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 choices. We consider order type (market and limit), order side, automatic execution vs. the auction process, order pricing aggressiveness, order cancellation, and the passage of time without order activity. Our multinomial logit specification and new statistical test allow us to comprehensively test order-choice 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.) favorable (unfavorable) private information increases the likelihood of buy (sell) orders; and, 6.) limit orders are more likely late in the trading day; 7.) positive first-order autocorrelation exists in order type; 8.) negative autocorrelation exists in the order flow process over longer horizons. Our results become richer when we consider orders' pricing aggressiveness.

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

JEL classification: G14, D44.

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Determinants of Order Choice on the New York Stock Exchange

Characterizing a trader's order submission choice 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 choice 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* first-order, serial correlation in order type. When we aggregate each order type over five-minute intervals to examine longer-term order flow processes, we find *negative* serial correlation in changes of the order flow processes, which supports the theoretical predictions of Parlour (1998). This negative serial correlation in the order flow changes generates longer-term mean-reversion of the order flow level of each order type.

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 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 I presents a literature review and states our hypotheses. Section II describes the data we obtain from the NYSE. In Section III, we explain the empirical methodology. Section IV presents our results. Section V concludes. The appendix describes our new test of the statistical significance of an impulse sensitivity.

I. 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, Foucault (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. 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.

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[1] All hypotheses are stated as the alternative.

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 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 might 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. Technical traders use past public information (such as own returns, market returns, etc.) to forecast future price movements. An extensive academic literature analyzes technical trading rules based on past security returns and/or market returns (see Brown and Jennings 1990; Gencay 1998; Sullivan 1999; Lo, Mamaysky, and Wang 2000;

Ready 2002). It is not unusual for day traders to use minute-by-minute “momentum” or “contrarian” trading strategies.[2] The presence of such traders suggests that there may be short-term patterns to exploit. We allow for this possibility with the following hypothesis.

Market Return Hypothesis: A non-zero market return is associated with changes in order choice.

Own Return Hypothesis: A non-zero own return is associated with changes in order choice.

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. 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

[2] See many examples in “Risky Business: The Day Traders” in the *Investigate Reports* video series available on the A&E web site (www.aetv.com).

queue at the bid (ask) side of the book. This reduces the attractiveness of submitting another limit order of the same kind. Hence, we should observe negative serial correlation in order type.

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

Last Five Minutes. By contrast with the Parlour assumption of full transparency, the NYSE the limit order book was closed to off-exchange traders during our sample period. In other words, off-exchange traders might not see the last order before making their order choice. Although marketable orders usually fill and print quickly, specialists have 30 seconds to post at- and inside-the-quote limit orders and behind-the-quote limit orders are completely non-transparent to off-floor traders. To give the Parlour model a fair test, we aggregate each type of order flow over five minute intervals and test for negative serial correlation in changes in the order flow process.

Last Five Minutes Hypothesis: The change in the number of limit buys (sells) over five minute intervals is lower if the lagged change in the number of limit buys (sells) over five minute intervals is higher.

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

II. 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 choices; those resulting in electronic submission of orders. Generally, these are the smaller, more easily executed orders. Our sample includes over 5.1 million events. We exclude

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

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 I provides some descriptive statistics for these and other variables.

[Insert Table I.]

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. 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%.

III. Methodology

III.A. 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,

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

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 I 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.

Based on extant theoretical and empirical work on order submission strategy, we identify 17 explanatory variables.[7] 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; [8]

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);

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[6] Peterson and Sirri (2002) provide a more detailed discussion of marketable limit orders.
[7] Using the Belsley, Kuh, and Welsch (1980) method, we do not find a muti-collinearity problem among our explanatory variables.
[8] We obtain similar results if we use both dollar spread and price (or inverse price) in the regressions.

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;

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

16. Private information is a measure of the traders' current 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.

III.B. Models

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

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

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.[9]

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.[10] 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.

IV. Results

IV.A. Stock-By-Stock Estimation

[9] 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.

[10] 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.

We estimate equation (1) separately for each stock using all events for the stock.[11] Table II reports the results of the 7-way event structure estimation, which ignores limit orders' pricing aggressiveness. Table III 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 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 II

[11] 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., for all stocks simultaneously) 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.

and III 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, interpret, and test 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.[12] For example, in Table II Panel A, the Market Buy coefficient in the Last Limit Sell column is +0.575, but Panel B's Market Buy impulse sensitivity in the Last Limit Sell column 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.

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 II.

[Insert Tables II and III.]

