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Quote-based competition and trade execution costs in NYSE-listed stocks ☆

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Abstract

This study examines quotations, order routing, and trade execution costs for seven markets that compete for orders in large-capitalization NYSE-listed stocks. The competitiveness of quote updates from each market varies with measures of the profitability of attracting additional order and with volatility and inventory measures. The probability of a trade executing on each market increases when the market posts competitive quotes. Execution costs for non-NYSE trades when the local market posts competitive (non-competitive) quotes are virtually the same (substantially exceed) costs for matched NYSE trades. Collectively, these results imply a significant degree of quote-based competition for order flow and are consistent with off-NYSE liquidity providers using competitive quotations to signal when they are prepared to give better-than-normal trade executions.

JEL classificaion: G14; K22

Keywords: Competition for order flow; Quotation strategies; Trading costs

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1. Introduction

Those who design or regulate securities markets face tradeoffs between considerations that favor consolidating trading in a single integrated market and counter-arguments in favor of allowing trading to "fragment" across multiple markets. Presently, stocks listed on US equity exchanges are traded not only on the listing market but also on five regional stock markets, the National Association of Securities Dealers (NASD) market, several Electronic Communications Networks including Instinet and Island, crossing networks such as Posit, and on foreign equity markets. Whether this fragmentation of trading across venues is optimal is the subject of considerable debate.

The purpose of this paper is to shed light on these issues by providing some empirical evidence on the degree to which competition (through quotations in particular) affects order-routing decisions and trade execution costs for NYSE-listed stocks. The evidence focuses on three main questions. First, what factors determine whether liquidity providers on each market post competitive quotations? Second, what considerations, including quote competitiveness, affect trade location? Third, does the competitiveness of quotations affect trading costs?

One rationale for consolidating trading in a single market is that each order is exposed to all other displayed orders. Additional incentive-based arguments in favor of consolidation are advanced by those who advocate a centralized limit-order book for the trading of equities, which would incorporate a system of price/time priority rules.[1] Under a price/time priority system, market orders are executed against the highest bid or lowest offer, or in the case of a tie on price, against the bid or offer established earliest.[2] Proponents of consolidated trading with price and time priority argue that it improves incentives for liquidity suppliers (either designated market makers or limit-order traders) to aggressively compete for market orders by revealing their trading interest and by being the first to establish more favorable prices.

Detractors of enforced centralized trading focus on the benefits of competition between markets and also point out that traders have varying goals and priorities. For example, while some traders are primarily concerned with obtaining the best price, others might prioritize speed of execution. Larger traders whose orders cannot be immediately executed are often concerned with keeping their trading intentions confidential to avoid adverse price movements prior to the implementation of their trades. Small traders, in contrast, are likely to prefer that their order be widely

[1] Recent advocates of a central limit-order book include the heads of Goldman Sachs, Merrill Lynch, and Morgan Stanley (see "Sweeping Changes in Markets Sought," Wall Street Journal, February 29, 2000, C-1). See also the Security and Exchange Commission "Request for Comment on Issues Relating to Market Fragmentation" available at the web site http://www.sec.gov/rules/sro/ny9948n.htm, and comments filed in response, available at http://www.sec.gov/rules/sro/ny9948nc.shtml.

[2] Presently, price and time priority is not enforced across US equity markets. Individual exchanges do enforce versions of price/time priority within their market. The NYSE, for example, enforces price priority, and uses a combination of order size and order placement time to determine priority for limit orders that are tied on price.

disseminated to interact with the best available liquidity. Blume (2001) and Harris (1993) argue that different markets develop to serve different investors' needs and that the fragmentation of trading across markets is the natural result of innovation by markets and competition for traders' orders. Stoll (2001) observes that a central linkage intended to consolidate trading across markets could hinder innovation, because any new technology implemented by a market would have to conform to the linkage. He also notes that enforcing time priority across markets can actually contribute to fragmentation. For example, with time priority enforced across markets a limit order with a competitive price will execute even if it is posted in a small illiquid market. Without cross-market enforcement of time priority, limit-order traders have incentives to send their orders to liquid markets where the likelihood of execution is high, so orders will naturally tend to cluster in one or a few venues.

