**Information, Execution Quality, and Order Routing on Nasdaq**

Prior research indicates that both execution speed and cost are important to traders, but that these two dimensions of execution quality are negatively related across U.S. equity markets. In our paper, we examine how Nasdaq traders, who are (un)informed about future price changes, trade-off between speed and cost in their order routing decisions. We find that informed traders are more likely to choose trading systems that allow them to trade-off lower cost for faster speed whereas uninformed traders are more likely to choose trading systems that allow them to sacrifice speed for lower costs. Our results indicate that traders' have varying preferences for the different dimensions of execution quality based on their information levels and that these differences subsequently influence order routing decisions.

## 1. Introduction

U.S. equities trade in multiple markets and research shows that execution quality is an important determinant of which market center traders choose to submit their orders too. For example, Boehmer et al. (2007) examine market center execution quality reports for New York Stock Exchange listed stocks. They find market centers reporting low execution costs and fast fills subsequently attract more order flow. While execution cost and execution speed are important measures of execution quality, these two dimensions of execution quality are also negatively related. Market centers that report faster (slower) fill rates also tend to report higher (lower) trading costs (see, for example, Boehmer, 2005, and Battalio et al. 2003).[1] If execution speed and execution cost are important to traders, but negatively related across markets, then which dimension of execution quality do traders prefer and how does this subsequently influence their order routing decision? In our paper, we provide some insight for answering this question. Our paper focuses on speed vs. cost trade-offs, and subsequent order routing choice, with respect to trader information content. For example, are informed traders more willing to sacrifice speed for lower costs, or are they more willing to pay a higher out of pocket cost in exchange for faster execution? How informed traders make such trading decisions has important implications for market design, market prices and transaction dynamics. Using unique data on more than 3,000 traders from a U.S. broker-dealer, we find that informed traders are more likely to trade-off lower costs for faster speed in their order routing decisions.

Our paper focuses on trader's order routing decision and subsequent execution quality in the Nasdaq marketplace. On Nasdaq-listed stocks, competing market makers in the Nasdaq market center provide a significant and stable source of liquidity. Traders can execute against market maker displayable quotes using automated execution systems or, for larger orders, negotiate with market makers for trading at different (favorable) prices. An alternative to trading with a market maker is to

[1] Other studies document an inverse relation between speed and cost occurs across the trading day (Garvey and Wu, 2008) and when market structure changes (Hendershott and Moulton, 2008).

place a limit order in the marketplace and, effectively, compete with market makers for trading at better prices.[2] Traders can display their limit order in the consolidated quote stream by placing it on the Nasdaq stock market, or on any number of competing electronic trading systems.[3] The multiple execution options available to traders routinely force them to make important tradeoff decisions with respect to execution cost and execution speed. While some traders may prefer speed to cost or vice versa, economic theory generally assumes that informed traders have a tendency to execute their orders quickly in order to exploit short-lived information. That is, order routing options that offer fast execution, whether on Nasdaq or on a competing electronic trading system that is part of the consolidated quote stream, should attract more informed traders.

We find traders are much more likely to experience lower trading costs when they use market maker trading systems that offer price improvement opportunities, but these execution systems result in much slower execution because human intermediation is involved in the trading process. Traders can execute faster if they use market maker automated execution systems, but execution over these systems typically result in much higher trading costs because traders are forced to pay the bid-ask spread. We find price impacts are significantly higher for orders executed over automated market maker trading systems than on negotiated market maker trading systems, which suggest informed traders are more willing to route their orders over trading systems that trade-off lower costs for faster speed.

An alternative to trading with a Nasdaq market maker is to route a limit order to an electronic trading system. While traders can avoid the bid-ask spread by posting a limit order in the marketplace,

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[2] This came about with the 1997 Order Handling Rules. Several researchers have examined the effect of this important rule change. See, for example, Chung and Chuwonganant (2004), Bessembinder (2000) and Barclay et al. (1999).

[3] Alternative trading systems, such as Electronic Communication Networks, typically display their order in the consolidated quote streams through exchanges. Some market centers do not publicly display their orders (i.e. dark pools). However, market centers that display their orders have traditionally attracted a majority of Nasdaq order flow.

this opens them up to adverse selection costs when (if) execution occurs. Both informed and uninformed traders choose this option. We find that the information content behind a limit order is highly dependent upon how the order is priced in relation to the national best bid and offer (NBBO) at the time of submission. Execution speed declines and price impacts rise as traders submit more aggressively priced limit orders. Price impacts are highest and execution speed is fastest for marketable limit orders, i.e. buy (sell) limit price set greater (less) than or equal to the national best offer (bid) at the time of order submission. On the other hand, price impacts decline and execution time rises as orders are priced further away from the inside quotes.

Our study contributes to the financial literature in two important ways. First, we contribute to the literature on informed trader behavior in securities markets. Theoretical models generally classify traders as either informed or uninformed (i.e. liquidity traders) based on their information content. Informed traders play a significant role in the price discovery process and understanding the motives and actions of this trader group has long been an important focus of microstructure studies. By using data on individual traders our study is able to directly test common assumptions and theories about informed trader behavior that has been put forward in prior studies. For example, several studies have used transaction level data to examine quotes (e.g. Huang, 2002) and trades (Barclay et al. 2003) on Nasdaq and on Electronic Communication Networks (ECNs). ECNs are electronic limit order books that automatically match buy and sell orders at specified prices. The financial literature has found that Electronic Communication Networks (ECNs) quotes (e.g. Huang 2002) and trades (e.g. Barclay et al. 2003) are more informative than Nasdaq market maker quotes and trades. Barclay et al. (2003) argue informed traders have a preference for trading on ECNs because trading is completely anonymous and fast. Do trading systems offering speed and anonymity attract more informed traders? It is difficult to answer this question by examining quote and trade data on Nasdaq and ECNs because both of these markets offer traders similar execution services. For example, Nasdaq market makers have long offered automated or fast execution (with pre-trade anonymity) options for public traders.[4] By using data on individual traders, rather than transaction level data, we are able to measure execution speed directly, and then test whether trading systems (both on Nasdaq and ECNs) that offer fast execution and anonymity do, indeed, attract more informed traders.

Our study also contributes to the financial literature on execution quality. Despite frequent references and overtures to execution quality, or what defines a "best execution", no clear definition exists (see Macey and O'Hara, 1997). The multiple dimensions of execution quality, and varying preferences of individual traders, have largely complicated efforts to uniformly define execution quality across all traders and or executions.[5] A small but growing academic literature has begun to examine execution quality along more than one dimension. These studies show that traders are concerned about both execution speed and execution costs (e.g. Boehmer et al. 2007), but that these two dimensions of execution quality are negatively related (e.g. Boehmer, 2005). Because the data used in prior studies usually do not identify individual traders, it is not possible to assess how individual market participants trade-off between speed and costs.[6] For example, it is not possible to determine, say, what increase in costs traders are willing to accept for a reduction in speed. By using proprietary order level data on individual traders our study is able to directly address speed-cost tradeoffs in the context of traders

[4] Barclay et al. (2003) acknowledge market makers offer competing (fast execution) services to ECNs, but they do not analyze orders executed over automated market maker trading systems. Instead, their analysis focuses more generally on market maker trades vs. ECN trades.

[5] A multi-dimensional analysis of execution quality is not possible with transaction level data, which only allows for researchers to compute a uni-dimensional estimate of execution costs. With transaction level data, execution speed is not measurable and execution costs are evaluated in terms of the parts (i.e. trades) rather than the sum of the parts (i.e. the order). See Bessembinder (2003) for some of the issues involved assessing trade execution costs from transaction level data.

[6] For example, Battalio et al. (2003) use dealer audit trail data to examine execution quality dimensions whereas Boehmer (2005), Boehmer et al. (2007), and Hendershott and Moulton (2008) use market center execution quality (Dash 5) reports. Dash 5 reports are published monthly by market centers for each stock, in four aggregate order size categories: 100-499, 500-1,999, 2,000-4,999, and 5,000-9,999 shares. While Garvey and Wu (2008) use trader-defined order level data, their focus is on how execution quality dimensions vary across the trading day rather than on individual order routing strategies.

order routing choice.  A better understanding of which execution quality dimension traders prefer has many useful applications including helping to clarify what "best execution" actually means.