Percentage spreads. In Table II, 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 III, 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

[12] They may differ because the multinomial logit coefficients affect the denominator of a probability calculation, as well as the numerator.

limit orders behave more like market orders than like non-marketable limit orders as the 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 is inconsistent with the Depth Hypothesis. It appears that, as quoted depth increases, liquidity providers are more likely to join an already long queue. Table III, 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. 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 III 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 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 short-term "momentum" trading; buying (selling) as the price increases (decreases). For limit orders, some of this might be mechanical refilling of the bid (ask) side of the limit order book after a price increase (decrease).

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 II is large relative to the increase in marketable order likelihood, which is weakly consistent with the Volatility Hypothesis.[13] Table III 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 III 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

[13] 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.

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 II, all events' impulse sensitivities 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 less likely early or late in the trading day. Table III 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 first-order serial correlations of order types.

Consider marketable orders. Examining Table II, we find that marketable buy (sell) orders are most likely to follow marketable buy (sell) orders. That is, the largest impulse sensitivity in the "Last Market Buy" ("Last Market Sell") column is associated with marketable buy (sell) orders. This is evidence from the marketable order categories of positive serial correlation in order type (a positive diagonal effect). This finding is consistent with the findings in Biais, Hillion, and Spatt (1995) and Yeo (2002) and is inconsistent with 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 positive serial correlation from the limit order categories is also inconsistent with the Last Event Hypothesis.[14] Clearly, the Parlour predictions do not hold on an order-by-order basis. Table III 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

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[14] As a robustness check on the positive serial correlation in order type findings, we check two alternative specifications. First, we estimate the same 7-way event structure but drop the spread, bid depth, and ask depth explanatory variables. Second, we estimate the same 7-way event structure but drop the spread, bid depth, ask depth, volume, and volatility explanatory variables. Our thought was that perhaps these highly transparent (to off-floor traders) explanatory variables absorb some impact of the less transparent Last Event variables. In unreported results, the positive serial correlation in order type (positive diagonal effect) is every bit as strong in these two alternative specifications.

order. Table III 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.

Private information. Although own return and market return in the previous five-minute interval might control for public information arriving in the market, we also might wish to control for current 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 private information variable suggests unfavorable private information, 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.[15]

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

[15] As a robustness check, we drop the "look-ahead" private information variable and re-estimate the 7-way event structure and the 13-way event structure. The non-reported results do not change our conclusions with respect to other variables.

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.

IV.B. Robustness

As a robustness check, we estimate the 7-way event structure and the 13-way event structure using data from the first day of our sample (April 3) or the last day of our sample (June 27). The results that we obtain, but don't report, are strongly similar to the results in Tables II and III.[16] We perform additional robustness checks on the 7-way event structure and report the results in Table IV. 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, and determine if differences in order choice emerge toward the close of the trading day in Panel C. 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 IV.]

Automatic Executions (NYSE 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

[16] We also perform a non-reported robustness check for potential endogeneity problems. It is possible that 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). This alternative specification does not alter our conclusions in any meaningful manner.

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 IV, 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, findings worth highlighting. First, the U-shaped intra-day pattern in the likelihood of Direct+ orders is 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 than traditional market 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.[17]

We re-estimate the logit model after eliminating "duplicate" orders. The results are in Panel B of Table IV. 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. In particular, the positive first-order 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 than 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) 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 IV, suggest some differences in order choice. 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.[18]

Order Size

[17] 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.

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

Table V 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 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 V.]

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 VI 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 VI.]

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.

IV.C. The Order Flow Process Over Longer Time Intervals

Parlour (1998) assumes full transparency of the limit order book, but the NYSE limit order book was closed to off-exchange traders during our sample period. To give the Parlour model a fair test, we analyze order choices aggregated over longer time intervals. Specifically, we estimate a new version of equation (1) aggregated over five-minute intervals. To do this we define an order flow process for each order type (market buy, market sell, limit buy, limit sell, cancel buy, cancel sell) or no activity event by counting the number of orders/events during five-minute intervals throughout the trading day. The new dependent variables are the change in the number of orders/events for a given stock over a five-minute interval compared to the previous five-minute interval. Similarly, the new version of the "Last Event" variables are "Last Five Minute" explanatory variables, defined as the change in the number of orders/events for a given stock over the last five-minute period compared to the lag two five-minute period. In the same spirit, the new version of spread, bid size, and ask size are the average spread, average bid size, and average ask size over the five-minute interval. NYSE at the BBO becomes the fraction of the five-minute interval that the NYSE quoted prices match *both* the best bid and the best offer.

