits. To address this, we redefine "last" order to be the order activity in the past 30 seconds. That is, we sum the number of shares in each type of event (cancel buy, cancel sell, limit buy, limit sell, market buy, and market sell) during the 30 seconds before the order of interest. (We obtain similar results using a five-minute interval and/or counting the number of orders instead of the number of shares.) Re-estimating equation (1) and computing the impulse sensitivities produces the results reported in Panel D. This redefinition does not alter our conclusions regarding the Last Event Hypothesis; we continue to support the diagonal effect of Bias, Hillion, and Spatt (1995). Our support for the Depth and Own Return Hypotheses, however, is weakened by this specification. At the same time, it provides stronger support for the Unbalanced Depth Hypothesis.

Order Size

Table 5 provides the impulse sensitivities resulting from re-estimating equation (1) conditional on the size of the order. We arbitrarily construct three order-size categories. Small

[15] Eliminating time and time-from-noon-squared does not change our conclusions on the other variables.

orders are defined as orders of fewer than 1,000 shares. Medium orders range between 1,000 and 9,999 shares. Large orders exceed 9,999 shares. We pool (across stocks) all orders in the given size categories for each re-estimation.

[Insert Table 5.]

Generally, we find the effects noted for the entire sample are strongest for the small- and medium-sized orders and weakest for the large orders. For example, we find that there is little relation between quoted spread or size and order type for the largest orders. This is probably because the order size dwarfs quoted size for these orders. Likewise, we find that the coefficient estimates on the Last Event variables are relatively small for the largest order regression. Finally, we note that the Market Return Hypothesis is supported by the large and small order subsets and that the time effect noted earlier (an increase in the likelihood of limit orders as the day passes) is limited to medium and large orders.

Volume and Price Level

Recall that 100 of our sample securities are selected to provide cross-sectional dispersion across trading volume and security price. As a robustness check, we re-estimate the logit model conditioning on volume and price. Table 6 shows these results. Panel A pools the data from the 50 most active stocks. Panel B's (C's) impulse sensitivities result from examining the high-volume:high-priced (:low-priced) stocks. Finally Panel D pools the low-volume stocks' data. Pooling all 50 low volume stocks is necessary to obtain convergence of the maximum likelihood estimation of equation (1).

[Insert Table 6.]

Although the results generally are strongest for the higher volume subsets, most conclusions are consistent across the various volume-price groups. A few exceptions are evident. For the low-volume stocks, we find that the likelihood of marketable orders falls as the volume and volatility in the prior five-minute interval increases. This might suggest that market orders in low-volume stocks are subject to sloppy executions in difficult markets. The Volatility Hypothesis (of Foucault, 1999) is supported for the low-volume stocks. In addition, the likelihood of limit buy (sell) orders increases (decreases) as the market return from the previous five-minute interval increases for the low price and lowest-volume stocks. For the lowest-volume stocks, there is some evidence consistent with the claim that traders switch from limit to market orders as the day passes. Finally, the largest impulse sensitivity with the Last Event Market Buy (Sell) is associated with limit buy (sell) orders in all but the highest volume stocks, suggesting that as liquidity is extinguished on one side of the book liquidity is added on the opposite side.

Section 6: Conclusion

This paper analyzes the mix of limit orders and market orders across different securities and under different market conditions for a sample of 148 stocks trading on the NYSE. We estimate a multinomial logit model of order choice using the extant theoretical literature to suggest the variables influencing traders' order submission strategies. Our analysis estimates the likelihood of observing the arrival of different types of orders, the likelihood of the cancellation of previous orders, and the likelihood of no order activity. We also distinguish between market and limit buy and sell orders and among four categories of pricing-aggressiveness for limit orders. The main results are that: (a) high spreads increase the likelihood of non-marketable limit orders whereas tight spreads increase the likelihood of market orders and marketable limit orders; (b) the higher the depth on the ask (bid) side the more aggressive liquidity suppliers on that side of the market become; (c) the higher the volume in the immediate past, the greater the contemporaneous activity; (d) the higher the stock's or market's return in the immediate past, the greater the likelihood of buy orders and lower the likelihood of sell orders for that stock; (e) higher own-stock return volatility in the recent past increases the likelihood of limit orders relative to the likelihood of market orders for that stock; (f) as the trading day moves toward the close there are more on-the-quote limit orders; (g) there is an intra-day U-shaped pattern to order arrival rates for all event types; (h) there is positive serial correlation in order types; and (i) favorable (unfavorable) private information increases the likelihood of buy (sell) orders.

Appendix: Testing The Statistical Significance of an Impulse sensitivity

Let $\hat{\boldsymbol{\pi}}$ be a vector of unrestricted reduced form parameter estimates and $\boldsymbol{\Psi}$ be the covariance matrix of the parameter estimates $\hat{\boldsymbol{\pi}}$. Let $\mathbf{h}(\boldsymbol{\pi})$ be a r-dimensional set of r restrictions, which are nonlinear in $\boldsymbol{\pi}$, and $\mathbf{H} = \partial \mathbf{h}(\boldsymbol{\pi})' / \partial \boldsymbol{\pi}$. For a sample size T, the Wald test statistic

$$q = T\mathbf{h}(\hat{\boldsymbol{\pi}})' (\mathbf{H}'\boldsymbol{\Psi}\mathbf{H})^{-1} \mathbf{h}(\hat{\boldsymbol{\pi}})$$

is asymptotically $\chi^2_{(r)}$ and is asymptotically equivalent to a likelihood ratio test (see Byron, 1974 and Judge et al, 1985, pgs 615-616).

We apply the Wald technique to calculate the statistical significance of an impulse sensitivity, where the unrestricted reduced form parameter estimates arise from a multinomial logit. An impulse sensitivity is the change in probability of a particular dependent variable caused by a one standard deviation shock in an independent variable.

Let $i = 1, 2, \ldots, I$ index the dependent variables, *excluding the base case variable*. Let $j = 1, 2, \ldots, J$ index the independent variables, including the intercept. Stack the $I \times J$ reduced form estimated coefficients into a (1xIJ) vector $\mathbf{c}$ in ji order.[18]

Let a_j and b_j be the mean and standard deviation of the j^{th} independent variable.[19] Insert these values into (1xIJ) vectors to create I vectors $\mathbf{m_i}$ and IJ vectors $\mathbf{s_{ji}}$ as shown below. For example, here are $\mathbf{m}_1$, $\mathbf{m}_2$, $\mathbf{s}_{11}$, $\mathbf{s}_{21}$, $\mathbf{s}_{12}$, and $\mathbf{s}_{22}$

[18] The ji order matches the SAS ordering of outputs from a multinomial logit.