The remainder of our paper proceeds as follows.  In the next Section, we discuss the Nasdaq market structure and develop our main hypothesis.  Section 3 describes the data.  In Section 4, we examine what order routing choices traders make and in Section 5 we examine the multiple dimensions of order execution quality and information across different Nasdaq trading systems.  In Section 6, we provide an individual trader level analysis of the factors influencing traders order routing choice and Section 7 concludes.

## 2. Hypothesis Development

### *2.1. The Nasdaq Market Structure and Order Routing Choice*

Traders have multiple options with where to route Nasdaq stock orders for execution.  In the Nasdaq stock market, registered market makers stand ready to buy and sell securities throughout the trading day.  Traders can execute against market maker quotes using automated execution systems operated by Nasdaq, or by directly setting up (automated) execution links with a designated market making firm.  Smaller orders are typically executed over automated trading systems.  While automated trading is fast and usually anonymous on a pre-trade basis, execution costs are higher because traders must pay the dealer bid-ask spread.  Market makers also enter into contractual arrangements with broker-dealers, hedge funds, institutional investors, etc. to execute their orders at competitive prices through negotiated dealings.  Typically, larger orders are executed over these negotiated trading systems.  Negotiated dealings with market makers can be slow and are not anonymous, but execution costs are typically lower because identity is known and market makers have adequate time to understand a client's motive for trading.

An alternative to trading with a market maker is to submit a limit order. Traders can directly place their limit order alongside market maker quotes in the Nasdaq stock market,[7] or on a number of competing electronic trading systems. Because most market centers forward their quotes to the consolidated quote stream, traders can simultaneously view and readily access quotes and orders across the multiple market centers. After the implementation of the 1997 SEC Order Handling Rules, Electronic Communication Networks (ECNs) became a popular execution venue for limit order traders on Nasdaq. ECNs are electronic limit order books that automatically match buy and sell orders at specified prices. The Securities and Exchange Commission classifies ECNs as alternative trading systems (ATS) for regulatory purposes and limit orders placed in their books are typically displayed on the consolidated quote stream through exchanges. The ATS regulatory status offered by the SEC is important because it enables an inexpensive way for new trading systems (ECNs or other ATSs) to enter the U.S. marketplace and compete with the traditional Exchanges for order flow by offering competitive pricing and or other attractive features. More successful ATSs often merge with each other or are acquired by traditional Exchanges. Some ATSs turn into Exchanges themselves. For example, the Better Alternative Trading System (i.e. BATS) transitioned from an ECN to an Exchange in November 2008. BATS was an ECN for less than three years.

*2.2. Predictions on Trader Order Routing Choice on Nasdaq*

In competitive securities markets, such as U.S. equity markets, trader information horizons are assumed to be relatively short and traders with information will be forced to execute quickly before competitive forces begin to erode (eliminate) their information advantage. Short information horizons and informed traders preference for fast execution are standard modeling assumption in much of the market microstructure literature, which assumes informed traders (exclusively) use market orders (see,

[7] Nasdaq began accepting nonmarket-maker limit orders on February 10, 2003.

for example, Rock, 1990 and Glosten, 1994). Informed traders strong preference for executing quickly is also consistent with Barclay et al. (2003). While traders who posses information are more likely to be concerned about executing quickly in order to capitalize off of their information, traders who do not posses information are probably less likely to be concerned about executing quickly, and more likely to be more concerned about achieving low execution costs.

The above argument suggest traders' have varying preferences for the different dimensions of execution quality based on their information levels and that these differences systematically influence order routing decisions. The notion that traders have varying preferences for the different dimensions of execution quality is consistent with Garvey and Wu (2008), who argue that these differences in preferences result in intraday time varying patterns in order execution quality dimensions. In the context of our study, differences in preferences towards speed and cost will result in more informed traders choosing to route their order over trading systems that offer fast execution. On the other hand, uninformed traders will choose trading systems that offer low execution costs. For example, in the context of Nasdaq's market structure described above, this suggest that informed traders are more likely to use automated market maker trading systems whereas uninformed traders are more likely to use negotiated market maker trading systems.

The main hypothesis we set out to test in this paper is as follows:

*H1: Informed traders are more likely to route their orders over trading systems that trade-off lower costs for faster speed whereas uninformed traders are more likely to route their orders over trading systems that trade-off faster speed for lower costs.*

## 3. Data

We use three data sources in our study. First, proprietary order level data are obtained from a large U.S. broker-dealer. The proprietary data enable us to examine order routing choices, execution quality, and the information content of more than 3,000 active traders in the U.S. equity markets. We then obtain historical intraday pricing data from Reuters[8] so that we can simultaneously examine market conditions, such as the bid-ask spread, bid/ask depth, market volatility, and trading volume when traders make order routing decisions. Finally, we use The Center for Research and Security Price (CRSP) database to analyze summary trading information on the stocks being traded, such as a stock's price, market capitalization and trading activity.

The proprietary data originate from a large U.S. broker-dealer with clients and branch office locations throughout the U.S. There are multiple trading operations within the broker-dealer. We obtained data from the firm's brokerage operation where they provided their clients with direct access trade execution software and administrative trading support. Unlike traditional brokerage firms who take care of their clients order execution process, direct access brokerages allow their clients to choose where and how their order is routed for execution. Thus, direct access brokerage data provide an ideal setting for examining trader's order routing choice.

Firms providing direct access execution services tend to attract more sophisticated market participants who trade often and in large trade sizes. For example, the average trader in our sample executes 33 trades a day and the average trade size is 1,203 shares.[9] Because traders who use direct access brokers trade often and in large sizes, a sizeable portion of trading volume in U.S. equity markets subsequently flows through these brokerage firms. For example, Goldberg and Lupercio (2004) find that

[8] For information on Reuters tick history database, see http://about.reuters.com/productinfo/tickhistory/.
[9] The average trade size on Nasdaq stocks during our sample period was approximately 579 shares (source: Nasdaq Market Center reports).

approximately 40% of Nasdaq and NYSE trading volume is executed by the more active traders (25+ trades per day) who trade through Direct Access brokers.

Our sample period runs from October 7, 1999 to August 1, 2003. The data are in the form of an order-level transaction database. For every order request, we have information such as the identity of the trader, the time of submission, the time of execution, the market(s) where the order was sent, the original volume submitted, the executed volume, the execution price, the stock symbol, the order type, the contra party (if given up), the location of the trader in the U.S., and various other information. If the order received multiple fills, we have the information listed for each fill. In total, data consists of over 10 billion executed shares with a trade value exceeding $101 billion. There are over 6 million orders and 8 million trades. The orders are submitted by 3,258 accounts on 4,667 securities.

We analyze data on Nasdaq listed stock trading during the main trading hours. We filtered the data to include Nasdaq stocks because these stocks represent a majority (95%) of the orders in our data and because of order routing differences between NYSE and Nasdaq-listed stocks. Nasdaq stocks trade in multiple trading venues. The primary benefit of using a direct access broker is the ability to route orders to various trading venues. In contrast, NYSE-listed trading is mainly confined to a single trading location (NYSE) during our approximate four year sample period. Therefore, clients opened an account at our firm with the primary intent of benefiting their Nasdaq trading. Because trading before the open or after the close occurs in a different manner, we excluded these orders too. Finally, we excluded orders on stocks in which we were unable to retrieve data from The Center for Research and Security Price (CRSP) database or intraday data from the Reuters tick history database. We link trading information from these two publicly available data sources to our proprietary data when conducting our empirical analysis.