We estimate the new version of equation (1) using Ordinary Least Squares (OLS). In Panel A, we report estimated OLS regression coefficients, where each row is one OLS regression. In Panel B, we report economic sensitivities. An economic sensitivity is the change in the number of orders/events caused by a one standard deviation shock in the explanatory variable. The **bold numbers** are significant at the 1% level based on a standard t-test. Since we are aggregating by five-minute intervals, the sample size is reduced to 11,398.

[Insert Table VII.]

We find that the five-minute order flow process has very different properties than the order-by-order process. None of the coefficients for percent spread, relative bid size, relative ask size, relative volume, or time squared are statistically significant or economically significant. Most of the Last Five Minute coefficients are both statistically significant and economically significant. Looking down the Panel A diagonal of the Last Five Minute coefficients, Last Cancel Buy has a -0.41 coefficient with Cancel Buy, Last Cancel Sell has a -0.37 coefficient with Cancel Sell, and the remaining diagonal terms are -0.43, -0.53, -0.30, and -0.39. All of these diagonal terms are highly negative and statistically significant. All of the off-diagonal coefficients are positive or less negative than the diagonal coefficients. Turning to the Panel B, the economic sensitivities of the Last Five Minute variables tend to be much larger in absolute value than the economic sensitivities of the other explanatory variables. All of the diagonal terms have large negative economic sensitivities. All of the off-diagonal economic sensitivities are positive or less negative than the diagonal economic sensitivities. Overall, this is a strong evidence of a *negative* serial correlation in changes in the order flow process (that is, a *negative* diagonal effect). It is both statistically and economically significant. This supports the Last Five Minutes Hypothesis and strongly supports the Parlour model.

How can the order-by-order results and the five-minute results be reconciled? First of all, it is not unusual to have very different patterns at different levels of time aggregation. For example, stock returns exhibit *negative* serial correlation on a minute-by-minute basis due to bid-ask bounce (see Jegadeesh 1990 and Lehmann 1990), *positive* serial correlation over 3 to 12 month holding periods (see Jegadeesh and Titman 1993 and Rouwenhorst 1998), and *negative* serial correlation over 3 to 5 year holding periods (see DeBondt and Thaler 1985). Second, the order-by-order results and five-minute results *both* are consistent with order flow processes for each type of order that follow slow mean-reverting processes. The five minute *negative* serial correlation in changes causes the *level* of the process to mean-revert, which drives the process back towards long-run balance. In other words, we find that the economic forces analyzed by Parlour control the longer-term, five-minute dynamics, which tend to maintain the longer-term equilibrium.

V. Conclusion

This paper analyzes the trader's order choice decision 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: 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.) favorable (unfavorable) private information increases the likelihood of buy (sell) orders; and, 6.) limit orders are more likely late in the trading day; 7.) positive first-order autocorrelation exists in order type; 8.) negative autocorrelation exists in the order flow process over longer horizons.

As with all empirical studies, several caveats are in order. First, we note that our empirical design captures individual orders, not complete order strategies. Although we adjust for a simple form of order splitting, we cannot anticipate all possible strategies. We also note that all strategies are not equally available to all traders. For example, the model might suggest that an order be cancelled, but we cannot observe that outcome if an order has not been previously placed. Third, we have only NYSE order data. Without data from all venues trading NYSE-listed securities, we cannot fully characterize order choice. During our sample period 83% of the sample stocks traders (86% of the volume) occurred on the NYSE. Finally, we focus exclusively on electronically-submitted (system) orders. We do not have access to most orders originally routed to a floor broker instead of the specialist.

Our results have implications for traders, trading venues, and regulators. Traders that demand liquidity can adapt their order submissions to maximize the likelihood their orders will fill at minimum cost. Liquidity suppliers can access the competition they are likely to face and the profitability of their orders. Exchange and regulators can use these results when suggesting alterations in trading mechanisms and rules.

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 $I \ x \ J$ reduced form estimated coefficients into a (1x IJ) vector $\mathbf{c}$ in ji order.[19]

Let a_j and b_j be the mean and standard deviation of the j^{th} independent variable.[20] Insert these values into (1x IJ) 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 $\mathbf{s}_{22}$