[19] As one of the dependent variables, the intercept has a mean of 1 and a standard deviation of 0.

$$\mathbf{m}_1 = \begin{bmatrix} a_1 \\ 0 \\ 0 \\ 0 \\ \hline a_2 \\ 0 \\ 0 \\ 0 \\ \hline \vdots \end{bmatrix} \quad \mathbf{m}_2 = \begin{bmatrix} 0 \\ a_1 \\ 0 \\ 0 \\ \hline 0 \\ a_2 \\ 0 \\ 0 \\ \hline \vdots \end{bmatrix} \begin{matrix} \left.\begin{matrix} \\ \\ \\ \\ \end{matrix}\right\} I \text{ elements in each partition} \\ \\ J \text{ partitions} \\ \\ \\ \end{matrix} \quad \mathbf{s}_{11} = \begin{bmatrix} a_1 + b_1 \\ 0 \\ 0 \\ 0 \\ \hline a_2 \\ 0 \\ 0 \\ 0 \\ \hline \vdots \end{bmatrix} \quad \mathbf{s}_{21} = \begin{bmatrix} a_1 \\ 0 \\ 0 \\ 0 \\ \hline a_2 + b_2 \\ 0 \\ 0 \\ 0 \\ \hline \vdots \end{bmatrix} \quad \mathbf{s}_{12} = \begin{bmatrix} 0 \\ a_1 + b_1 \\ 0 \\ 0 \\ \hline 0 \\ a_2 \\ 0 \\ 0 \\ \hline \vdots \end{bmatrix} \quad \mathbf{s}_{22} = \begin{bmatrix} 0 \\ a_1 \\ 0 \\ 0 \\ \hline 0 \\ a_2 + b_2 \\ 0 \\ 0 \\ \hline \vdots \end{bmatrix}.$$

We insert the first mean, a_1, in the 1st element of the first partition of $\mathbf{m}_1$, the second mean, a_2, in the 1st element of the second partition of $\mathbf{m}_1$, and so on for all J partitions. Similarly, into all of the $\mathbf{m_i}$ vectors, we insert the means in the ith element of each partition. We construct $\mathbf{s}_{11}$ identically to $\mathbf{m}_1$, except that we insert the shock b_1 into the 1st element of the first partition only. Similarly, all of the $\mathbf{s_{ji}}$ vectors are identical to the corresponding $\mathbf{m_i}$ vector, except that they add the shock b_j only to the ith element of the jth partition.

Let p_{ji}^m be the jith probability evaluated at the means of the dependent variables. Let p_{ji}^s be the jith probability evaluated at the mean plus the one standard deviation shock for the jth dependent variable and at the means of the other dependent variables. Let Δp_{ji} be the jith change in probability, which is calculated as

$$\Delta p_{ji} \equiv p_{ji}^s - p_{ji}^m = \frac{\exp(\mathbf{c}'\mathbf{s_i})}{1+\sum_{k=1}^{I}\exp(\mathbf{c}'\mathbf{s_{jk}})} - \frac{\exp(\mathbf{c}'\mathbf{m_i})}{1+\sum_{k=1}^{I}\exp(\mathbf{c}'\mathbf{m_k})}.$$

Let $\partial\Delta p_{ji}/\partial\mathbf{c}$ be a (IJ x1) vector of partial derivatives. Using the quotient rule, we get

$$\frac{\partial \Delta p_{ji}}{\partial \mathbf{c}} = \frac{\mathbf{s_{ji}} \cdot \exp\left(\mathbf{c}'\mathbf{s_{ji}}\right)\left\{1+\sum_{k=1}^{I}\exp\left(\mathbf{c}'\mathbf{s_{jk}}\right)\right\} - \exp\left(\mathbf{c}'\mathbf{s_{ji}}\right)\left\{\sum_{k=1}^{I}\mathbf{s_{jk}} \cdot \exp\left(\mathbf{c}'\mathbf{s_{jk}}\right)\right\}}{\left\{1+\sum_{k=1}^{I}\exp\left(\mathbf{c}'\mathbf{s_{jk}}\right)\right\}^2} - \frac{\mathbf{m_i} \cdot \exp\left(\mathbf{c}'\mathbf{m_i}\right)\left\{1+\sum_{k=1}^{I}\exp\left(\mathbf{c}'\mathbf{m_k}\right)\right\} - \exp\left(\mathbf{c}'\mathbf{m_i}\right)\left\{\sum_{k=1}^{I}\mathbf{m_k}'\exp\left(\mathbf{c}'\mathbf{m_k}\right)\right\}}{\left\{1+\sum_{k=1}^{I}\exp\left(\mathbf{c}'\mathbf{m_k}\right)\right\}^2}.$$

We test a single $\left(r=1\right)$, cross-equation restriction $\Delta p_{ji} = 0$. Using the covariance matrix $\mathbf{\Psi}$[20] of the reduced form parameter estimates $\mathbf{c}$ with a sample size of T, the Wald test statistic

$$q = T\left(\Delta p_{ji}\right)\left(\frac{\partial \Delta p_{ji}}{\partial \mathbf{c}}' \mathbf{\Psi} \frac{\partial \Delta p_{ji}}{\partial \mathbf{c}}\right)^{-1}\left(\Delta p_{ji}\right)$$

is asymptotically distributed $\chi^2_{(1)}$.

For the base case dependent variable, the j[th] change in probability is

$$\Delta p_j \equiv p_j^s - p_j^m = \frac{1}{1+\sum_{\mathbf{l}=1}^{I}\exp\left(\mathbf{c}'\mathbf{s_{jl}}\right)} - \frac{1}{1+\sum_{\mathbf{l}=1}^{I}\exp\left(\mathbf{c}'\mathbf{m_l}\right)}.$$

For the base case dependent variable, the (IJ x1) vector of partial derivatives $\partial \Delta p_j / \partial \mathbf{c}$ is

$$\frac{\partial \Delta p_j}{\partial \mathbf{c}} = \frac{-\sum_{k=1}^{I}\mathbf{s_{jk}} \cdot \exp\left(\mathbf{c}'\mathbf{s_{jk}}\right)}{\left\{1+\sum_{k=1}^{I}\exp\left(\mathbf{c}'\mathbf{s_{jk}}\right)\right\}^2} + \frac{\sum_{k=1}^{I}\mathbf{m_k}'\exp\left(\mathbf{c}'\mathbf{m_k}\right)}{\left\{1+\sum_{k=1}^{I}\exp\left(\mathbf{c}'\mathbf{m_k}\right)\right\}^2}.$$

For the single restriction $\Delta p_j = 0$ using the same covariance matrix $\mathbf{\Psi}$, the Wald statistic

$$q = T\left(\Delta p_j\right)\left(\frac{\partial \Delta p_j}{\partial \mathbf{c}}' \mathbf{\Psi} \frac{\partial \Delta p_j}{\partial \mathbf{c}}\right)^{-1}\left(\Delta p_j\right)$$

is asymptotically distributed $\chi^2_{(1)}$.