## 4. Order Routing Choice on Nasdaq

Traders in our sample use both automated and negotiated execution systems when trading with market makers. And they often route their limit orders to ECNs.[10] While traders usually route their orders directly to a trading venue, they also use algorithmic sweep orders that search across multiple markets for the best price available and then automated order routing subsequently occurs. With a sweep order, a trader does not specifically choose an execution venue (or price) upon order submission. We begin our analysis by providing summary information on traders order routing decisions in Table 1. Approximately 70% of the orders are limit orders routed directly to electronic limit order books, 20% of the orders are routed directly to Nasdaq market makers, and 10% of the orders are market sweep orders in which the trader does not specify a particular execution venue. Using intraday tick data provided by Reuters, we segregate limit (ECN) orders further based on the relation of the limit price to the national best bid and offer (NBBO). When submitting a limit order, traders are most likely to set their limit price at the national best bid (offer). For each of the 5 million orders, we also examine whether the order was a buy/sell and market conditions, such as the bid-ask spread and depth at the time of order submission. Buy (sell) orders are more likely to be associated with more (less) aggressive order types and order routing strategies. For example, limit orders with a price at or below the inside quotes are more likely to be sell orders. Traders also appear to have a greater tendency to route their orders to market makers when trading conditions become more difficult. For example, when the bid-ask spread is wider, traders are more likely to submit their order to a market maker.

[10] Traders route their orders to nine ECNs, but not all ECNs were in continuous operation over the entire sample period. Because the ECNs all have the same trading features, and display their orders on the consolidated quote stream, we group all ECN orders together.

## 5. Order Level Analysis

### *5.1. Execution quality measurement*

We compute some common measures of execution quality and information across the various execution venues available to traders. Execution speed is computed as the difference in seconds between the original order submission time and the final trade execution time (share weighted across multiple trade orders). The percentage of an order filled is the executed order size divided by the submitted order size. Price impacts are used as a proxy for information and measure the change in the NBBO midpoint five minutes after a trader's order is executed. In order to calculate price impacts, each order on every stock is matched with the corresponding national best bid and offer (NBBO) using intraday tick data from Reuters. For execution costs, we distinguish between marketable orders, which are market orders and marketable limit orders with a buy (sell) limit price set greater (less) than or equal to the national best offer (bid), and non-marketable, which are limit orders priced away from the inside quotes and not immediately executable. For marketable buy (sell) orders, we measure execution cost by calculating the effective spread, which is computed as twice the (negative) difference between the share-weighted execution price and the NBBO quote midpoint at the time of order submission.[11] We estimate non-marketable order execution cost following similar approaches used by Peterson and Sirri (2003) and Harris and Hasbrouck (1996). The ex post cost of executing a limit buy order is computed as the difference between the share-weighted execution price and the national best bid price five minutes after execution. The ex post cost of executing a limit sell order is computed as the difference between the national best offer price five minutes after execution and the share-weighted execution price.

### *5.2. Non-parametric and regression analysis*

[11] We also estimate our results using the raw execution speed and cost difference (not share-weighted). The results are qualitatively similar to those reported.

According to our hypothesis, trading systems that enable fast execution and higher execution costs will attract more informed traders. On the other hand, trading systems that provide slower execution and lower execution costs will attract more uninformed (large) traders. Table 2 shows, on average, execution on automated market maker trading systems is 11 times faster than on negotiated market maker trading systems (6 vs. 68 seconds). The difference is statistically significant at the 1% level. The price impact, on average, is nearly 17 times higher on automated market maker trading systems than on negotiated market maker trading systems ($0.0661 vs. $0.0039). This price impact difference is also highly significant. While negotiated market maker trading systems provide slower execution, they provide an important economic function in that they provide a venue for traders to execute larger order sizes at competitive prices. The average submitted order size for automated (negotiated) market maker trading systems is 2,791 (1,399) shares. And orders executed on automated market maker trading systems have, on average, an effective spread 18 times higher than orders executed on negotiated market maker trading systems ($0.1159 vs. $0.0063).

If a trader chooses to post a limit order in the marketplace, rather than trade directly with a Nasdaq market maker, the price attached to the limit order is an important determinant of how fast it will execute and the level of information behind the order. Execution speed (price impacts) systematically increases (decreases) with how the order is priced in relation to the National Best Bid or Offer. The longer execution time associated with a marketable limit orders can occur because execution is not guaranteed with this order type. A trader may submit a marketable limit order to a limit order book, but the market may quickly move away from the limit price before the order gets posted.

With market sweep orders, execution is fast (5 seconds) and execution costs are high (the effective spread is $0.0983). Because execution is fast (and anonymous) with sweep orders, informed traders are more likely to use this order routing option. The price impact for sweep orders is $0.0549, which is slightly under the price impact for orders executed through automated market maker trading systems. Execution speed is fastest for sweep orders (5 seconds). Sweep orders may, in certain cases, provide faster execution than automatic market maker execution because these orders often execute on ECNs. And ECNs have a reputation for providing fast executions.

We examine the differences in speed and information (i.e. price impacts) across trading systems while controlling for various factors that may influence traders order routing decision.[12] For example, the bid-ask spread in the marketplace, or the size of an order, could both reasonably affect how a trader routes their order. We estimate two regressions. For price impacts, we estimate an ordinary least square regression and for execution speed we estimate an accelerated failure time (AFT) model that assumes execution speed follows a Weibull distribution. As noted in Garvey and Wu (2008), the AFT model is advantageous for estimating the determinants of execution speed because it ignores censoring (i.e., a cancellation of an order censors the duration of execution). The regressions take the format:

$$Price\ impact_{i,t} = \alpha_{i,t} + \sum_{j=1}^{4} b_{j,D_j} D_j + \sum Controls + \varepsilon_{i,t} \quad (1)$$

$$\log Execution\ Speed_{i,t} = \alpha_{i,t} + \sum_{j=1}^{4} b_{j,D_j} D_j + \sum Controls + \varepsilon_{i,t} \quad (2)$$

The independent variables include four order routing dummies, *D,* which represent each order routing method, *j*, available to traders (note that non-marketable orders are included in the intercept term). Traders route marketable orders over market maker trading systems (automated and negotiated) and alternative trading systems (ECNs). They also use algorithmic sweep orders. The control variables in both regressions include: size of the order (shares), NBBO percentage spread at the

[12] Execution costs are measured differently for marketable orders and non-marketable orders. Thus, we focus on execution speed and price impact for our regressions with all orders. We compare differences in marketable order execution costs across the different trading systems in the next Section.

time of order submission (100*(ask price –bid price )/midpoint price), depth at the inside price, which for marketable buy (sell) orders is the ask (bid) depth at the time of order submission and vice versa for non-marketable orders, total trading volume on the stock within the half-hour interval, price volatility within the half-hour interval, which is computed by subtracting the minimum execution price by the maximum execution price and dividing the difference by the average execution price within the half-hour interval, a dummy variable that takes the value of 1, or 0 otherwise, if the order is placed after decimalization,[13] a dummy variable that takes the value of 1, or 0 otherwise, if the order is a buy order, dummy variables representing trading around the open and close of trading, the prior year-end market capitalization for the stock, the prior year-end price for the stock, and the prior year average daily turnover for the stock (volume / shares outstanding).[14]

We also control for trader-specific effects. The approximate three thousand traders are classified into groups and category dummies are used to make the regressions more computationally feasible (note trader control estimates are omitted from the Tables for brevity). The traders are sorted into 25 groups using a sorting procedure based on two trader characteristics: 1) the average order size and 2) the average daily number of orders executed. Traders who have the highest (rank #1 out of 5) average order size and the highest average daily number of orders executed are classified as group 1, traders who have the highest average order size and the second highest (rank #2 out of 5) average daily number of orders executed are classified as group 2, and so forth for the remaining 25 combinations. The size in which a trader trades in, or how active they are, may be good indicators of how sophisticated a trader is. And the sophistication level of a trader could reasonably affect our price impact and execution speed measures.

[13] Nasdaq-listed stocks were phased into decimal pricing over three phase-in dates beginning March 12, 2001 and ending April 9, 2001.

[14] Related stock data information is obtained from the CRSP database.

The regression results for our two parametric models are reported in Table 3. The results reveal similar patterns to the non-parametric results. For example, price impacts are highest for orders routed over automated trading systems. The coefficient representing orders routed over automated market maker trading systems in the price impact regression is positive, large, and highly significant. For execution speed, market sweep orders execute the fastest. The coefficient representing market sweep orders in the execution speed regression is the most negative and highly significant.