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

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

$$
\mathbf{m}_1=\begin{bmatrix} a_1\\0\\0\\0\\\hline a_2\\0\\0\\0\\\hline \vdots \end{bmatrix}
\quad
\mathbf{m}_2=\begin{bmatrix} 0\\a_1\\0\\0\\\hline 0\\a_2\\0\\0\\\hline \vdots \end{bmatrix}
\begin{array}{l}\left.\vphantom{\begin{array}{c}0\\0\\0\\0\end{array}}\right\} I \text{ elements in each partition}\\[1em] J \text{ partitions}\\ \\ \\ \end{array}
\quad
\mathbf{s}_{11}=\begin{bmatrix} a_1+b_1\\0\\0\\0\\\hline a_2\\0\\0\\0\\\hline \vdots \end{bmatrix}
\quad
\mathbf{s}_{21}=\begin{bmatrix} a_1\\0\\0\\0\\\hline a_2+b_2\\0\\0\\0\\\hline \vdots \end{bmatrix}
\quad
\mathbf{s}_{12}=\begin{bmatrix} 0\\a_1+b_1\\0\\0\\\hline 0\\a_2\\0\\0\\\hline \vdots \end{bmatrix}
\quad
\mathbf{s}_{22}=\begin{bmatrix} 0\\a_1\\0\\0\\\hline 0\\a_2+b_2\\0\\0\\\hline \vdots \end{bmatrix}.
$$

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 $(r=1)$, cross-equation restriction $\Delta p_{ji} = 0$. Using the covariance matrix $\boldsymbol{\Psi}$[21] of the reduced form parameter estimates $\mathbf{c}$ with a sample size of T, the Wald test statistic

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

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 $\boldsymbol{\Psi}$, the Wald statistic

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

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

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

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Table I. 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. Private 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
Private information	0.002676	0.015272	-0.121806	0.249431

Table II. Estimation of the 7-Way Event Structure on a Stock-By-Stock Basis

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 Can. Buy	Last Can. Sell	Last Limit Buy	Last Limit Sell	Last Mkt. Buy	Last Mkt. Sell	Private 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**	**1.773**	**1.045**	**1.560**	**1.016**	**1.005**	**0.876**	2.085	**-0.288**
Cancel Sell	**36.70**	-0.108	**-0.558**	**1.15**	**-25.53**	**1.54**	**-70.07**	-2.006	**.419**	**0.888**	**1.712**	**1.002**	**1.512**	**0.735**	**1.095**	0.406	**-0.352**
Limit Buy	**136.46**	**0.574**	**-0.318**	**1.32**	2.442	**1.47**	**81.602**	**1.905**	**.404**	**1.506**	**1.101**	**1.354**	**0.924**	**0.951**	**0.865**	**7.154**	**-0.346**
Limit Sell	**154.9**	**-0.362**	**0.399**	**1.41**	**18.010**	**1.49**	**-84.91**	0.837	**.443**	**1.114**	**1.520**	**0.960**	**1.317**	**0.842**	**.0997**	**-10.53**	**-0.387**
Market Buy	**-132.8**	**0.835**	-0.018	**1.17**	**90.639**	**1.67**	**121.96**	1.074	**.768**	**0.757**	**0.570**	**0.674**	**0.575**	**1.089**	**0.469**	**9.068**	**-0.286**
Market Sell	**-114.0**	**0.207**	**0.611**	**0.77**	**-104.8**	**1.14**	**-105.4**	-0.043	**.719**	**0.504**	**0.855**	**0.612**	**0.732**	**0.647**	**1.074**	**-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**	**2.41**	**0.812**	**2.21**	**0.83**	**0.80**	**0.45**	0.01	**-0.26**
Cancel Sell	0.06	-0.14	**-0.39**	**0.14**	**-0.57**	**0.52**	**-0.34**	**-0.16**	**0.42**	**0.83**	**2.171**	**0.71**	**2.08**	**0.32**	**0.83**	-0.12	**-0.28**
Limit Buy	**3.17**	**0.69**	**-0.41**	**0.38**	**1.08**	**0.64**	**0.28**	**0.48**	**0.63**	**2.72**	**1.023**	**3.93**	**1.18**	**1.31**	**0.80**	**0.71**	**-0.49**
Limit Sell	**3.50**	**-0.39**	**0.55**	**0.48**	**-1.13**	**1.04**	**-0.38**	**0.38**	**0.79**	**0.99**	**2.559**	**1.02**	**3.40**	**0.73**	**1.18**	**-0.75**	**-0.66**
Market Buy	**-2.13**	**0.48**	0.01	**0.31**	**1.57**	**0.40**	**0.64**	0.068	**1.64**	0.01	**-0.263**	**0.15**	-0.12	**1.58**	**0.12**	**0.40**	-0.02
Market Sell	**-1.98**	0.04	**0.34**	0.21	**-1.34**	**0.45**	**-0.35**	**-0.23**	**1.53**	**-0.23**	**0.166**	**-0.09**	**0.26**	**0.21**	**1.87**	**-0.60**	-0.13
No Activity	**-2.67**	-0.36	0.06	**-1.70**	**-0.59**	**-3.60**	-0.10	-0.45	**-5.20**	**-6.74**	**-6.468**	**-7.95**	**-7.64**	**-4.98**	**-5.27**	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 III. Estimation of the 13-Way Event Structure on a Stock-By-Stock Basis