[20] See Maddala (1999), page 37 for details on how to calculate the covariance matrix $\mathbf{\Psi}$ in a multinomial logit.

References

Ahn, H., K. Bae, and K. Chan, 2001, "Limit Orders, Depth, and Volatility," *Journal of Finance* 56, 767-88.

Bae, K-H., H. Jang, and K. Park, 2002, "Traders' Choice between Limit and Market Orders: Evidence from NYSE Stocks," *Journal of Financial Markets*, forthcoming.

Belsley, D. A., E. Kuh, and R. E. Welsch, 1980, Regression Diagnostics, Wiley Publishing, New York.

Beber, A., and C. Caglio, 2002, "Orders Submission Strategies and Information: Empirical Evidence from the NYSE," unpublished paper, University of Pennsylvania.

Biais, B., P. Hillion, and C. Spatt, 1995, "An Empirical Analysis of the Limit-order Book and the Order Flow in the Paris Bourse," *Journal of Finance* 50, 1655-89.

Bloomfield, R., M. O'Hara, and G. Saar, 2002, "The 'Make or Take' Decision in an Electronic Market: Evidence on the Evolution of Liquidity," Unpublished paper, Cornell University.

Byron, R. P., 1974, "Testing Structural Specification Using the Unrestricted Reduced Form," *Econometrica*, 42, 869-84.

Chung, K., B. Van Ness, and R. Van Ness, 1999, "Limit Orders and the Bid-Ask Spread," *Journal of Financial Economics* 53, 255-87.

Cohen, K., S. Maier, R. Schwartz, and D. Witcomb, 1981, "Transactions Costs, Order Placement Strategy, and Existence of the Bid-Ask Spread," *Journal of Political Economy* 89, 287-305.

Cushing, D., and A. Madhavan, 2000, "Stock Returns and Trading at the Close," *Journal of Financial Markets* 3, 45-62.

Danielsson, J., and R. Payne, 2002, "Measuring and Explaining Liquidity on an Electronic Limit Order Book: Evidence from Reuters D2000-2," unpublished paper, Financial Markets Group, London School of Economics.

Easley, D., N. Kiefer, and M. O'Hara, 1997, "One Day in the Life of a Very Common Stock," *Review of Financial Studies*, 10, 805-35.

Foucault, T., 1999, "Order Flow Composition and Trading Costs in a Dynamic Limit Order Market," *Journal of Financial Markets* 2, 99-134.

Handa, P., and R. Schwartz, 1996, Limit Order Trading, *Journal of Finance* 51, 1835-61.

Harris, L., 1998, "Optimal Dynamic Order Submission Strategies in Some Stylized Trading Problems," *Financial Markets, Institutions, and Instruments* 7, 1-75.

Harris, L., and J. Hasbrouck, 1996, "Market versus Limit Orders: the SuperDOT Evidence on Order Submission Strategy," *Journal of Financial and Quantitative Analysis* 31, 212-31.

Hasbrouck, J., and G. Saar, 2002, "Limit Orders and Volatility in a Hybrid market: The Island ECN," unpublished paper, New York University.

Hollifield, B., R. Miller, and P. Sandas, 1999, "An Empirical Analysis of Limit Order Markets," Unpublished paper, Rodney White Center for Financial Research Working Paper 029-99, University of Pennsylvania.

Hollifield, B., R. Miller, P. Sandas, and J. Slive, 2002, "Liquidity Supply and Demand in Limit Order Markets," Unpublished paper, Rodney White Center for Financial Research Working Paper, University of Pennsylvania.

Judge, G.G., W.E. Griffiths, R.C. Hill, H. Lutkepohl, and T.C. Lee, 1985, *The Theory and Practice of Econometrics*, John Wiley and Sons, New York.

Kavajecz, K., 1999, "A Specialist's Quoted Depth and the Limit Order Book," *Journal of Finance* 54, 747-72.

Maddala, G.S., 1999, *Limited-Dependent and Qualitative Variables in Econometrics*, Cambridge University Press, Cambridge.

Parlour, C., 1998, "Price Dynamics in Limit Order Markets," *Review of Financial Studies* 11, 789-816.

Peterson, M., and E. Sirri, 2000, "Order Submission Strategy and the Curious Case of Marketable Limit Orders," *Journal of Financial and Quantitative Analysis* 37, 221-41.

Ranaldo, A., 2002, "Order Aggressiveness in Limit Order Book Markets," *Journal of Financial Markets*, forthcoming.

Roth, A., K. Murnigham, and F. Schoumaker, 1988, "The Deadline Effect in Bargaining: Some Experimental Evidence," *American Economic Review* 78, 806-23.

Sandas, P., 2001, "Adverse Selection and Competitive Market Making: Empirical Evidence from a Pure Limit Order Market," *Review of Financial Studies* 14, 705-34.

Seppi, D., 1997, "Liquidity Provision with Limit Orders and a Strategic Specialist," *Review of Financial Studies* 10, 103-50.

Smith, J., 2000, “Market versus Limit Order Submission Behavior at a Nasdaq Market Maker,” Unpublished paper, Nasdaq Economic Research.

Swinscow, T., 1997, *Statistics at Square One*, 9th edition, London, BMJ Publishing.

United States Securities and Exchange Commission, 2001, Report on Comparison of Order Executions Across Equity Market Structures, Office of Economic Analysis.

United States Securities and Exchange Commission, 2001, “Disclosure of Order Execution and Routing Practices.”

Yeo, W., 2002, “Persistent Pattern in Limit Order Submission,” unpublished paper, Indiana University.

Table 1. Descriptive Statistics

The Table reports descriptive statistics for the sample of 148 stocks trading on the New York Stock Exchange during the week of April 30 – May 4, 2001. Order size is the pooled time series cross-sectional average of the number of shares submitted in orders. Daily share volume is the pooled time series cross-sectional average of the volume in shares transacted. The shares outstanding variable is the volume weighted average of the shares outstanding for the firms in the sample. The National Best Bid Size is the size associated with the lowest bid price across all markets quoting the stock. The National Best Offer Size is the size associated with the highest ask price across all markets quoting the stock. Percent spread is the national best bid-ask spread divided by the average of the national best bid price and the national best ask price. Time is the number of five-minute intervals since midnight. Own return is the change in the midpoint of the security's bid-ask spread over the five minutes prior to the order arrival or cancellation. Market return is the change in the midpoint of the midpoint of the bid-ask spread of the exchange traded fund representing the Exchange Traded Fund tracking the S&P500 Index. Information variable is measured as [(closing quote midpoint) - (order-time quote midpoint)/(order-time quote midpoint)].