*5.3. Trader order routing choice and controlling for endogeneity*

While our OLS and AFT regression models attempt to measure variations in execution quality and information across different Nasdaq trading systems, econometric issues may arise with our model specifications. Trader's choice of order routing may, in (large) part, arise endogenously. For example, if a trader has a difficult order to fill they may be more likely to route the order to a market maker (using either automated or negotiated trading systems). Nasdaq market makers, unlike electronic limit order books, provide a guaranteed source of liquidity throughout the trading day. Trader's execution quality expectations would presumably be conditional on the decision to route the order to the market maker, indicating that regressions of execution quality on order characteristics might provide inconsistent estimates of the effect of market maker trading systems.

In order to alleviate endogeneity concerns with our model specifications and control for any self-selectivity bias potentially present in our models, we estimate a simple two-stage econometric procedure that allows us to directly test execution quality and information differences between orders routed over two different trading systems. Our approach is similar to the one taken by other studies in the financial literature to correct for endogeneity issues when examining trader choice.[15] The first stage

[15] For example, Madhavan and Cheng (1997) adopt this procedure to control for NYSE traders endogenous choice between executing trades in the upstairs versus downstairs market. Conrad et al. (2003) also use this procedure to

regression predicts traders order routing choice using a probit model, which is then included into the two (OLS and AFT) second stage regression models. We focus on trader's decision to submit a marketable order and we compare execution cost, execution speed, and price impacts between orders routed to a market maker for automated execution vs. the three alternative marketable order routing options: 1) marketable limit order routed to an ECN 2) negotiated order routed to a market maker and 3) market sweep order. Orders routed over automated market maker trading systems appear to be the most informative. Moreover, execution is fast and trading costs are high with these orders. Thus, we would like to see if these results hold up while controlling for endogeneity concerns.

Panel A of Tables 4, 5, & 6 report results for our (3) first-stage regressions. The dependent variable is equal to one for orders routed to a market maker for automated execution and 0 for marketable orders routed over other trading systems. The first stage probit regressions also include several potential determinants of traders order routing choice including: submitted order size (shares), NBBO percentage spread at the time of order submission (100*(ask price –bid price )/midpoint price), depth at the inside price, which for marketable buy (sell) orders is the ask (bid) depth at the time of order submission, and a dummy variable that takes the value of 1, or 0 otherwise, if the order is a buy order. Many of the controls are statistically significant in the first stage regressions, although sign and magnitude vary.

Our main focus is on the second stage regressions, which are reported in Panel B of Tables 4, 5, 6. In our second stage regressions, we use the same controls reported in our prior OLS and AFT baseline regressions, along with the added selectivity correction variable, which is a function of the estimation of the first stage probit model. The importance of the selectivity correction can be seen by its high statistical significance in most of the second stage regressions. Controlling for selectivity and various order characteristics, market condition changes, market structure changes, stock characteristics, and

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control for institutional traders endogenous choice between executing their trades in traditional markets versus alternative trading systems.

trader characteristics, execution cost and execution speed are both lower for orders routed over automated market maker trading systems versus marketable limit orders routed to electronic trading systems and for sweep orders, which route across multiple markets. These results can be seen through the negative and statistically significant automated market maker execution dummy. When controlling for selectivity with automated versus negotiated market maker execution, execution speed is slower and execution cost is lower for orders routed over negotiated market maker trading systems.

Price impacts are highest for orders routed over automated market maker trading systems. For all three price impact regressions, the dummy variable representing orders routed over these trading systems are positive and statistically significant. We suspect traders who are more informed are likely to prefer this order routing option the most because trading is fast, anonymous (on a pre-trade basis), and execution is guaranteed (for a limited number of shares). While traders can achieve lower execution costs by using negotiated market maker trading systems, execution is slow and trading is not anonymous. Traders can control their execution price if they route a marketable limit order to an electronic limit order book, but execution is not guaranteed because the market may move against the trader before the limit order reaches the market. While sweep orders are attractive because they execute fast, they might take longer to execute in certain situations because the order can execute over several markets. After controlling for endogeneity, we find market sweep orders do not execute faster than orders routed over automated market maker trading systems.

Order routing options that offer fast execution, whether on Nasdaq or on a competing electronic trading system that is part of the consolidated quote stream, should attract more informed traders. Our analysis confirms this prediction. We find that orders routed over automated market maker marker trading systems are most informative, or have the highest price impacts associated with them. We suspect these trading systems attract the most informed traders because unlike electronic limit order books, market maker automated execution systems offer speed, (pre-trade) anonymity, and guaranteed execution for a limited number of shares. These three aspects of execution are critical to traders who posses short term information. Traders who are less informed will sacrifice speed (and possibly execution) and route their orders over trading systems that enable them to execute at a more favorable price.

**6. Individual Trader Level Analysis**

In this section, we provide further testing of our main hypothesis that informed traders have a strong preference speed, and that this subsequently influences their order routing decision. While our prior results are based on an order level analysis, we now test our main hypothesis using a trader level analysis. First, we examine the relation between execution speed and information at the individual trader level. We first calculate each traders average execution speed and price impact across the different trading systems. The average value is weighted by the share volume of each order. We then sort traders into quintiles based on their average trading speed, and calculate average price impacts across the five groups. The average value is weighted by the number of orders associated with traders in each group. The results are shown in Figure 1. For marketable orders (automated, market sweep orders, and marketable limits routed to ECNs), a pattern emerges showing that the faster a traders order executes, the higher the price impact. Informed traders are generally associated with fast execution.

We provide evidence supporting our main hypothesis using a trading concentration analysis, too. For each trader, we calculate the percentage of trading activity occurring on the different trading systems. For example, if a trader executes 1 million shares over our sample period, among which 200 thousand shares are executed using automated market maker trading systems, then the concentration level of this trader on automated trading systems is 20%. We calculate the concentration level of each trader across the different trading systems. Then, we sort traders into quintiles based on their average price impact. The average price impact values are weighted by the share volume of orders. Table 7 reports the average trader concentration level for each quintile. The results show that traders who have the largest price impact (i.e. most informed), concentrate their trading most on automated market maker trading systems. These trading systems offer faster execution, but relatively higher costs than other trading systems. On the other hand, traders with the smallest price impact, are more likely to submit limit order to electronic trading systems priced at or below the inside quote.

**7. Conclusion**

Execution quality is important to traders in financial markets. Yet how traders assess execution quality is unclear because there are multiple ways to do so. Perhaps the two most important dimensions of execution quality are the speed at which an order executes (i.e. execution speed) and the cost incurred with executing (i.e. execution cost). While prior studies indicate that both execution cost and execution speed are important, prior research also shows that these two dimensions of execution quality are negatively related. For example, market centers that report faster (slower) fill rates also tend to report higher (lower) trading costs (Boehmer, 2005, and Battalio et al. 2003). If traders are forced to sacrifice one dimension of execution quality for another, then do traders have a preference for a particular dimension and to what extent are traders willing to trade-off one dimension for the other? In our paper, we provide some insight for answering these questions by analyzing the order routing decisions of traders on Nasdaq listed stocks.

We find that execution quality directly influences order routing decisions and that traders have varying preferences for the different dimensions of execution quality. Traders who are more informed about future short term price changes are more willing to route their orders over trading systems that offer lower costs for faster speed. On the other hand, traders who are not (less) informed about future price changes are more willing to route their orders over trading systems that sacrifice speed for lower costs. The trade-off between speed and cost is quite significant. For example, we find that orders routed over automated market maker trading systems execute, on average, 11 times faster than orders routed over negotiated market maker trading systems (i.e. human intermediated trading systems). Automated trading systems are clearly faster than negotiated trading systems, yet human intermediated trading systems can offer much lower costs because trading is not anonymous and market makers have ample time to uncover individuals motivate for trade. We find that effective spreads, on average, are more than 18 times lower on negotiated market maker trading systems than on automated trading systems.

Our study examines how individual's trade-off between speed and cost in their order routing decisions. Whether or not individual preferences towards execution quality vary with market structure is an interesting question for future research. Our study is focused on trading in Nasdaq-listed stocks. Trader's preferences toward execution quality, and or extent to which traders are willing to trade-off one dimension for another, might vary in other market settings with different trading structures than Nasdaq.