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 Can. Buy	Last Can. Sell	Last Limit Buy	Last Limit Sell	Last Mkt. Buy	Last Mkt. Sell	Private 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**	**0.46**	**-4.69**	**2.44**	**-2.84**	**2.03**	**-4.06**	-1.77	**-0.22**
Cancel Sell	**56.49**	**-0.48**	**-0.26**	**1.08**	5.23	**1.44**	**-35.66**	-0.54	**0.42**	**-4.61**	0.33	**-2.98**	**2.46**	**-4.3**	**2.15**	-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**	**1.26**	**1.15**	**1.51**	**1.20**	**0.82**	**0.84**	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**	**1.16**	**1.07**	**1.23**	**0.91**	**0.80**	**0.73**	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**	**1.28**	**0.87**	**1.35**	**0.92**	**0.79**	**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**	**1.03**	**1.08**	**0.93**	**1.33**	**0.83**	**1.04**	**-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**	**1.32**	**0.74**	**1.40**	**0.71**	**1.06**	**-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**	**1.30**	**1.04**	**0.93**	**1.36**	**0.67**	**0.98**	**-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**	**1.03**	**0.77**	**0.94**	**0.80**	**0.94**	0.44	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**	0.51	**1.06**	0.44	**0.78**	**0.84**	**1.38**	**-16.58**	0.41
Market Buy	2.69	-0.35	0.29	**1.01**	**65.28**	**1.16**	**123.8**	2.78	**0.79**	**0.78**	**0.57**	**0.92**	**0.81**	**1.36**	**0.64**	5.10	0.15
Market Sell	-9.69	-0.46	0.32	-.49	**-76.94**	0.67	**-146.3**	1.47	**0.72**	**0.59**	**0.81**	**0.81**	**.093**	**0.61**	**1.40**	-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**	0.04	**-1.05**	**1.74**	**-1.15**	**1.06**	**-1.10**	0.01	**-0.08**
Cancel Sell	0.02	**-0.04**	**-0.05**	**0.04**	0.01	**0.14**	**-0.06**	**-0.04**	**0.10**	**-0.93**	0.05	**-1.09**	**1.61**	**-1.02**	**1.05**	-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**	**1.17**	**1.07**	**1.45**	**0.92**	**0.51**	**0.50**	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	**1.09**	**0.02**	**1.80**	**0.44**	**0.65**	**0.41**	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	**1.21**	**0.78**	**1.74**	**0.62**	**0.73**	**0.50**	**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	**0.70**	**1.15**	**0.54**	**1.56**	**0.44**	**0.74**	**-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	**0.55**	**0.98**	**0.40**	**1.53**	**0.44**	**0.55**	**-0.43**	**-0.22**
BTQ Limit Sell	-0.10	**0.14**	**-0.37**	**0.25**	0.07	**035**	0.00	-0.02	**1.01**	**1.00**	**1.03**	**0.86**	**1.20**	**0.86**	**0.45**	-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**	**0.32**	**0.12**	**0.28**	**1.69**	**0.69**	**0.18**	**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**	**0.22**	**0.39**	**0.19**	**0.34**	**0.23**	**0.78**	**-0.31**	0.10
Market Buy	**-0.54**	**0.20**	**0.11**	**0.19**	**0.57**	**0.25**	**0.90**	**0.18**	**1.26**	**0.59**	**0.23**	**0.60**	**0.39**	**1.60**	**0.46**	**0.17**	0.02
Market Sell	**-0.65**	**0.09**	**0.19**	**0.07**	**-0.37**	**0.35**	**-0.99**	0.03	**1.12**	**0.25**	**0.67**	**0.42**	**0.69**	**0.50**	**1.90**	**-0.29**	**-0.14**