Variable	**Mean**	**Std. Deviation**	**Minimum**	**Maximum**
Order size	1,231.88	5,501.62	100	900,000
Daily share volume	2,242,779	1,555,359	555	6,454,023
Shares outstanding (in 000)	2,118,639	1,942,579	61	9,932,929
National Best Bid Size ('00)	27.60	68.57	1	5,880
National Best Offer Size ('00)	37.01	103.59	1	8,376
Spread midpoint ($)	43.80	23.04	0.525	118.9
Spread ($)	0.0523	0.0492	0.00	6.14
Percent spread	0.0015	0.0020	0.00	0.2615
Last Event Market Buy	0.1250	0.3306	0	1
Last Event Market Sell	0.1266	0.3320	0	1
Last Event Limit Buy	0.1641	0.3702	0	1
Last Event Limit Sell	0.1546	0.3615	0	1
Time	153.76	24.52	114	192
Own Return	0.000141	0.009252	-0.086896	0.106667
Market Return	0.000058	0.001043	-0.002974	0.004434
Information	0.002676	0.015272	-0.121806	0.249431

Table 2. Estimation of the 7-Way Event Structure For All Orders

The table reports the results from estimating equation (1). In Panel A, we report the estimated regression coefficients. In Panel B, we report the impulse sensitivities (change in the probability of an event caused by a one standard deviation shock in the explanatory variable). In each panel we report the mean from 86 regressions. For 85 of our sample stocks, the maximum likelihood estimation of equation (1) converges. For the other sample stocks, we pool data into an eighty-sixth regression.

Event	Percent Spread	Rel. Bid Size	Rel. Ask Size	Rel. Vol.	Own Ret.	Own Ret. Sqr.	Mkt. Ret.	Time	Time Sqr.	Last Mkt. Buy	Last Mkt. Sell	Last Limit Buy	Last Limit Sell	Last Can. Buy	Last Can. Sell	Infor-mation	NYSE At NBBO
Panel A: Mean Estimated Regression Coefficients																	
Cancel Buy	**39.28**	**-1.041**	**-0.200**	**0.99**	**45.308**	**1.36**	**82.925**	0.068	**.380**	**1.005**	**0.876**	**1.560**	**1.016**	**1.773**	**1.045**	2.085	**-0.288**
Cancel Sell	**36.70**	-0.108	**-0.558**	**1.15**	**-25.53**	**1.54**	**-70.07**	-2.006	**.419**	**0.735**	**1.095**	**1.002**	**1.512**	**0.888**	**1.712**	0.406	**-0.352**
Limit Buy	**136.46**	**0.574**	**-0.318**	**1.32**	2.442	**1.47**	**81.602**	**1.905**	**.404**	**0.951**	**0.865**	**1.354**	**0.924**	**1.506**	**1.101**	**7.154**	**-0.346**
Limit Sell	**154.9**	**-0.362**	**0.399**	**1.41**	**18.010**	**1.49**	**-84.91**	0.837	**.443**	**0.842**	**.0997**	**0.960**	**1.317**	**1.114**	**1.520**	**-10.53**	**-0.387**
Market Buy	**-132.8**	**0.835**	-0.018	**1.17**	**90.639**	**1.67**	**121.96**	1.074	**.768**	**1.089**	**0.469**	**0.674**	**0.575**	**0.757**	**0.570**	**9.068**	**-0.286**
Market Sell	**-114.0**	**0.207**	**0.611**	**0.77**	**-104.8**	**1.14**	**-105.4**	-0.043	**.719**	**0.647**	**1.074**	**0.612**	**0.732**	**0.504**	**0.855**	**-12.90**	**-0.170**
Panel B: Mean Impulse Sensitivities (%)																	
Cancel Buy	0.04	**-0.32**	**-0.16**	**0.14**	**0.57**	**0.51**	**0.47**	-0.07	**0.20**	**0.80**	**0.45**	**2.21**	**0.83**	**2.41**	**0.812**	0.01	**-0.26**
Cancel Sell	0.06	-0.14	**-0.39**	**0.14**	**-0.57**	**0.52**	**-0.34**	**-0.16**	**0.42**	**0.32**	**0.83**	**0.71**	**2.08**	**0.83**	**2.171**	-0.12	**-0.28**
Limit Buy	**3.17**	**0.69**	**-0.41**	**0.38**	**1.08**	**0.64**	**0.28**	**0.48**	**0.63**	**1.31**	**0.80**	**3.93**	**1.18**	**2.72**	**1.023**	**0.71**	**-0.49**
Limit Sell	**3.50**	**-0.39**	**0.55**	**0.48**	**-1.13**	**1.04**	**-0.38**	**0.38**	**0.79**	**0.73**	**1.18**	**1.02**	**3.40**	**0.99**	**2.559**	**-0.75**	**-0.66**
Market Buy	**-2.13**	**0.48**	0.01	**0.31**	**1.57**	**0.40**	**0.64**	0.068	**1.64**	**1.58**	**0.12**	**0.15**	-0.12	0.01	**-0.263**	**0.40**	-0.02
Market Sell	**-1.98**	0.04	**0.34**	0.21	**-1.34**	**0.45**	**-0.35**	**-0.23**	**1.53**	**0.21**	**1.87**	**-0.09**	**0.26**	**-0.23**	**0.166**	**-0.60**	-0.13
No Activity	**-2.67**	-0.36	0.06	**-1.70**	**-0.59**	**-3.60**	-0.10	-0.45	**-5.20**	**-4.98**	**-5.27**	**-7.95**	**-7.64**	**-6.74**	**-6.468**	0.36	**1.86**
Panel C: Hypothesis Predicted Signs of the Impulse Sensitivities																	
Cancel Buy				+					+					-			
Cancel Sell				+					+						-		
Limit Buy	+	**Depth - Unbal+**		+	-	+	+	≠0	+			-		+		+	
Limit Sell	+		**Depth - Unbal+**	+	+	+	-	≠0	+				-		+	-	
Market Buy	-	**Unbal+**		+	-	-	+	≠0	+	-						+	-
Market Sell	-		**Unbal+**	+	+	-	-	≠0	+		-					-	-
No Activity				-					-								

Coefficients for bid size, ask size, time, and time squared are multiplied by 1,000. Coefficients for relative volume (own return squared) are multiplied by 1,000,000 (10,000).

Bold numbers are significant at the .01 level with both a standard cross-sectional t-test and a Chi-square test of proportions using the 86 regressions on the regression coefficient estimates in Panel A and the impulse sensitivities in Panel B. The test of proportions tests the null hypothesis that significantly more than one-half of the individual coefficient estimates (in Panel A) or impulse sensitivities (in Panel B) have the same sign as the mean.