The fragmentation of trading across stock markets is controversial in part due to information and agency costs. Brokerage firms or financial institutions rather than investors typically choose which market to route an order, and the execution cost that the investor pays to have the trade completed is not readily observable. The US Securities and Exchange Commission (SEC) states that brokerage firms have a fiduciary obligation to seek "best execution" for client orders, but does not explicitly define the duty of best execution. Macey and O'Hara (1997) and Ferrell (2000) provide discussions of brokers' best execution duties. Many orders in both NYSE and Nasdaq-listed stocks are routed to market makers based on "preferencing" agreements. These orders are sometimes executed at a particular venue without an opportunity to interact with the trading interest available at alternate market centers.[3]

Several authors, including Dutta and Madhavan (1997) and Huang and Stoll (1996) suggest that preferencing agreements could lead to higher trading costs because they inhibit incentives to use quotations to compete for order flow. Bloomfield and O'Hara (1998) report experimental evidence indicating that preferencing agreements inhibit competition. Chung et al. (2001) provide the first direct empirical evidence on the issue. They study Nasdaq-listed stocks and find that quotes are less competitive and spreads are wider for those stocks with more preferenced order flow.

In addition to the possibility that preferencing agreements lead to wider bid–ask spreads, there is the possibility that orders routed under these agreements are not directed to the market where they would receive the best execution. These concerns are highlighted by former SEC chairman Arthur Levitt:[4]

[3] One form of preferencing agreement is a "payment-for-order-flow" arrangement, where a market maker pays a brokerage firm for routing the order to it. Another form is "internalization," where brokerage firms take the opposite side of customer orders, or cross customer orders against each other, and then route the trade to affiliated market makers for execution and reporting.

[4] These comments are excerpted from a speech by to the Securities Industry Association delivered on November 4, 1999. The full text is available at the web site www.sec.gov/news/speeches/spch315.htm. See also US SEC (2000).

> I worry, however, that the duty of best execution is being neglected by those who fail to review carefully their order-routing arrangements. I worry that best execution may be compromised by payment for order flow, internalization and certain other practices that can represent conflicts between the interests of brokers and their customers.

Orders routed under preferencing agreements are usually executed at prices matching the best quote available from any liquidity supplier. In this case price priority is not violated, but time priority typically is. Some orders are executed at prices outside the best quote, in which case price priority is also violated. NASD regulations (applicable to Nasdaq-listed stocks) do not require trades to be executed at prices that match the best quotes (see Smith et al., 1998). NASD regulations specify only that market makers "buy or sell … so that the resultant price to the customer is as favorable as possible under prevailing market conditions" (NASD rule 2320). For NYSE-listed stocks, the execution of an order smaller than the quote size at a price outside the best quotes violates the Intermarket Trading System (ITS) agreement, and can give rise to a "trade through" complaint (see Hasbrouck et al., 1993), which is subject to self-regulation within the ITS. Only if a trade is executed at a price outside a market or dealer's *own* quote is the SEC's "firm quote" rule violated.

Other orders, particularly on the listing market, are "price improved" (i.e., executed at prices within the best quotes.) When price improvement is possible it is not clear whether orders executed at a price matching the best quote have been routed so as to receive the best price. That price improvement is possible indicates that some available liquidity is not displayed in the best quotations. This could reflect that the lack of price/time priority enforcement across markets blunts incentives to publicly display trading interest in the form of limit orders or quotations. Courts find that the possibility of price improvement implies that a practice of routinely routing orders for execution at prices equaling the best quotes could fail to fulfill a broker's duty of best execution. On the other hand, the SEC states that brokers can consider factors other than price, such as execution speed.

This paper provides empirical evidence relevant to the ongoing debate, focusing on the degree to which quote competitiveness affects the routing of orders and trade execution costs in one hundred large-capitalization NYSE-listed securities, during the month of June 2000. More specifically, the analysis answers the following questions. First, how aggressively does each market quote, in terms of frequency of price and time priority? Second, what factors govern the decision to post competitive versus noncompetitive quotations? Third, what are the empirical determinants of execution venue? Are orders routed more often to markets posting better quotes? Do larger quote sizes attract orders? Or, do trade characteristics such as trade size and information content drive execution venue? Fourth, how do trade execution costs in cases where market makers receive orders in response to posting competitive quotes compare to trading costs when market makers receive orders even though their quotes are not competitive? And finally, how do trading costs for trades executed off the primary market (the NYSE) compare to trading costs at the NYSE, when off-NYSE market makers do or do not post competitive quotes?