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**Table 1**
**Order routing summary trading statistics**

This table reports summary trading statistics for different order routing strategies used by traders on Nasdaq-listed stocks. The sample is based on 3 thousand traders, who conducted their trading through a U.S. broker-dealer during a near four year sample period ending Aug. 2003. The traders combined to execute 10 billion shares and 9 million trades through 5 million orders. Traders had three general order routing execution options: 1) submit an order to a Nasdaq market maker (automated or negotiated execution), 2) submit an market sweep order to execute at the best price(s) available across all trading venues, or 3) submit a limit order to a specific electronic trading system (or electronic limit order book). All limit orders were submitted to Electronic Communication Networks that displayed their order books in the consolidated quote stream through exchanges. NBBO (national best bid and offer) percentage spread (100*(ask price –bid price)/midpoint price) is computed from order submission time and averaged across all orders. Depth is the number of shares available in the marketplace at order submission time and averaged across all orders. For marketable buy (sell) orders the inside bid (offer) depth is used and vice versa for non-marketable orders. Percentage buy is the percentage of buy orders relative to all (buy and sell) orders.

| | Trades (000's) | Orders (000's) | Shares (000's) | NBBO % spread | Avg. Depth | % Buy |
|---|---|---|---|---|---|---|
| Market Maker | | | | | | |
| Negotiated | 388.3 | 272.2 | 759,922.5 | 1.024 | 24,082 | 61.4% |
| Automated | 1,139.1 | 638.3 | 893,218.7 | 0.393 | 5,125 | 55.4% |
| | | | | | | |
| Market Sweep Orders | 824.4 | 769.6 | 633,226.8 | 0.514 | 1,793 | 57.9% |
| | | | | | | |
| Limit Orders | | | | | | |
| Marketable | 1,039.1 | 631.9 | 1,152,799.1 | 0.259 | 9,373 | 52.6% |
| Quote improving | 1,077.3 | 678.4 | 1,178,521.7 | 0.500 | 20,966 | 50.7% |
| At the quote | 2,646.7 | 1,876.1 | 4,301,413.7 | 0.374 | 14,683 | 46.1% |
| Below the quote | 845.9 | 548.1 | 688,448.8 | 0.250 | 5,443 | 44.1% |

**Table 2**
**Order routing choice: execution quality**

This table reports summary trading statistics for different order routing execution methods used by traders on Nasdaq-listed stocks. The sample is based on 3 thousand traders, who conducted their trading through a U.S. broker-dealer during a near four year (46 months) sample period ending Aug. 2003. The traders combined to execute 10 billion shares and 9 million trades through 5 million orders. Traders used three general order routing execution options: 1) submit an order to a Nasdaq market maker (automated or negotiated execution), 2) submit a market sweep order to execute at the best price(s) across all trading venues, or 3) submit a limit order to a specific electronic trading system. All limit orders were submitted to Electronic Communication Networks that displayed their limit order books in the consolidated quote stream through Exchanges. Limit order orders are further distinguished based on whether they are marketable (i.e. limit order with a buy (sell) price set greater (less) than or equal to the national best offer (bid)), quote improving (i.e. limit order with a buy (sell) price above (below) the national best bid (offer), at the quote (i.e. limit order with a buy (sell) price equal to the national best bid (offer), and below the quote (i.e. limit order with a buy (sell) price below (above) the national best bid (offer) price). Submitted order size is the average submitted order size (shares) across all orders, % filled is the average percentage of the submitted order size filled across all orders, execution speed is computed in seconds from initial submission to final execution (share-weighted for multiple trade orders) and averaged across all orders, price impact measures the change in the NBBO midpoint five minutes after a trader's order is executed and averaged across all orders, effective spread is computed as twice the (negative) difference between the share-weighted execution price and the NBBO quote midpoint at the time a trader submits their order and averaged across all orders, and ex-post cost is computed as the difference between the share-weighted execution price and the national best bid or offer price five minutes after execution. The ex post cost of executing a marketable buy (sell) order is computed as the difference between the national best offer (bid) price five minutes after execution and the share-weighted execution price. The ex-post cost of executing a non-marketable buy (sell) order is computed as the difference between the national best bid (offer) price five minutes after execution and the share weighted execution price.

| | Submitted Order Size | % Filled | Speed (Seconds) | Price Impact | Effective Spread | Ex-post Cost |
|---|---|---|---|---|---|---|
| Market Maker Orders | | | | | | |
| Negotiated | 2,791 | 71.3% | 67.5 | 0.0039 | 0.0063 | |
| Automated | 1,399 | 67.7% | 6.2 | 0.0661 | 0.1159 | |
| Market Sweep Orders | 823 | 84.8% | 5.0 | 0.0549 | 0.0983 | |
| Limit Orders | | | | | | |
| Marketable | 1,824 | 69.8% | 45.1 | 0.0320 | 0.0880 | |
| Quote improving | 1,737 | 70.8% | 149.7 | -0.0042 | - | 0.0296 |
| At the quote | 2,293 | 79.0% | 176.8 | -0.0171 | - | 0.0181 |
| Below the quote | 1,256 | 75.0% | 371.3 | -0.1574 | - | 0.0269 |

**Table 2A**
**Order routing choice: Non-parametric results**

This table reports mean differences between execution speed, price impact, and execution cost for order routing execution methods (See Table 2). The *p*-value tests whether the mean difference is significantly different from zero.

| | Execution speed | | Price Impact | | Execution cost | |
|---|---|---|---|---|---|---|
| | Difference | *p*-value | Difference | *p*-value | Difference | *p*-value |
| Automated vs. | | | | | | |
| Negotiated | -61.30 | <0.0001 | 0.0621 | <0.0001 | 0.1096 | <0.0001 |
| Market sweep | 1.24 | <0.0001 | 0.0112 | <0.0001 | 0.0176 | <0.0001 |
| Marketable | -38.85 | <0.0001 | 0.0341 | <0.0001 | 0.0279 | <0.0001 |
| Quote improving | -143.50 | <0.0001 | 0.0703 | <0.0001 | - | - |
| At the quote | -170.64 | <0.0001 | 0.0832 | <0.0001 | - | - |
| Below the quote | -365.11 | <0.0001 | 0.2235 | <0.0001 | - | - |
| Negotiated vs. | | | | | | |
| Market sweep | 62.54 | <0.0001 | -0.0509 | <0.0001 | -0.0920 | <0.0001 |
| Marketable | 22.45 | <0.0001 | -0.0280 | <0.0001 | -0.0817 | <0.0001 |
| Quote improving | -82.20 | <0.0001 | 0.0081 | <0.0001 | - | - |
| At the quote | -109.34 | <0.0001 | 0.0210 | <0.0001 | - | - |
| Below the quote | -303.81 | <0.0001 | 0.1613 | <0.0001 | - | - |
| Market sweep vs. | | | | | | |
| Marketable | -40.09 | <0.0001 | 0.0229 | <0.0001 | 0.0103 | <0.0001 |
| Quote improving | -144.74 | <0.0001 | 0.0591 | <0.0001 | - | - |
| At the quote | -171.88 | <0.0001 | 0.0720 | <0.0001 | - | - |
| Below the quote | -366.35 | <0.0001 | 0.2123 | <0.0001 | - | - |
| Marketable | | | | | | |
| Quote improving | -104.65 | <0.0001 | 0.0361 | <0.0001 | - | - |
| At the quote | -131.79 | <0.0001 | 0.0491 | <0.0001 | - | - |
| Below the quote | -326.26 | <0.0001 | 0.1894 | <0.0001 | - | - |
| Quote improving vs. | | | | | | |
| At the quote | -27.14 | <0.0001 | 0.0129 | <0.0001 | 0.0116 | <0.0001 |
| Below the quote | -221.61 | <0.0001 | 0.1532 | <0.0001 | 0.0027 | 0.0020 |
| At the quote vs. | | | | | | |
| Below the quote | -194.5 | <0.0001 | 0.0103 | <0.0001 | -0.0088 | <0.0001 |