Table 3. Estimation of the 13-Way Event Structure Choice For All Orders

The table reports the results from estimating equation (1). In Panel A, we report the estimated regression coefficients. In Panel B, we report the impulse sensitivities (change in the probability of an event caused by a one standard deviation shock in the explanatory variable). In each panel we report the mean from 86 regressions. For 85 of our sample stocks, the maximum likelihood estimation of equation (1) converges. For the other sample stocks, we pool data into an eighty-sixth regression.

Event	Percent Spread	Rel. Bid Size	Rel. Ask Size	Rel. Vol.	Own Ret.	Own Ret. Sqr.	Mkt. Ret.	Time	Time Sqr.	Last Mkt. Buy	Last Mkt. Sell	Last Limit Buy	Last Limit Sell	Last Can. Buy	Last Can. Sell	Infor-mation	NYSE At NBBO
Panel A. Regression Coefficient Estimates																	
Cancel Buy	**48.51**	-0.43	**-0.43**	**0.96**	**12.13**	**1.40**	**36.44**	-0.19	**0.40**	**2.03**	**-4.06**	**2.44**	**-2.84**	**0.46**	**-4.69**	-1.77	**-0.22**
Cancel Sell	**56.49**	**-0.48**	**-0.26**	**1.08**	5.23	**1.44**	**-35.66**	-0.54	**0.42**	**-4.3**	**2.15**	**-2.98**	**2.46**	**-4.61**	0.33	-3.16	**-0.28**
BTQ Limit Buy	7.21	**-1.55**	**0.60**	**0.86**	-3.68	**0.93**	1.15	0.08	**0.74**	**0.82**	**0.84**	**1.51**	**1.20**	**1.26**	**1.15**	8.12	-0.08
ATQ Limit Buy	**159.0**	**-0.87**	-0.09	**1.31**	54.84	-1.81	**104.9**	3.65	**0.27**	**0.80**	**0.73**	**1.23**	**0.91**	**1.16**	**1.07**	4.66	**-0.20**
ITQ Limit Buy	**237.2**	**2.37**	**-2.05**	**1.28**	6.21	**0.90**	**115.8**	2.67	**0.30**	**0.79**	**0.87**	**1.35**	**0.92**	**1.28**	**0.87**	9.34	**-0.24**
ITQ Limit Sell	**275.8**	**-1.85**	**1.64**	**0.98**	**16.65**	**0.90**	**-126.8**	0.48	**0.28**	**0.83**	**1.04**	**0.93**	**1.33**	**1.03**	**1.08**	**-11.16**	**-0.31**
ATQ Limit Sell	**179.7**	0.17	**-0.37**	**1.19**	**38.43**	**1.30**	**-93.21**	1.18	**0.32**	**0.71**	**1.06**	**0.74**	**1.40**	**0.71**	**1.32**	**-14.01**	**-0.27**
BTQ Limit Sell	14.70	0.17	**-1.02**	**0.96**	-6.38	**1.44**	-4.20	4.04	**0.84**	**0.67**	**0.98**	**0.93**	**1.36**	**1.30**	**1.04**	**-7.69**	**-0.29**
Mkt. Limit Buy	**-468.3**	**1.89**	**-1.00**	**1.34**	34.03	**1.84**	**174.7**	-0.09	**0.69**	**0.94**	0.44	**0.94**	**0.80**	**1.03**	**0.77**	9.28	**-0.20**
Mkt. Limit Sell	**-379.5**	**-0.74**	**1.27**	**1.20**	-15.45	**1.66**	**-131.1**	**-3.00**	**0.68**	**0.84**	**1.38**	0.44	**0.78**	0.51	**1.06**	**-16.58**	0.41
Market Buy	2.69	-0.35	0.29	**1.01**	**65.28**	**1.16**	**123.8**	2.78	**0.79**	**1.36**	**0.64**	**0.92**	**0.81**	**0.78**	**0.57**	5.10	0.15
Market Sell	-9.69	-0.46	0.32	-.49	**-76.94**	0.67	**-146.3**	1.47	**0.72**	**0.61**	**1.40**	**0.81**	**.093**	**0.59**	**0.81**	-4.57	-0.07
Panel B. Mean Impulse Sensitivities (%)																	
Cancel Buy	0.08	**-0.04**	**-0.07**	**0.03**	0.01	**0.14**	**0.06**	-0.04	**0.08**	**1.06**	**-1.10**	**1.74**	**-1.15**	0.04	**-1.05**	0.01	**-0.08**
Cancel Sell	0.02	**-0.04**	**-0.05**	**0.04**	0.01	**0.14**	**-0.06**	**-0.04**	**0.10**	**-1.02**	**1.05**	**-1.09**	**1.61**	**-0.93**	0.05	-0.04	**-0.93**
BTQ Limit Buy	**-0.36**	**-0.37**	**0.29**	**0.12**	**-0.15**	**0.34**	-0.00	-0.14	**0.85**	**0.51**	**0.50**	**1.45**	**0.92**	**1.17**	**1.07**	0.06	**-0.18**
ATQ Limit Buy	**1.07**	**-0.34**	-0.14	**0.10**	-0.12	**0.23**	**0.54**	**0.42**	-0.06	**0.65**	**0.41**	**1.80**	**0.44**	**1.09**	**0.02**	0.27	**-0.14**
ITQ Limit Buy	**2.26**	**1.04**	**-1.07**	**0.22**	0.10	0.17	**0.80**	**0.32**	0.37	**0.73**	**0.50**	**1.74**	**0.62**	**1.21**	**0.78**	**0.57**	**-0.29**
ITQ Limit Sell	**2.55**	**-0.78**	**0.96**	**0.20**	**0.14**	0.12	**-0.80**	0.19	-0.08	**0.44**	**0.74**	**0.54**	**1.56**	**0.70**	**1.15**	**-0.37**	**-0.43**
ATQ Limit Sell	**1.17**	-0.07	-0.23	**0.16**	**0.28**	**0.31**	**-0.45**	0.25	0.01	**0.44**	**0.55**	**0.40**	**1.53**	**0.55**	**0.98**	**-0.43**	**-0.22**
BTQ Limit Sell	-0.10	**0.14**	**-0.37**	**0.25**	0.07	**035**	0.00	-0.02	**1.01**	**0.86**	**0.45**	**0.86**	**1.20**	**1.00**	**1.03**	-0.12	-0.08
Mkt. Limit Buy	**-1.64**	**0.27**	**-0.12**	**0.16**	0.16	**0.36**	**0.60**	**-0.11**	**0.57**	**0.69**	**0.18**	**0.28**	**1.69**	**0.32**	**0.12**	**0.24**	-0.05
Mkt. Limit Sell	**-1.50**	-0.02	**0.23**	**0.19**	0.01	**0.39**	**-0.42**	**-0.28**	**0.56**	**0.23**	**0.78**	**0.19**	**0.34**	**0.22**	**0.39**	**-0.31**	0.10
Market Buy	**-0.54**	**0.20**	**0.11**	**0.19**	**0.57**	**0.25**	**0.90**	**0.18**	**1.26**	**1.60**	**0.46**	**0.60**	**0.39**	**0.59**	**0.23**	**0.17**	0.02
Market Sell	**-0.65**	**0.09**	**0.19**	**0.07**	**-0.37**	**0.35**	**-0.99**	0.03	**1.12**	**0.50**	**1.90**	**0.42**	**0.69**	**0.25**	**0.67**	**-0.29**	**-0.14**
No Activity	**-2.36**	-0.06	0.28	**-1.70**	**-0.72**	**-3.20**	**-0.17**	**0.74**	**-5.48**	**-6.20**	**-6.47**	**-8.97**	**-8.97**	**-6.24**	**-6.08**	0.22	**1.60**