To provide points of reference for interpreting the empirical results, consider two hypothetical market structures that might be viewed as opposite ends of a continuum. In the first, all orders are routed according to preferencing agreements, or on the basis of predetermined criteria. Then, quotes would be irrelevant. There would be no reason to expect quote placements to vary systematically with market conditions, and execution venue would be independent of quote competitiveness. Further, trade execution costs could vary across markets, since costs such as "payment for order flow" would have to be recouped through execution costs. In the second hypothetical structure, price and time priority are strictly enforced across markets. In this setting, quotation placement would be highly strategic, quote characteristics would fully determine execution venue (leaving no explanatory role for other variables such as trade size, trader identity, etc.), and since each order would be executed against the best quote or limit order on any market, execution costs would be independent of execution venue.

The empirical results provide some indication of where the actual market for NYSE stocks lies on the continuum between these hypothetical structures. On average, the NYSE posts the most competitive quotes.[5] However, off-NYSE quotes also provide non-trivial displayed liquidity, as they almost always (95.4% of the time) match at least one side of the NYSE quotes, and establish one side of the best quotes without NYSE participation about 11% of the time.

Quotations strategies do vary systematically with market conditions, and order routing does respond systematically to quote placement. New quotations from each market are less likely to improve on the existing quote when markets are volatile and are more likely to improve on the exiting quotes when spreads are wide. Off-NYSE quote updates are more likely to be competitive when markets are more active. NYSE quotes that improve on the existing quotes tend to be for smaller sizes than noncompetitive quotes, while off-NYSE quotes that improve on existing quotes tend to be for larger sizes. Quote competitiveness and quote sizes are significant determinants of execution venue. However, trade characteristics (including trade size and the amount of information the trade conveys) are also important, and 37.1% of total sample trades and 65.9% of off-NYSE trades are completed when the executing market is not displaying the best quote. Trades executed off the NYSE when orders are routed to markets that are not displaying competitive quotes (i.e., orders routed under preferencing agreements) receive executions that are worse than for matched NYSE trades. In contrast, execution costs for trades completed off the NYSE when the local market posts competitive quotes are virtually the same as for matched NYSE trades.

[5] Note that the TAQ database identifies the market center from which a quote originates, but not the specific identity of the liquidity provider, who might be a designated marketmaker, a floor trader, or a public limit-order trader. Chung et al. (1999) use the Trades, Orders, Records, and Quotes (TORQ) dataset (which pertains to a limited set of securities during 1990 and 1991) to provide an empirical analysis of the relative contributions of specialist versus limit-order interest in NYSE quotations.

Collectively, these results indicate that there is substantial quote-based competition for order flow in NYSE-listed stocks. In particular, the results are consistent with off-NYSE liquidity providers using quotations as a selective signaling device to indicate when they are prepared to give better-than-normal trade executions. Order routing responds systematically to these signals. The quote based competition for order flow is incomplete, however as trade characteristics affect execution venue, many trades are executed away from the market posting the best quote, and average trade execution costs vary across markets when trades are routed to markets with noncompetitive quotes.

This paper is organized as follows. Section 2 describes how this paper relates to the existing literature, discusses the sample employed, and provides descriptive data on market shares and trade characteristics for each exchange. Section 3 provides analysis of the overall competitiveness of quotations posted by each market, and of the empirical determinants of time-series variation in quote competitiveness. Section 4 reports on the determinants of trade execution venue, while Section 5 provides estimates of trade execution costs on the basis of whether the executing market was posting a competitive quote at the time of the trade. Section 6 discusses several policy alternatives and concludes.

2. Previous literature, sample selection, and description

2.1. Related studies

This analysis is most closely related to those provided by Lee (1993), Bessembinder and Kaufman (1997), Battalio et al. (1997), and Blume and Goldstein (1997). The first two studies listed above show that trade execution costs for off-NYSE trades slightly exceed costs for NYSE trades. That result is confirmed here and refined to indicate that it is entirely attributable to trades routed away from the NYSE when the executing market quote is inferior to the NYSE quote (i.e., in response to preferencing agreements).