No Activity	**-2.36**	-0.06	0.28	**-1.70**	**-0.72**	**-3.20**	**-0.17**	**0.74**	**-5.48**	**-6.24**	**-6.08**	**-8.97**	**-8.97**	**-6.20**	**-6.47**	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 IV. 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 Can. Buy	Last Can. Sell	Last Limit Buy	Last Limit Sell	Last Mkt. Buy	Last Mkt. Sell	Private 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	2.59	1.03	1.90	0.85	0.73	0.38	0.07	-0.24
Cancel Sell	0.89	0.10	-0.75	0.07	-0.14	0.14	-0.56	-0.26	0.47	1.02	2.36	0.82	1.76	0.40	0.80	-0.08	-0.25
Direct+ Buy	-0.12	0.01	-0.01	0.01	-0.02	-0.02	0.02	-0.01	0.01	0.01	0.001	0.01	-0.001	0.03	-0.0001	0.01	0.001
Direct+ Sell	-0.06	-0.01	0.002	0.01	-0.001	0.003	-0.01	-0.004	0.005	-0.0008	0.01	0.0006	.0008	-0.00	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	1.92	0.89	3.12	1.19	1.17	0.56	0.28	-0.72
Limit Sell	3.37	-0.48	-0.30	0.29	0.95	-0.72	-0.55	0.17	1.01	0.89	1.82	1.16	2.94	0.57	1.17	-0.42	-0.82
Market Buy	-3.21	-0.14	-0.40	0.69	-0.14	0.14	1.52	-0.02	1.95	1.63	-0.09	0.51	0.12	2.10	0.41	0.32	-0.43
Market Sell	-3.12	0.21	-0.53	0.58	-0.14	0.17	-1.37	0.30	1.84	-0.11	0.26	0.10	0.61	0.45	2.62	-0.50	-0.40
No Activity	-1.76	0.64	2.23	-2.05	-0.59	0.45	-0.14	0.50	-6.45	-6.50	-6.29	-1.76	-7.51	-5.77	-5.97	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	1.48	0.99	1.72	0.87	0.69	0.44	0.08	-0.26
Cancel Sell	0.67	0.39	-0.69	0.10	-0.14	0.13	-0.50	-0.21	0.49	0.92	1.40	0.83	1.60	0.42	0.75	-0.07	-0.27
Limit Buy	2.39	-0.76	-0.79	0.27	-0.36	0.22	0.50	0.14	0.92	1.84	1.06	2.00	1.39	1.23	0.67	0.28	-0.81
Limit Sell	3.31	-3.41	-0.34	0.30	0.97	-0.74	-0.51	0.18	1.04	1.09	1.78	1.42	2.00	0.68	1.26	-0.44	-0.84
Market Buy	-3.60	0.01	-0.42	0.78	-0.18	0.17	1.59	-0.06	2.03	0.41	0.10	0.78	0.35	2.07	0.53	0.36	-0.42
Market Sell	-3.41	0.67	-0.55	0.66	-0.15	0.18	-1.42	-0.35	1.94	0.10	0.47	0.35	0.86	0.55	2.28	-0.52	-0.39
No Activity	-0.88	2.69	3.06	-2.21	-0.67	0.49	-0.15	0.46	-6.79	-5.86	-5.80	-7.13	-7.08	-5.69	-5.92	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	2.09	0.68	1.39	0.51	0.46	0.30	-0.09	-0.29
Cancel Sell	2.53	0.98	-0.58	-0.07	-0.08	0.20	-0.38	-5.87	-6.51	0.76	1.88	0.47	1.38	0.21	0.67	-0.30	-0.67
Limit Buy	9.90	-3.21	0.76	-0.14	-0.26	0.14	0.56	-16.02	-13.58	1.65	0.68	2.96	1.36	1.02	0.56	-0.16	-0.34
Limit Sell	9.34	2.58	-0.50	0.35	0.05	-0.08	-0.36	-16.09	-15.39	0.87	2.08	1.54	3.24	0.83	1.00	-0.84	-0.46
Market Buy	-8.38	-2.06	-1.12	0.95	-0.46	0.53	1.37	-14.80	82.02	0.02	-3.96	0.34	-0.04	3.18	0.55	1.95	-0.03
Market Sell	-5.13	-0.75	0.52	0.23	-0.25	0.41	-1.18	-12.47	-12.44	-0.41	-0.07	-0.11	0.19	0.36	2.26	-1.93	0.02
No Activity	-9.76	7.96	1.97	-1.12	1.02	-0.94	-0.71	71.74	-27.59	-5.00	-4.86	-6.61	-6.66	-6.08	-5.36	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	1.46	-0.00	0.04	-0.01	-0.13	0.03	0.09	-0.17
Cancel Sell	2.58	4.40	-0.20	-0.02	-0.17	0.16	-0.67	-0.31	0.56	-0.04	1.34	0.00004	-0.02	0.02	-0.17	-0.12	-0.18
Limit Buy	7.66	7.91	0.56	0.21	-0.41	0.25	0.66	0.12	0.87	0.34	-0.17	1.63	-0.10	-0.08	-0.21	0.28	-0.45
Limit Sell	7.47	7.51	0.45	0.16	0.88	0.68	-0.66	0.18	1.08	-0.19	0.33	-0.09	1.47	-0.24	-0.08	-0.49	-0.58
Market Buy	-3.57	6.58	0.03	0.97	-0.18	0.17	1.81	-0.04	2.15	0.10	-0.22	-0.08	-0.09	1.08	-0.15	0.38	-0.36
Market Sell	-3.32	6.84	-0.06	0.79	-0.18	0.20	-1.63	-0.36	2.04	-0.31	0.17	-0.16	-0.10	-0.11	1.40	-0.58	-0.32
No Activity	-13.09	-37.7	-0.99	-2.12	-0.35	0.27	-0.22	0.64	-7.08	-1.36	-1.44	-1.35	-1.14	-0.55	-0.83	0.46	2.05