BTQ = Behind-The-Quote; ATQ = At-The-Quote; ITQ = Inside-The-Quote. Coefficients for bid size, ask size, time, & time squared are multiplied by 1,000. Coefficients for relative volume & own return squared are multiplied by 1,000,000 & 10,000 respectively. **Bold numbers** are significant at the .01 level using a both a standard cross-sectional t-test and a Chi-square test of proportions using the 86 regressions on the regression coefficient estimates in Panel A and the impulse sensitivities in Panel B. The test of proportions tests the null hypothesis that significantly more than one-half of the individual coefficient estimates (in Panel A) or impulse sensitivities (in Panel B) are in the same direction as the mean.

Table 4. Impulse Sensitivities (%) for the Robustness Checks of the 7-Way Event Structure

We report impulse sensitivities (change in an event's probability due to a shock in an explanatory variable). To do this, we estimate equation (1) and evaluate the estimated logistic at the explanatory variables' mean values. We then re-evaluate the estimated logistic after adding a one standard deviation to one explanatory variable.

Event	Percent Spread	Rel. Bid Size	Rel. Ask Size	Rel. Vol.	Own Ret.	Own Ret. Sqr.	Mkt. Ret.	Time	Time Sqr.	Last Mkt. Buy	Last Mkt. Sell	Last Limit Buy	Last Limit Sell	Last Can. Buy	Last Can. Sell	Infor-mation	NYSE At NBBO
Panel A. Inclusion of Direct+ Orders																	
Cancel Buy	0.62	0.10	-0.14	0.06	0.47	-0.41	0.55	-0.19	0.31	0.73	0.38	1.90	0.85	2.59	1.03	0.07	-0.24
Cancel Sell	0.89	0.10	-0.75	0.07	-0.14	0.14	-0.56	-0.26	0.47	0.40	0.80	0.82	1.76	1.02	2.36	-0.08	-0.25
Direct+ Buy	-0.12	0.01	-0.01	0.01	-0.02	-0.02	0.02	-0.01	0.01	0.03	-0.0001	0.01	-0.001	0.01	0.001	0.01	0.001
Direct+ Sell	-0.06	-0.01	0.002	0.01	-0.001	0.003	-0.01	-0.004	0.005	-0.00	0.01	0.0006	.0008	-0.0008	0.01	0.0002	0.002
Limit Buy	3.40	-0.43	-0.08	0.31	-0.36	0.24	0.55	0.12	0.84	1.17	0.56	3.12	1.19	1.92	0.89	0.28	-0.72
Limit Sell	3.37	-0.48	-0.30	0.29	0.95	-0.72	-0.55	0.17	1.01	0.57	1.17	1.16	2.94	0.89	1.82	-0.42	-0.82
Market Buy	-3.21	-0.14	-0.40	0.69	-0.14	0.14	1.52	-0.02	1.95	2.10	0.41	0.51	0.12	1.63	-0.09	0.32	-0.43
Market Sell	-3.12	0.21	-0.53	0.58	-0.14	0.17	-1.37	0.30	1.84	0.45	2.62	0.10	0.61	-0.11	0.26	-0.50	-0.40
No Activity	-1.76	0.64	2.23	-2.05	-0.59	0.45	-0.14	0.50	-6.45	-5.77	-5.97	-1.76	-7.51	-6.50	-6.29	0.31	2.89
Panel B. Correcting for Possible Order Splitting																	
Cancel Buy	0.61	0.40	-0.25	0.07	0.55	-0.47	0.49	-0.16	0.34	0.69	0.44	1.72	0.87	1.48	0.99	0.08	-0.26
Cancel Sell	0.67	0.39	-0.69	0.10	-0.14	0.13	-0.50	-0.21	0.49	0.42	0.75	0.83	1.60	0.92	1.40	-0.07	-0.27
Limit Buy	2.39	-0.76	-0.79	0.27	-0.36	0.22	0.50	0.14	0.92	1.23	0.67	2.00	1.39	1.84	1.06	0.28	-0.81
Limit Sell	3.31	-3.41	-0.34	0.30	0.97	-0.74	-0.51	0.18	1.04	0.68	1.26	1.42	2.00	1.09	1.78	-0.44	-0.84
Market Buy	-3.60	0.01	-0.42	0.78	-0.18	0.17	1.59	-0.06	2.03	2.07	0.53	0.78	0.35	0.41	0.10	0.36	-0.42
Market Sell	-3.41	0.67	-0.55	0.66	-0.15	0.18	-1.42	-0.35	1.94	0.55	2.28	0.35	0.86	0.10	0.47	-0.52	-0.39
No Activity	-0.88	2.69	3.06	-2.21	-0.67	0.49	-0.15	0.46	-6.79	-5.69	-5.92	-7.13	-7.08	-5.86	-5.80	0.30	3.02
Panel C. Orders in the Final 15 Minutes of Trading																	
Cancel Buy	1.48	-5.51	0.01	-0.20	-0.001	-0.27	0.70	-6.46	-6.49	0.46	0.30	1.39	0.51	2.09	0.68	-0.09	-0.29
Cancel Sell	2.53	0.98	-0.58	-0.07	-0.08	0.20	-0.38	-5.87	-6.51	0.21	0.67	0.47	1.38	0.76	1.88	-0.30	-0.67
Limit Buy	9.90	-3.21	0.76	-0.14	-0.26	0.14	0.56	-16.02	-13.58	1.02	0.56	2.96	1.36	1.65	0.68	-0.16	-0.34
Limit Sell	9.34	2.58	-0.50	0.35	0.05	-0.08	-0.36	-16.09	-15.39	0.83	1.00	1.54	3.24	0.87	2.08	-0.84	-0.46
Market Buy	-8.38	-2.06	-1.12	0.95	-0.46	0.53	1.37	-14.80	82.02	3.18	0.55	0.34	-0.04	0.02	-3.96	1.95	-0.03
Market Sell	-5.13	-0.75	0.52	0.23	-0.25	0.41	-1.18	-12.47	-12.44	0.36	2.26	-0.11	0.19	-0.41	-0.07	-1.93	0.02
No Activity	-9.76	7.96	1.97	-1.12	1.02	-0.94	-0.71	71.74	-27.59	-6.08	-5.36	-6.61	-6.66	-5.00	-4.86	1.41	1.18
Panel D. Define Last Order as the Cumulative Orders over the Previous 30 Seconds																	
Cancel Buy	2.26	4.43	0.22	0.14	0.41	-0.38	0.70	-0.24	0.36	-0.13	0.03	0.04	-0.01	1.46	-0.00	0.09	-0.17
Cancel Sell	2.58	4.40	-0.20	-0.02	-0.17	0.16	-0.67	-0.31	0.56	0.02	-0.17	0.00004	-0.02	-0.04	1.34	-0.12	-0.18
Limit Buy	7.66	7.91	0.56	0.21	-0.41	0.25	0.66	0.12	0.87	-0.08	-0.21	1.63	-0.10	0.34	-0.17	0.28	-0.45
Limit Sell	7.47	7.51	0.45	0.16	0.88	0.68	-0.66	0.18	1.08	-0.24	-0.08	-0.09	1.47	-0.19	0.33	-0.49	-0.58
Market Buy	-3.57	6.58	0.03	0.97	-0.18	0.17	1.81	-0.04	2.15	1.08	-0.15	-0.08	-0.09	0.10	-0.22	0.38	-0.36
Market Sell	-3.32	6.84	-0.06	0.79	-0.18	0.20	-1.63	-0.36	2.04	-0.11	1.40	-0.16	-0.10	-0.31	0.17	-0.58	-0.32
No Activity	-13.09	-37.7	-0.99	-2.12	-0.35	0.27	-0.22	0.64	-7.08	-0.55	-0.83	-1.35	-1.14	-1.36	-1.44	0.46	2.05