Blume and Goldstein (1997) show that off-NYSE market shares are substantially greater when local market quotes are competitive than when noncompetitive. The multiple logistic regression analysis provided here indicates that having price priority increases the likelihood of trade execution, which is consistent with the central Blume and Goldstein result, and also shows the incremental effects of quotation-time priority, quotation size, whether the quote is competitive due to omission or commission, trading intensity, and trades' information content on execution venue.

Battalio et al. (1997) study the adoption of preferencing programs that facilitated brokers' internalization of customer order flow on the Cincinnati and Boston Exchanges, reporting that execution costs for trades completed at these markets did not increase after the programs were adopted. However, they also reported higher execution costs at Boston and Cincinnati as compared to New York and did not attempt to measure whether trades routed to these regional exchanges under these programs paid higher costs than similar trades sent to the NYSE. This study provides measures of execution costs on and off the NYSE, for trades obtained when quotes are competitive and for trades completed under preferencing programs.

2.2. Overview of the sample employed

This study focuses on the one hundred largest NYSE common stocks by market capitalization during the month of June 2000.[6] The largest stocks are selected because they are among the most active and are subject to substantial competition from off-NYSE liquidity providers. The month of June 2000 is selected because it was the most recent available at the time this project was initiated. The need to implement logistic regression on available computing systems and the large sample sizes involved preclude further expanding the sample. All specifications reported here were also estimated using data from January 2000 with very similar results.

The data for this study is drawn from the Trade and Quote (TAQ) database, made available by the NYSE. The TAQ database is subject to some limitations, as it reports ECN trades as occurring on the NASD and omits trades completed on foreign markets. As a consequence the empirical analyses conducted here focus on domestic trades in NYSE-listed stocks completed at the NYSE, the five regional exchanges (Boston, Philadelphia, Cincinnati, Chicago, and Pacific), and the combination of the NASD dealer market and ECN activity.

A total of 5.40 million trades and 11.55 million quotes for the one hundred sample stocks that are time-stamped during regular NYSE trading hours (9:30 a.m. to 4:00 p.m.) are obtained from the TAQ database. Of these, a total of 0.069 million (1.3% of sample) trades and 0.115 million (1.0% of sample) quotes were eliminated on the basis of error filters.[7] Preliminary analysis indicates that the reporting of opening trades differs across markets. The NYSE opens with a call auction, and reports a single opening trade of relatively large size. The regional exchanges often report a large number of small trades at the same price as the NYSE open. To avoid having market share and order-routing statistics affected by differential reporting of opening trades, I eliminate the 0.250 million sample trades that are reported before 9:45 a.m.

The National Best Bid and Offer (NBBO) quotes are not reported in the TAQ database and must be reproduced from the available data. A total of 0.154 million

[6] Capitalization data is obtained from the web site http://www.nyse.com/marketinfo/marketinfo.html. The sample actually consists of the 101 largest firms at month end, but excludes Berkshire Hathaway, Inc. due to its high share price (over $53,000), wide bid–ask spread (averaging $200), low trading volume, and lack of off-NYSE quotations.

[7] Trades are omitted if they are indicated in the TAQ database to be coded out of time sequence, or coded as involving an error or a correction (TAQ error correction indicators of two or greater). Trades indicated to be exchange acquisitions or distributions, or that involve nonstandard settlement (TAQ Sale Condition codes A, C, D, N, O, R, and Z) are also omitted, as are trades that are not preceded by a valid same-day quote. Also omitted are trades that involve price changes (since the prior trade) of 50% or more if the prior price is over $2 per share. Quotes are omitted if either the ask or bid price is non-positive, as are quotes associated with trading halts or designated order imbalances, or that are non-firm (TAQ quote condition codes 4,7,9,11,13,14,15, 19,20, 27, and 28). For purposes of the ongoing computation of the best bid or offer, these quotes are treated indicating the exchange's withdrawal from the market.

trades occurred when the computed NBBO bid–ask spread was non-positive and were also eliminated from the sample. With the exception of market shares reported on Table 1, the results reported are based on the remaining 4.933 million trades.