**Table 3**
**Order routing choice: regression results**

This table provides regression results highlighting price impact and execution speed patterns in relation to traders order routing choice. The sample is based on 3 thousand traders, who conducted their trading through a U.S. broker-dealer over a near four year (46 months) sample period ending Aug. 2003. The traders combined to execute 10 billion shares and 9 million trades through 5 million orders. Execution speed is computed in seconds from initial submission to final execution (share-weighted for multiple trade orders). Price impact measures the change in the NBBO midpoint five minutes after a trader's order is executed. Price impact and execution speed observations are used as dependent variables in two separate regressions. For price impacts, an ordinary least square (OLS) regression is estimated. For execution speed, an accelerated failure time (AFT) model is estimated, which assumes execution speed follows a Weibull distribution. Non-marketable orders are represented in the intercept term for both regressions. Independent variables include: a dummy variable that takes the value of 1, or 0 otherwise, if the order is routed over an automated market maker trading system, a dummy variable that takes the value of 1, or 0 otherwise, if the order is routed over a negotiated market maker trading system (i.e. price improvement opportunities through human intermediation), a dummy variable that takes the value of 1, or 0 otherwise, if a marketable limit order is routed to a electronic limit order book, a dummy variable that takes the value of 1, or 0 otherwise, if an order is routed as a market sweep order (algorithmic order that searches across multiple markets for the best price and routes out accordingly), log executed order size (shares), NBBO percentage spread (100*(ask price –bid price )/midpoint price) at the time of order submission, log depth at the inside price (offer (bid) depth for marketable buy (sell) orders and vice versa for non-marketable orders) at the time of order submission, log total trading volume on the stock within the half-hour interval when the order is submitted, price volatility within the half-hour interval when the order is submitted, which is computed by subtracting the minimum execution price by the maximum execution price and dividing the difference by the average execution price within the half-hour interval, a dummy variable that takes the value of 1, or 0 otherwise, if the order is a buy, a dummy variable that takes the value of 1, or 0 otherwise, if the order is executed after decimalization, four time dummy variables for four one-hour periods around the open and close of trading (the time period representing the 11:30 a.m. to 3:00 p.m. period is included in the intercept term), the prior year-end log market capitalization of the stock, the prior year-end price of the stock, and the prior year average daily turnover (volume/shares outstanding) of the stock. In addition to the reported controls, both regressions also use dummies to control for trader-specific effects. The traders are sorted in 25 groupings using a sorting procedure based on trader's average daily number of orders executed and average order size. The trader controls are not reported. The *p*-values for the coefficient estimates are reported in the Table.

| Dependent Variable = | Price Impact | | Execution Speed | |
|---|---|---|---|---|
| | Coefficient | *p*-value | Coefficient | *p*-value |
| Intercept | -0.1041 | <0.0001 | 0.0629 | <0.0001 |
| Automated market maker order | 0.1131 | <0.0001 | -0.0376 | <0.0001 |
| Negotiated market maker order | 0.0350 | <0.0001 | -0.0132 | <0.0001 |
| Marketable limit order | 0.0742 | <0.0001 | -0.0126 | <0.0001 |
| Market sweep order | 0.1025 | <0.0001 | -0.0418 | <0.0001 |
| *Controls* | | | | |
| Log(Executed order share size) | -0.0062 | <0.0001 | 0.0041 | <0.0001 |
| NBBO % spread | 0.0020 | <0.0001 | -0.0002 | 0.0639 |
| Log(Bid/Ask depth) | 0.0040 | <0.0001 | -0.0025 | <0.0001 |
| Log(Half-hour volume) | -0.0001 | 0.0004 | 0.0002 | <0.0001 |
| Half-hour price volatility | 0.0007 | 0.7464 | -0.0004 | 0.8494 |
| Buy/Sell Indicator | 0.0081 | <0.0001 | -0.0037 | <0.0001 |
| Decimal pricing dummy | 0.0113 | <0.0001 | -0.0165 | <0.0001 |
| 9:30 – 10:30 a.m. dummy | 0.0017 | 0.0012 | -0.0014 | 0.0085 |
| 10:30 – 11:30 a.m. dummy | -0.0025 | <0.0001 | 0.0015 | 0.0039 |
| 2:00 – 3:00 p.m. dummy | -0.0037 | <0.0001 | 0.0045 | <0.0001 |
| 3:00 – 4:00 p.m. dummy | -0.0034 | <0.0001 | 0.0078 | <0.0001 |
| Log(Market capitalization) | -0.0006 | <0.0001 | -0.0008 | <0.0001 |
| 1/Price | -0.0013 | 0.0107 | -0.0027 | <0.0001 |
| Turnover | -0.1063 | <0.0001 | 0.0620 | <0.0001 |
| Trader Controls | Yes | | Yes | |
| Adj. $R^2$ | 1.3% | | | |
| Log Likelihood | | | -9818931 | |
| Obs. (000's) | 5,414.6 | | 5,414.6 | |

**Table 4**
**Order routing choice: automated market maker vs. negotiated market maker**

This table provides two-stage regression results comparing orders routed over automated market maker trading systems versus orders routed over negotiated market maker trading systems. The sample is based on 3 thousand traders, who conducted their trading through a U.S. broker-dealer over a near four year (46 months) sample period ending Aug. 2003. The traders combined to execute 10 billion shares and 9 million trades through 5 million orders. The first stage regression (Panel A) is a Probit model with a dependent variable equal to one for an order routed over an automated market maker trading system and 0 for an order routed over a negotiated market maker trading system. Execution speed, execution costs, and price impacts serve as dependent variables in the second stage regression. Execution speed is computed in seconds from initial submission to final execution (share-weighted for multiple trade orders). Execution cost represents the effective spread, which is computed as twice the (negative) difference between the share-weighted execution price and the NBBO quote midpoint at the time of order submission. Price impact measures the change in the NBBO midpoint five minutes after a trader's order is executed. For execution costs and price impacts, an ordinary least square (OLS) second stage regression is estimated. For execution speed, a second stage accelerated failure time (AFT) model is estimated, which assumes execution speed follows a Weibull distribution. Independent variables include: a dummy variable that takes the value of 1, or 0 otherwise, if the trader routes the order over an automated market maker trading system, or 0 otherwise, log submitted and executed order share size, NBBO percentage spread (100*(ask price –bid price )/midpoint price) at the time of order submission, log depth at the inside price (offer (bid) depth for marketable buy (sell) orders and vice versa for non-marketable orders) at the time of order submission, log total trading volume on the stock within the half-hour interval when the order is submitted, price volatility within the half-hour interval when the order is submitted, which is computed by subtracting the minimum execution price from the maximum execution price and dividing the difference by the average execution price within the half-hour interval, a dummy variable that takes the value of 1, or 0 otherwise, if the order is a buy, a dummy variable that takes the value of 1, or 0 otherwise, if the order is executed after decimalization, four time dummy variables for four one-hour periods around the open and close of trading (the time period representing the 11:30 a.m. to 3:00 p.m. period is included in the intercept term), the prior year-end log market capitalization of the stock, the prior year-end price of the stock, and the prior year average daily turnover (volume/shares outstanding) of the stock. In addition to the reported controls, both regressions also use dummies to control for trader-specific effects. The traders are sorted in 25 groupings using a sorting procedure based on trader's average daily number of orders executed and average order size. The trader controls are not reported. The *p*-values for the coefficient estimates are reported in the Table.