Table 5. Impulse Sensitivities (%) of the 7-Way Event Structure By Order Size

The table reports the impulse sensitivities (change in the probability of an event caused by a one standard deviation shock in the explanatory variable). To do this, we first estimate equation (1) and evaluate the estimated logistic equation at the mean value of all explanatory variables. We then re-evaluate the estimated logistic after adding a one standard deviation to one explanatory variable and report the change in the probability.

Event	Percent Spread	Rel. Bid Size	Rel. Ask Size	Rel. Vol.	Own Ret.	Own Ret. Sqr.	Mkt. Ret.	Time	Time Sqr.	Last Mkt. Buy	Last Mkt. Sell	Last Limit Buy	Last Limit Sell	Last Can. Buy	Last Can. Sell	Infor-mation	NYSE At NBBO
Panel A: Large Orders (< 9,999 shares)																	
Cancel Buy	0.01	0.002	-0.002	0.0009	0.03	-0.02	0.004	-0.003	0.06	0.02	0.02	0.04	0.03	0.04	0.02	-0.003	-0.01
Cancel Sell	0.01	-0.09	0.002	0.007	-0.002	0.003	-0.01	-0.003	0.08	0.02	0.03	0.03	0.04	0.03	0.04	-0.004	-0.01
Limit Buy	0.05	-0.07	0.004	0.02	-0.006	0.004	0.01	0.004	0.21	0.08	0.08	0.15	0.11	0.08	0.06	-0.008	-0.04
Limit Sell	0.06	-0.36	-0.0001	0.03	-0.009	0.01	-0.01	0.02	0.28	0.10	0.12	0.12	0.18	0.07	0.09	-0.02	-0.07
Market Buy	0.01	-0.11	0.003	0.02	0.21	-0.13	0.02	-0.02	0.24	0.15	0.11	0.11	0.11	0.05	0.05	0.02	-0.02
Market Sell	0.03	-0.24	-0.02	0.03	-0.01	0.01	-0.04	-0.01	0.23	0.09	0.14	0.08	0.09	0.04	0.05	-0.03	-0.02
No Activity	-0.18	0.89	0.02	-0.10	-0.21	0.13	0.02	0.01	-1.13	-0.49	-0.52	-0.55	-0.57	-0.33	-0.35	0.05	0.18
Panel B: Medium Orders (999 < shares < 10,000)																	
Cancel Buy	0.75	-0.21	-0.27	0.23	0.13	-0.14	0.07	-0.10	0.57	0.48	0.36	0.94	0.55	1.10	0.57	0.03	-0.22
Cancel Sell	0.82	-2.39	-0.04	0.22	-0.04	0.05	0.16	-0.08	0.67	0.41	0.58	0.62	1.02	0.64	1.17	-0.02	-0.21
Limit Buy	0.18	-1.45	-0.79	0.61	-0.13	0.07	-0.19	0.13	1.54	0.98	0.82	1.88	1.19	1.30	0.85	0.06	-0.73
Limit Sell	0.19	-1.19	-0.78	0.67	0.71	-0.54	0.09	0.18	1.62	0.86	1.14	1.28	2.08	0.89	1.41	-0.19	-0.77
Mkt. Buy	-1.33	-0.93	-0.51	0.57	-0.03	0.04	-0.10	-0.19	1.61	1.61	0.62	0.80	0.57	0.52	0.35	0.15	-0.44
Mkt. Sell	-1.31	-3.91	-0.23	0.55	0.05	0.07	0.81	-0.26	1.64	0.64	1.69	0.59	0.83	0.37	0.56	-0.28	-0.44
No Activity	-2.65	10.11	2.59	-2.87	-0.57	0.42	-0.65	0.32	-7.67	-5.00	-5.23	-6.14	-6.26	-4.85	-4.94	0.24	2.84
Panel C: Small Orders (< 1,000 shares)																	
Cancel Buy	0.02	0.15	-0.13	0.05	0.54	-0.45	0.51	-0.17	0.37	0.81	0.50	1.97	1.01	2.53	1.10	0.04	-0.31
Cancel Sell	0.37	0.53	-1.44	0.09	-0.13	0.11	-0.48	-0.25	0.46	0.46	0.82	0.91	1.72	1.03	2.18	-0.08	-0.30
Limit Buy	2.01	-1.31	0.47	1.84	-0.29	0.20	0.60	-0.03	0.71	1.29	0.70	3.16	1.37	1.96	1.08	0.26	-0.64
Limit Sell	1.91	-1.87	-0.06	0.004	0.89	-0.70	-0.60	-0.02	0.76	0.64	1.17	1.27	2.77	1.06	1.74	-0.36	-0.70
Mkt. Buy	-2.62	-0.48	-0.48	0.49	-0.16	0.14	1.23	0.07	1.80	2.22	0.51	0.65	0.30	0.35	0.11	0.25	-0.38
Mkt. Sell	-2.34	0.47	0.63	0.40	-0.11	0.13	-1.15	-0.17	1.63	0.52	2.40	0.27	0.74	0.07	0.42	-0.39	-0.32
No Activity	6.47	2.50	2.72	-1.24	-0.73	0.56	-0.11	0.56	-5.58	-5.95	-6.12	-8.26	-7.93	-7.03	-6.65	0.29	2.68

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Table 6. Impulse Sensitivities (%) of the 7-Way Event Structure By Volume and Price Category

The table reports the impulse sensitivities (change in the probability of an event caused by a one standard deviation shock in the explanatory variable) derived from equation (1) estimates.