2.3. Market shares by exchange

Table 1 reports on sample market shares in terms of trades and trading volume for the NYSE, the five regional stock exchanges, and the NASD dealer market. The NYSE executed a small majority (51.7%) of trades in the one hundred sample stocks during June 2000. The NASD completed 19.4% of trades, while the five regional exchanges executed the remaining 28.9%. Among these, the Chicago Stock Exchange executed 8.2% of sample trades, closely followed by the Boston Stock Exchange with an 8.1% market share and the Cincinnati Stock Exchange with 6.2%. The Pacific Exchange and the Philadelphia Exchange completed 4.2% and 2.2% of sample trades, respectively.

The NYSE market share for large trades is substantially greater than for small trades. The NYSE executed 93.6% of all sample trades exceeding 5,000 shares, compared to 33.8% of trades of less than 500 shares. As a consequence, the NYSE share of sample trading volume (84.9%) substantially exceeds its 51.7% share of sample trades. All five regional exchanges and the NASD market have much larger

Table 1
Descriptive statistics on trade market shares. Reported are percentages of trades and trading volume for 5.08 million trades completed between 9:45 a.m. and 4 p.m. in the one hundred largest NYSE-listed common stocks (excluding Berkshire-Hathaway) during June 2000. Large trades are those exceeding 5,000 shares, medium trades are from 500 to 5,000 shares, and small trades are less than 500 shares. NYSE denotes the New York Stock Exchange, NASD denotes the National Association of Securities Dealers (the "third market"), BOS denotes the Boston Stock Exchange, CIN the Cincinnati Stock Exchange, CHI the Chicago Stock Exchange, PAC the Pacific Stock Exchange, and PHI the Philadelphia Stock Exchange

Market:	NYSE	NASD	BOS	CIN	CHI	PAC	PHI
Panel A: Market shares, percent of sample trades							
All trades	51.67	19.40	8.06	6.24	8.21	4.24	2.18
Large trades	93.64	2.84	0.79	0.83	1.38	0.29	0.23
Medium trades	68.33	12.91	5.31	4.43	4.97	2.80	1.25
Small trades	33.76	26.40	11.08	8.31	11.50	5.83	3.13
Panel B: Market shares, percent of sample trades, by stock							
Mean	62.48	15.46	5.74	4.41	6.58	3.49	1.84
Minimum	20.87	2.29	0.35	0.00	0.54	0.10	0.01
Maximum	92.23	32.64	25.54	17.03	18.49	13.08	7.15
Panel C: Market shares, percent of sample trading volume							
All trades	84.94	6.49	2.09	1.81	3.04	1.04	0.60
Large trades	93.09	3.28	0.54	0.58	2.07	0.21	0.24
Medium trades	76.10	10.01	3.87	3.32	3.76	2.02	0.92
Small trades	38.15	24.72	10.42	7.87	10.46	5.44	2.94

shares for small trades as compared to large. The NASD completes 26.4% of small sample trades, compared to 2.8% of large trades. The five regional markets in aggregate executed just 3.5% of large (over 5000 share) trades, compared to 39.8% of small (under 500 share) trades.

There is considerable variation in market shares across the one hundred sample stocks. NYSE market shares range from 92.2% of trades in financial services firm Marsh and McLennan Companies to 20.9% of trades in Motorola, Inc. Off-NYSE market shares are highest for technology companies. The greatest NASD dealer market share (32.6%) is for trades in Honeywell, Inc. Both the Philadelphia Exchange and the Cincinnati Exchange have their highest market shares (7.2% and 17.0%, respectively) for trading in Motorola, while the Boston Exchange and the Chicago Exchange both reach their highest market shares (25.5% and 18.5%, respectively) for trading in Nokia Corporation. The maximum market share for the Pacific Exchange is 13.1%, for trading in the electronic commerce and information storage company EMC, Inc. All market shares are non-zero, with two exceptions. The Cincinnati Stock Exchange had no sample trades in either Goldman Sachs or Genentech, Inc.