**Panel A. Stage 1 Probit Model**

| | Coefficient | *p*-value |
|---|---|---|
| Intercept | 3.3776 | <0.0001 |
| Log (Submitted order share size) | -0.2048 | <0.0001 |
| Buy/Sell Indicator | -0.2251 | <0.0001 |
| NBBO % spread | -0.2658 | <0.0001 |
| Log(Bid/Ask depth) | -0.1558 | <0.0001 |
| | | |
| Trader controls | Yes | |
| Log likelihood | -410113.1 | |
| Obs. (000's) | 910.6 | |

**Panel B. Stage 2 Regression Models**

| | Execution speed | | Execution cost | | Price impacts | |
|---|---|---|---|---|---|---|
| | Coefficient | p-value | Coefficient | p-value | Coefficient | p-value |
| Intercept | 4.9976 | <0.0001 | 0.0606 | 0.0004 | -0.1338 | <0.0001 |
| Automated market maker dummy | -0.0471 | <0.0001 | -0.0090 | <0.0001 | 0.0449 | <0.0001 |
| Log(Executed order share size) | 0.0345 | <0.0001 | -0.0046 | <0.0001 | 0.0083 | <0.0001 |
| NBBO % spread | 0.2964 | <0.0001 | 0.0126 | <0.0001 | 0.0180 | <0.0001 |
| Log(Bid/Ask depth) | 0.1124 | <0.0001 | 0.0011 | 0.0694 | -0.0002 | 0.7596 |
| Log(Half-hour volume) | -0.0129 | <0.0001 | 0.0004 | <0.0001 | -0.0005 | <0.0001 |
| Half-hour price volatility | 0.2099 | <0.0001 | -0.0117 | 0.1673 | 0.0037 | 0.6706 |
| Buy/Sell Indicator | -0.2268 | <0.0001 | -0.0070 | <0.0001 | 0.0227 | <0.0001 |
| Decimal pricing dummy | -0.9561 | <0.0001 | 0.0127 | <0.0001 | -0.0864 | <0.0001 |
| 9:30 – 10:30 a.m. dummy | 0.0380 | <0.0001 | -0.0118 | <0.0001 | 0.0218 | <0.0001 |
| 10:30 – 11:30 a.m. dummy | -0.0229 | <0.0001 | -0.0001 | 0.9260 | 0.0035 | 0.0064 |
| 2:00 – 3:00 p.m. dummy | -0.0536 | <0.0001 | 0.0038 | 0.0013 | -0.0010 | 0.0038 |
| 3:00 – 4:00 p.m. dummy | -0.1125 | <0.0001 | 0.0068 | <0.0001 | -0.0022 | 0.1033 |
| Log(Market capitalization) | -0.0221 | <0.0001 | 0.0003 | 0.0005 | -0.0025 | <0.0001 |
| 1/Price | 0.5515 | <0.0001 | -0.0029 | 0.0065 | -0.0002 | 0.819 |
| Turnover | 6.9210 | <0.0001 | 0.0544 | 0.0373 | 0.2755 | <0.0001 |
| Selectivity correction | 0.2067 | <0.0001 | 0.0155 | 0.0010 | -0.0925 | <0.0001 |
| | | | | | | |
| Trader Controls | Yes | | Yes | | Yes | |
| Adj. $R^2$ | | | 0.12% | | 2.6% | |
| Log Likelihood | -1427375.2 | | | | | |
| Obs. (000's) | 910.6 | | 910.6 | | 910.6 | |

**Table 5**
**Order routing choice: automated market maker vs. market sweep order**

This table provides two-stage regression results comparing orders routed over automated market maker trading systems versus orders routed as market sweep orders. Market sweep orders are algorithmic orders that search across market centers for the best price available and route out accordingly (note that market sweep orders can execute in multiple markets). See remaining notes from Table 4.

**Panel A. Stage 1 Probit Model**

| | Coefficient | *p*-value |
|---|---|---|
| Intercept | 0.2877 | <0.0001 |
| Log (Submitted order share size) | 0.0476 | <0.0001 |
| Buy/Sell Indicator | -0.0897 | <0.0001 |
| NBBO % spread | -0.2987 | <0.0001 |
| Log(Bid/Ask depth) | 0.1337 | <0.0001 |
| | | |
| Trader controls | Yes | |
| Log likelihood | -886137.3 | |
| Obs. (000's) | 1,407.9 | |

**Panel B. Stage 2 Regression Models**

| | Execution speed | | Execution cost | | Price impacts | |
|---|---|---|---|---|---|---|
| | Coefficient | p-value | Coefficient | p-value | Coefficient | p-value |
| Intercept | 0.1725 | <0.0001 | 0.2290 | <0.0001 | -0.1552 | <0.0001 |
| Automated market maker dummy | -0.0471 | <0.0001 | -0.0090 | <0.0001 | 0.0449 | <0.0001 |
| Log(Executed order share size) | -0.0546 | <0.0001 | 0.0049 | <0.0001 | -0.0110 | <0.0001 |
| NBBO % spread | 0.2575 | <0.0001 | -0.0092 | 0.0007 | 0.0494 | <0.0001 |
| Log(Bid/Ask depth) | -0.2687 | <0.0001 | 0.0264 | <0.0001 | -0.0400 | <0.0001 |
| Log(Half-hour volume) | -0.0051 | <0.0001 | 0.0005 | <0.0001 | -0.0005 | <0.0001 |
| Half-hour price volatility | 0.0735 | 0.0005 | -0.0012 | 0.0031 | 0.0004 | 0.9015 |
| Buy/Sell Indicator | 0.1139 | <0.0001 | -0.0216 | <0.0001 | 0.0235 | <0.0001 |
| Decimal pricing dummy | -0.5276 | <0.0001 | 0.0126 | <0.0001 | -0.0612 | <0.0001 |
| 9:30 – 10:30 a.m. dummy | 0.2539 | <0.0001 | -0.0137 | <0.0001 | 0.0227 | <0.0001 |
| 10:30 – 11:30 a.m. dummy | 0.0929 | <0.0001 | 0.0004 | 0.7267 | 0.0021 | 0.0895 |
| 2:00 – 3:00 p.m. dummy | 0.0684 | <0.0001 | 0.0061 | <0.0001 | -0.0035 | 0.0062 |
| 3:00 – 4:00 p.m. dummy | 0.0934 | <0.0001 | 0.0062 | <0.0001 | -0.0011 | 0.3819 |
| Log(Market capitalization) | 0.0042 | <0.0001 | 0.0003 | 0.0001 | -0.0019 | <0.0001 |
| 1/Price | 0.1085 | <0.0001 | -0.0151 | <0.0001 | -0.0124 | <0.0001 |
| Turnover | 0.7406 | <0.0001 | 0.0746 | 0.0006 | 0.1273 | <0.0001 |
| Selectivity correction | -2.1362 | <0.0001 | 0.2374 | <0.0001 | -0.27045 | <0.0001 |
| | | | | | | |
| Trader Controls | Yes | | | | | |
| Adj. $R^2$ | | | 0.17% | | 1.45% | |
| Log Likelihood | -1792133 | | | | | |
| Obs. (000's) | 1,407.9 | | 1,407.9 | | 1,407.9 | |

**Table 6**
**Order routing choice: automated market maker vs. marketable limit order**

This table provides two-stage regression results comparing orders routed over automated market maker trading systems versus marketable limit order routed to an electronic limit order book. Marketable limit buy (sell) orders have a limit price greater (less) than or equal to the national best offer (bid). See remaining notes from Table 4.

**Panel A. Stage 1 Probit Model**

| | Coefficient | *p*-value |
|---|---|---|
| Intercept | 1.0220 | <0.0001 |
| Log (Submitted order share size) | -0.0069 | <0.0001 |
| Buy/Sell Indicator | 0.0015 | 0.5144 |
| NBBO % spread | -0.1638 | <0.0001 |
| Log(Bid/Ask depth) | -0.0415 | <0.0001 |
| | | |
| Trader controls | Yes | |
| Log likelihood | -857560.1 | |
| Obs. (000's) | 1,270.2 | |