Table V. 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 Can. Buy	Last Can. Sell	Last Limit Buy	Last Limit Sell	Last Mkt. Buy	Last Mkt. Sell	Private 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	0.04	0.02	0.04	0.03	0.02	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	0.03	0.04	0.03	0.04	0.02	0.03	-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	0.06	0.15	0.11	0.08	0.08	-0.008	-0.04
Limit Sell	0.06	-0.36	-0.0001	0.03	-0.009	0.01	-0.01	0.02	0.28	0.07	0.09	0.12	0.18	0.10	0.12	-0.02	-0.07
Market Buy	0.01	-0.11	0.003	0.02	0.21	-0.13	0.02	-0.02	0.24	0.05	0.05	0.11	0.11	0.15	0.11	0.02	-0.02
Market Sell	0.03	-0.24	-0.02	0.03	-0.01	0.01	-0.04	-0.01	0.23	0.04	0.05	0.08	0.09	0.09	0.14	-0.03	-0.02
No Activity	-0.18	0.89	0.02	-0.10	-0.21	0.13	0.02	0.01	-1.13	-0.33	-0.35	-0.55	-0.57	-0.49	-0.52	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	1.10	0.57	0.94	0.55	0.48	0.36	0.03	-0.22
Cancel Sell	0.82	-2.39	-0.04	0.22	-0.04	0.05	0.16	-0.08	0.67	0.64	1.17	0.62	1.02	0.41	0.58	-0.02	-0.21
Limit Buy	0.18	-1.45	-0.79	0.61	-0.13	0.07	-0.19	0.13	1.54	1.30	0.85	1.88	1.19	0.98	0.82	0.06	-0.73
Limit Sell	0.19	-1.19	-0.78	0.67	0.71	-0.54	0.09	0.18	1.62	0.89	1.41	1.28	2.08	0.86	1.14	-0.19	-0.77
Mkt. Buy	-1.33	-0.93	-0.51	0.57	-0.03	0.04	-0.10	-0.19	1.61	0.52	0.35	0.80	0.57	1.61	0.62	0.15	-0.44
Mkt. Sell	-1.31	-3.91	-0.23	0.55	0.05	0.07	0.81	-0.26	1.64	0.37	0.56	0.59	0.83	0.64	1.69	-0.28	-0.44
No Activity	-2.65	10.11	2.59	-2.87	-0.57	0.42	-0.65	0.32	-7.67	-4.85	-4.94	-6.14	-6.26	-5.00	-5.23	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	2.53	1.10	1.97	1.01	0.81	0.50	0.04	-0.31
Cancel Sell	0.37	0.53	-1.44	0.09	-0.13	0.11	-0.48	-0.25	0.46	1.03	2.18	0.91	1.72	0.46	0.82	-0.08	-0.30
Limit Buy	2.01	-1.31	0.47	1.84	-0.29	0.20	0.60	-0.03	0.71	1.96	1.08	3.16	1.37	1.29	0.70	0.26	-0.64
Limit Sell	1.91	-1.87	-0.06	0.004	0.89	-0.70	-0.60	-0.02	0.76	1.06	1.74	1.27	2.77	0.64	1.17	-0.36	-0.70
Mkt. Buy	-2.62	-0.48	-0.48	0.49	-0.16	0.14	1.23	0.07	1.80	0.35	0.11	0.65	0.30	2.22	0.51	0.25	-0.38
Mkt. Sell	-2.34	0.47	0.63	0.40	-0.11	0.13	-1.15	-0.17	1.63	0.07	0.42	0.27	0.74	0.52	2.40	-0.39	-0.32
No Activity	6.47	2.50	2.72	-1.24	-0.73	0.56	-0.11	0.56	-5.58	-7.03	-6.65	-8.26	-7.93	-5.95	-6.12	0.29	2.68