2.4. Characteristics of trades on each exchange

This section reports some summary statistics regarding trades on each of the seven markets, and describes the execution quality measures that will be used in this study. Table 2 indicates the average trade size is 1741 shares. Trades executed at the NYSE average 2,828 shares, while trades executed off the NYSE are much smaller, ranging from a mean of 419 shares on the Pacific Exchange to 580 shares on the NASD dealer market.

A widely used measure of trade execution quality is the effective bid–ask half-spread, defined for the time t trade in security i as

$$\text{Effective Half-Spread}_{it} = I_{it}(P_{it} - M_{it}), \tag{1}$$

where I_{it} is an indicator variable that equals one for customer-initiated buys and negative one for customer initiated sells, P_{it} is the trade price, and M_{it} is the midpoint of the NBBO quotes in effect for stock i at time t.[8] The effective half-spread measures how close the trade price comes to the quotation midpoint, viewed as a proxy for the underlying value of the stock.

[8] Trades are designated as reflecting customer buy or sell orders using the algorithm recommended by Ellis, Michaely, and O'Hara (EMO, 2000). All results reported here were also examined when trades were designated using the Lee and Ready (1991) algorithm. Estimates of average trading costs are slightly larger on each market when using the Lee and Ready method, but all inference is identical to that obtained using the EMO approach. As recommended by EMO and by Bessembinder (2003), trades are compared to quotes in effect at the trade report time, without any adjustment to time stamps to allow for possible reporting delays. As a sensitivity test, I repeated each empirical analysis while allowing for trade reporting lags ranging from 5 to 20 s. Adjusting trade time stamps did not alter any of the conclusions reported here, but had the effect of increasing somewhat the magnitude and statistical significance of the quote related variables reported on Table 5. To be conservative, I report results based on a zero time-stamp adjustment.

Table 2
Trade sample descriptive statistics. Reported are averages computed across trades on each market. Results exclude trades executed while the computed NBBO is nonpositive. The effective half-spread is the amount by which the trade price exceeds (for customer buys) or is below (for customer sells) the midpoint of the contemporaneous NBBO quotes. Price impact is the increase (after customer buys) or decrease (after customer sells) in the NBBO midpoint in the 10 min after the trade time. The realized half-spread is the difference between the trade's effective half-spread and its price impact. A trade is recorded as price improved when a customer buy (sell) is executed at a price below (above) the best contemporaneous ask (bid) quote. Trades are designated as customer buys and sells using the algorithm recommended by Ellis et al. (2000). Buy (sell) trades are recorded as outside the NBBO if the trade price exceeds (is less than) the best ask (bid) quote. Trades are recorded as small if the trade size is less than the size of the corresponding (ask for buys, bid for sells) NBBO quote. The number of trades in the preceding 10 min includes trades in the same stock executed on any market

Market:	NYSE	NASD	BOS	CIN	CHI	PAC	PHI	ALL
Number trades in sample	2,588,410	945,626	386,769	308,225	391,667	204,704	107,604	4,933,005
Trade size (shares)	2828	580	447	501	650	419	471	1741
Effective half-spread (cents)	3.68	4.18	4.63	3.67	4.48	4.17	3.75	3.94
Price impact (cents)	2.75	1.77	1.66	1.07	1.87	0.75	0.56	2.17
Realized half-spread (cents)	0.93	2.41	2.97	2.60	2.62	3.43	3.19	1.77
Percent price improved	29.24	21.07	15.52	18.43	21.66	18.38	21.24	24.70
Percent outside NBBO	2.61	4.98	5.16	1.54	5.33	4.90	3.65	3.53
Percent small and outside	0.36	3.07	3.12	1.08	3.19	3.57	2.29	1.54
Number trades preceding 10 Min	105	167	190	187	167	150	201	138

The average effective half-spread for the full sample is 3.94 cents. The effective half-spread is lowest at the Cincinnati Exchange, averaging 3.67 cents and the NYSE, averaging 3.68 cents. The highest average trading costs are 4.48 cents on the Chicago Exchange and 4.63 cents on the Boston Exchange. Finding slightly lower average effective spreads on the NYSE for the full sample is broadly consistent with the findings of prior authors, including Lee (1993), Peterson and Fialkowski (1994), and Bessembinder and Kaufman (1997).