**Panel B. Stage 2 Regression Models**

| | Execution speed | | Execution cost | | Price impacts | |
|---|---|---|---|---|---|---|
| | Coefficient | p-value | Coefficient | p-value | Coefficient | p-value |
| Intercept | 3.5981 | <0.0001 | 0.1647 | <0.0001 | 0.1268 | <0.0001 |
| Automated market maker dummy | -1.2548 | <0.0001 | -0.0198 | <0.0001 | 0.0211 | <0.0001 |
| Log(executed order share size) | 0.2009 | <0.0001 | -0.0020 | <0.0001 | -0.0011 | 0.0052 |
| NBBO % spread | 0.0732 | <0.0001 | -0.0020 | <0.0001 | 0.0019 | <0.0001 |
| Log(Bid/Ask depth) | -0.0126 | <0.0001 | 0.0011 | 0.0052 | -0.0111 | <0.0001 |
| Log(Half-hour volume) | -0.0096 | <0.0001 | 0.0002 | 0.0065 | -0.0005 | <0.0001 |
| Half-hour price volatility | -0.3318 | <0.0001 | -0.0139 | 0.0801 | 0.0046 | 0.5713 |
| Buy/Sell Indicator | -0.0408 | <0.0001 | -0.0040 | <0.0001 | 0.0074 | <0.0001 |
| Decimal pricing dummy | -0.3356 | <0.0001 | 0.0045 | 0.0001 | -0.0655 | <0.0001 |
| 9:30 – 10:30 a.m. dummy | -0.0439 | <0.0001 | -0.0061 | <0.0001 | 0.0189 | <0.001 |
| 10:30 – 11:30 a.m. dummy | 0.0211 | <0.0001 | 0.0031 | 0.0095 | 0.0017 | 0.1502 |
| 2:00 – 3:00 p.m. dummy | -0.1071 | <0.0001 | 0.0083 | <0.0001 | -0.0063 | <0.0001 |
| 3:00 – 4:00 p.m. dummy | -0.2197 | <0.0001 | 0.0095 | <0.0001 | -0.0042 | <0.0013 |
| Log(Market capitalization) | -0.0311 | <0.0001 | -0.0003 | 0.0006 | -0.0025 | <0.0001 |
| 1/Price | 1.1902 | <0.0001 | -0.0050 | <0.0001 | -0.0005 | 0.6345 |
| Turnover | 1.7977 | <0.0001 | 0.1458 | <0.0001 | 0.2753 | <0.0001 |
| Selectivity correction | 0.1666 | 0.0048 | 0.0826 | <0.0001 | -0.0137 | 0.1730 |
| | | | | | | |
| Trader Controls | Yes | | Yes | | Yes | |
| Adj. $R^2$ | | | | | | |
| Log Likelihood | -1858166.2 | | 0.11% | | 1.75% | |
| Obs. (000's) | 1,270.2 | | 1,270.2 | | 1,270.2 | |

**Figure 1**
**Trader level analysis: execution speed and price impacts across trading systems**

This table reports an individual trader-level analysis of execution speed and price impacts across different Nasdaq trading systems. The sample is based on 3 thousand traders, who conducted their trading through a U.S. broker-dealer during a near four year (46 months) sample period ending Aug. 2003. The traders combined to execute 10 billion shares and 9 million trades through 5 million orders. The average execution speed and average price impact for each trader is computed across the different trading systems. The average value is share-weighted by the share volume of each order. Execution speed is measured in seconds from initial submission to final execution (share-weighted for multiple trade orders). Price impacts measure the change in the NBBO midpoint five minutes after a trader's order is executed. Traders are sorted into quintiles based on their average execution speed, and average price impacts are computed across the five groups. Traders used three general order routing execution options: 1) submit an order to a Nasdaq market maker (automated or negotiated execution), 2) submit a market sweep order to execute at the best price(s) across all trading venues, or 3) submit a limit order to a specific electronic trading system. All limit orders were submitted to Electronic Communication Networks that displayed their orders in the consolidated quote stream. Limit order orders are further distinguished based on whether they are marketable (i.e. limit order with a buy (sell) price set greater (less) than or equal to the national best offer (bid)), quote improving (i.e. limit order with a buy (sell) price above (below) the national best bid (offer), at the quote (i.e. limit order with a buy (sell) price equal to the national best bid (offer), and below the quote (i.e. limit order with a buy (sell) price below (above) the national best bid (offer) price).

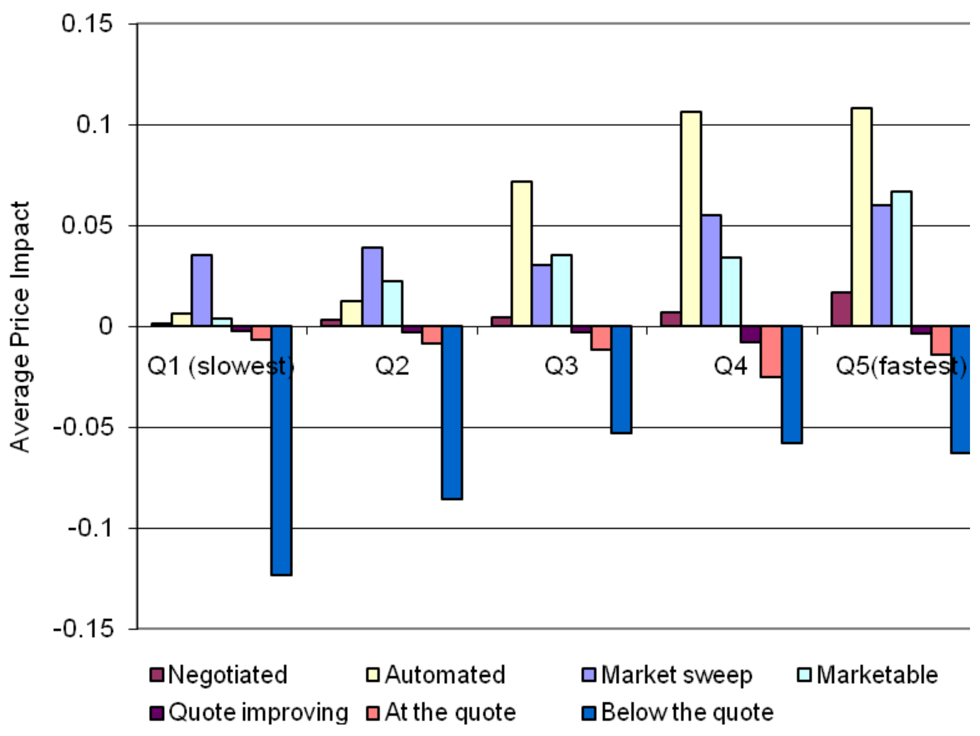

**Table 7**
**Trader level analysis: price impact and order routing concentration**

This table reports an individual trader-level analysis of price impacts and order routing concentration. The sample is based on 3 thousand traders, who conducted their trading through a U.S. broker-dealer during a near four year (46 months) sample period ending Aug. 2003. The traders combined to execute 10 billion shares and 9 million trades through 5 million orders. For each trader, the percentage of trading on each Nasdaq trading system is computed. Traders are sorted into quintiles based on their average price impact across orders. The average value is weighted by the share volume of each order. Price impact (PI) measures the change in the NBBO midpoint five minutes after a trader's order is executed. The table reports the average trader concentration level for each quintile. Traders used three general order routing execution options: 1) submit an order to a Nasdaq market maker (automated or negotiated execution), 2) submit a market sweep order to execute at the best price(s) across all trading venues, or 3) submit a limit order to a specific electronic trading system. All limit orders were submitted to Electronic Communication Networks that displayed their orders in the consolidated quote stream. Limit order orders are further distinguished based on whether they are marketable (i.e. limit order with a buy (sell) price set greater (less) than or equal to the national best offer (bid)), quote improving (i.e. limit order with a buy (sell) price above (below) the national best bid (offer), at the quote (i.e. limit order with a buy (sell) price equal to the national best bid (offer), and below the quote (i.e. limit order with a buy (sell) price below (above) the national best bid (offer) price).

| | Automated | Negotiated | Market sweep | Marketable | Quote improving | At the quote | Below the quote |
|---|---|---|---|---|---|---|---|
| Mean | 19.08% | 2.37% | 12.57% | 12.63% | 10.73% | 27.02% | 15.60% |
| Q1 (Lowest PI) | 11.45% | 1.46% | 7.33% | 7.91% | 8.84% | 31.93% | 31.08% |
| Q2 | 15.48% | 1.44% | 11.70% | 11.81% | 10.48% | 29.49% | 19.61% |
| Q3 | 15.21% | 1.45% | 9.58% | 14.36% | 12.63% | 33.90% | 12.87% |
| Q4 | 20.41% | 5.53% | 10.94% | 16.49% | 13.02% | 26.02% | 7.60% |
| Q5 (Highest PI) | 32.84% | 1.96% | 23.31% | 12.61% | 8.68% | 13.74% | 6.87% |