Event	Percent Spread	Rel. Bid Size	Rel. Ask Size	Rel. Vol.	Own Ret.	Own Ret. Sqr.	Mkt. Ret.	Time	Time Sqr.	Last Mkt. Buy	Last Mkt. Sell	Last Limit Buy	Last Limit Sell	Last Can. Buy	Last Can. Sell	Infor-mation	NYSE At NBBO
Panel A: Highest Volume Stocks																	
Cancel Buy	0.16	-0.28	-0.08	0.16	0.45	0.27	0.24	-0.19	0.27	0.69	0.37	1.76	0.81	2.45	0.95	0.10	-0.26
Cancel Sell	0.26	-0.17	-0.24	0.13	-0.49	0.37	-0.18	-0.16	0.38	0.39	0.75	0.79	1.62	0.94	2.25	-0.12	-0.26
Limit Buy	3.53	0.28	-0.15	0.41	0.83	0.29	-0.62	0.22	0.66	0.93	0.42	2.66	0.92	1.74	0.73	0.51	-0.48
Limit Sell	3.61	-0.23	0.21	0.46	-0.74	0.42	0.72	0.39	0.62	0.42	0.93	0.85	2.40	0.68	1.56	-0.58	-0.44
Mkt. Buy	-2.24	0.47	-0.006	0.41	1.82	0.55	0.06	-0.02	1.91	2.10	0.12	0.37	0.006	0.07	-0.17	0.36	-0.02
Mkt. Sell	-2.17	0.03	0.44	0.27	-1.67	0.54	-0.03	-0.30	1.79	0.17	2.45	-0.006	0.45	-0.20	0.15	-0.65	-0.09
No Activity	-3.15	-0.25	-0.13	-1.86	-0.18	-2.46	-0.19	-0.06	-5.56	-4.76	-5.06	-6.45	-6.24	-5.69	-5.48	0.39	1.56
Panel B: High-Volume, High-Price Stocks																	
Cancel Buy	0.02	-0.34	-0.21	0.15	0.77	0.49	0.70	0.06	0.07	0.95	0.53	2.74	0.92	2.71	0.63	-0.07	-0.25
Cancel Sell	-0.07	-0.20	-0.38	0.09	-0.63	0.41	-0.68	-0.10	0.49	0.21	0.88	0.65	2.47	0.71	2.36	-0.01	-0.47
Limit Buy	2.28	1.12	-0.64	0.25	1.21	0.72	-0.14	1.12	0.87	1.76	1.13	6.07	1.32	3.12	1.39	1.06	-0.79
Limit Sell	2.93	-0.43	0.96	0.40	-1.53	1.00	0.09	0.62	1.02	1.07	1.36	1.02	4.72	1.36	2.98	-0.77	-1.20
Mkt. Buy	-1.82	0.58	0.01	0.17	0.87	0.39	1.12	0.10	1.17	0.94	0.17	-0.08	-0.21	0.05	-0.29	0.44	-0.06
Mkt. Sell	-1.69	0.06	0.43	0.12	0.84	0.38	-0.51	-0.23	1.20	0.20	0.99	-0.22	0.07	-0.24	0.16	-0.46	-0.11
No Activity	-1.64	-0.78	-0.17	-1.20	-0.58	-3.41	0.41	-1.58	-4.84	-5.15	-5.08	-10.90	-9.31	-7.72	-7.24	-0.18	2.91
Panel C: High-Volume, Low-Price Stocks																	
Cancel Buy	-0.24	-0.46	-0.24	0.06	0.70	0.64	0.79	0.13	0.14	0.87	0.59	2.69	0.73	1.80	0.63	-0.20	-0.21
Cancel Sell	-0.33	-0.43	-0.33	0.26	-0.68	0.87	-0.35	-0.22	0.41	0.28	0.93	0.56	2.80	0.73	1.60	-0.28	-0.07
Limit Buy	3.52	1.35	3.52	0.51	1.78	1.14	0.39	0.36	0.25	1.60	1.32	4.41	1.71	4.85	1.27	0.73	-0.22
Limit Sell	4.13	-0.83	4.13	0.69	-1.71	0.77	-0.07	0.03	0.96	1.00	1.52	1.49	4.23	1.35	4.69	-1.16	-0.48
Mkt. Buy	-2.22	0.43	-2.22	0.22	0.85	0.42	1.73	0.27	1.47	0.97	0.04	-0.11	-0.33	-0.27	-0.44	0.37	-0.003
Mkt. Sell	-1.83	0.06	-1.83	0.17	-0.77	0.79	-1.09	-0.07	1.22	0.24	1.34	-0.17	-0.02	-0.31	.017	-0.60	-0.26
No Activity	-3.00	-0.12	3.00	-1.94	-1.40	-4.65	-0.17	-0.50	-4.48	-4.99	-5.78	-8.87	-9.13	-8.15	-7.09	1.15	1.06
Panel D: Low-Volume Stocks																	
Cancel Buy	-.39	.05	.003	.004	.043	9.73	.71	-.60	.25	1.50	.43	4.11	.86	3.59	.98	.68	-1.21
Cancel Sell	.13	-.08	-.07	.03	-1.54	3.90	-.31	-.65	.46	.27	1.65	.87	3.76	.57	2.86	-.18	-.67
Limit Buy	.17	-.08	-.22	.07	-1.23	7.95	1.58	.004	.39	3.73	2.70	8.79	1.55	6.07	2.34	2.33	-1.42
Limit Sell	.56	-1.06	.15	.07	-1.28	34.84	-1.75	-.25	1.02	3.07	3.48	1.62	7.56	1.81	5.91	-1.49	-1.99
Mkt. Buy	-1.75	.16	-.06	-.001	16.46	-6.78	.21	.42	1.36	1.32	.33	-.49	-.62	.01	-.57	1.56	-.52
Mkt. Sell	-1.50	.16	.01	-.01	-5.51	-7.23	-.06	.31	1.21	1.28	2.56	.11	.22	-.17	.28	-1.14	-.14
No Activity	2.77	.85	.19	-.17	-6.92	-42.42	-.38	.77	-4.71	-11.19	-11.17	-45.40	-13.35	-11.90	-11.83	-1.75	5.51