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

Table VII. OLS Regressions of Orders / No Activity Events Aggregated Over Five Minute Intervals

The table reports the results from estimating equation (1) aggregated over five minute intervals. In Panel A, we report the estimated OLS regression coefficients, where each row is one OLS regression. In each row, the dependent variable is the change in number of orders or no activity events for a given stock over a five minute interval compared to the previous five minute interval. In Panel B, we report the economic sensitivities (change in the number of orders or no activity events caused by a one standard deviation shock in the explanatory variable).

OLS Dependent Variable	Percent Spread	Rel. Bid Size	Rel. Ask Size	Rel. Vol.	Own Ret.	Own Ret. Sqr.	Mkt. Ret.	Time	Time Sqr.	Last 5 Min Can. Buy	Last 5 Min Can. Sell	Last 5 Min Limit Buy	Last 5 Min Limit Sell	Last 5 Min Mkt. Buy	Last 5 Min Mkt. Sell	Private Infor-mation	NYSE At NBBO
Panel A: Estimated OLS Regression Coefficients																	
Cancel Buy	7.37	0.001	-0.006	-0.07	72	-147	**1170**	**-60**	0.37	**-0.41**	**0.23**	**0.06**	**-0.10**	**0.11**	**-0.03**	**88.97**	1.41
Cancel Sell	2.28	0.001	-0.008	-0.05	**-227**	61	**-1986**	**-52**	0.63	**0.19**	**-0.37**	**-0.05**	0.01	**0.03**	**0.04**	29.38	0.62
Limit Buy	-0.38	0.003	-0.021	-0.18	**-613**	**748**	**1292**	**-72**	0.09	**0.16**	**0.41**	**-0.43**	**-0.17**	**0.14**	**0.04**	**147.67**	0.44
Limit Sell	0.70	0.003	-0.025	-0.12	137	-324	-841	**-55**	0.10	**0.29**	**0.25**	-0.01	**-0.53**	**0.09**	**0.05**	43.60	-2.54
Market Buy	-17.50	0.003	-0.019	-0.19	**-722**	**755**	**2975**	**-41**	0.06	0.05	**0.45**	0.02	**-0.15**	**-0.30**	**0.06**	**199.90**	3.46
Market Sell	-19.56	0.004	-0.036	-0.19	-245	107	**-1658**	**-49**	0.82	**0.37**	**0.13**	**-0.13**	-0.01	**0.06**	**-0.39**	31.22	2.58
No Activity	-24.16	0.005	-0.040	-0.13	-133	111	**-3214**	**-297**	-1.69	**0.62**	**0.67**	**-0.21**	**-0.34**	**-0.11**	0.04	**186.78**	**5.56**
Panel B: Economic Sensitivities (Change in the Number of Orders or No Activity Events Caused By One Std Dev Shock in the Explanatory Variable)																	
Cancel Buy	0.09	0.13	-0.10	-0.04	0.18	-0.23	**0.57**	**-1.37**	0.17	**-20.03**	**11.00**	**5.10**	**-8.34**	**8.88**	**-1.92**	**0.58**	0.25
Cancel Sell	0.03	0.15	-0.15	-0.03	**-0.57**	0.10	**-0.98**	**-1.18**	0.29	**9.21**	**-17.60**	**-4.11**	0.78	**2.27**	**2.76**	0.19	0.11
Limit Buy	0.00	0.42	-0.38	-0.10	**-1.53**	**1.19**	**0.63**	**-1.64**	0.04	**7.81**	**19.19**	**-37.19**	**-13.76**	**10.71**	**3.24**	**0.96**	0.08
Limit Sell	0.01	0.45	-0.46	-0.06	0.34	-0.51	-0.41	**-1.24**	0.04	**14.28**	**11.67**	-0.53	**-44.08**	**6.77**	**4.21**	0.28	-0.45
Market Buy	-0.22	0.42	-0.34	-0.11	**-1.80**	**1.20**	**1.46**	**-0.94**	0.03	2.31	**21.01**	1.56	**-12.20**	**-23.92**	**4.44**	**1.29**	0.61
Market Sell	-0.25	0.63	-0.66	-0.10	-0.61	0.17	**-0.81**	**-1.11**	0.38	**18.35**	**6.20**	**-11.01**	-1.07	**4.75**	**-30.05**	0.20	0.46
No Activity	-0.31	0.77	-0.73	-0.07	-0.33	0.18	**-1.58**	**-6.72**	-0.77	**30.16**	**31.55**	**-17.86**	**-28.20**	**-8.59**	3.11	**1.21**	**0.98**

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 based on a standard t-test. The sample size is 11,398.