The range in average effective half-spreads from the lowest cost market to the highest cost market is a relatively small 0.96 cents per share. It can be tempting to dismiss this amount, and with it issues related to the routing of orders across markets, as insignificant. It would be premature to do so, for at least two reasons. First, the aggregate dollar amounts are still substantial. The one-month, one hundred-stock sample examined here contained (before the trade omissions discussed in Section 2 above) 5.38 million trades for 9.36 billion shares. A penny per share in this sample equates to over $90 million dollars for the month. Second, it has been asserted (see Bessembinder and Kaufman, 1997; Easley et al., 1996; Battalio, 1997) that off-NYSE market makers may seek to "cream skim" order flow that originates from uninformed traders. Uninformed order flow is more profitable for dealers, since there is less likelihood of an adverse post-trade price movement that renders the trade unprofitable to the dealer ex post. Trades that are less costly for market makers could receive better executions. Even finding that effective spreads are equal across markets would not necessarily indicate that orders had received the best possible execution, if some markets successfully divert uninformed order flow.

To assess the cream-skimming argument requires a measure of trades' information content. The empirical approach used here is to assess each trade's price impact, defined as

$$\text{Price Impact}_{it} = I_{it}(M_{i,t+10} - M_{it}), \tag{2}$$

where $M_{i,t+10}$ is the midpoint of the NBBO quotes in effect 10 min after the trade time.[9] The price impact measure captures the increase in quotation midpoints after customer buys and the decrease in quotation midpoints after customer sells.

Table 2 reports the average price impact of trades completed on each market. The full sample average price impact is 2.17 cents per share. Consistent with the cream-skimming hypothesis, the average price impact of trades completed at the NYSE is greatest (2.75 cents per share), and the average impact of trades completed away from the NYSE is always less than the full-sample average, ranging from 0.56 cents on the Philadelphia Exchange to 1.77 cents on the NASD dealer market.

A measure of trade execution cost that considers the possible effect of trades' differing price impact is the realized half-spread, defined for each trade as the

[9] For trades executed in the last 10 min of trading the closing quote midpoint is used instead. The measured price impact for any individual trade contains substantial noise due to the arrival of additional information (including more trades) in the intervening 10 min. However, the average price impact computed over many trades should provide reliable evidence on whether markets are completing trades that contain more or less information.

effective half-spread less price impact. The realized half-spread measures revenue to the liquidity supplier, after allowing for the trade's price impact. Realized half-spreads average 1.77 cents per share for the full sample. The average realized half-spread is lowest on the NYSE, at 0.93 cents per share. Realized half-spreads off the NYSE average from 2.41 cents on the NASD dealer market to 3.4 cents on the Pacific Exchange. The somewhat larger cross-market differentials in average realized spreads as compared to average effective spreads confirm that observing similar effective spreads across markets is not necessarily sufficient to alleviate concerns regarding trade-routing practices.

Table 2 also reports on the percentage of trades that receive price improvement, which means they are executed at prices within the best quotes, as well as the percentage of trades that are executed at prices outside the quotes. Each market gives price improvement to a non-trivial proportion of trades. Price improvement rates range from 15.5% on Boston, to 18.4% on the Pacific and Cincinnati Exchanges, to 29.2% on the NYSE.

A substantial number of trades are executed at prices outside the NBBO quotations, ranging from 1.5% on Cincinnati to 5.3% on Chicago. However, most of these involve trades that are larger than the size of the NBBO quotation, and were therefore not entitled to an expectation of execution at the NBBO quote. (In cases where there is more than one quote at the NBBO the size of the largest quote at the NBBO is designated as the NBBO quote size, as opposed to using the sum of the quote sizes.) About 1.5% of all trades are smaller than the NBBO quote size, but are executed at prices outside the NBBO quotes. These trades are apparent "trade-through" violations. A trade through is a violation of ITS agreements, but not necessarily of the SEC "firm quote" rule, which is violated only if a market executes a trade at a price worse than its own quote.[10] Trade-through violations are observed for only 0.36% of NYSE trades and 1.08% of Cincinnati trades. In contrast, four of the five regional exchanges and the NASD market have more than 3% of trades that appear to constitute trade through-violations. Trade through violations may occur because multiple orders arrive at the same time, or because a market does not have effective mechanisms to prevent their occurrence.

Finally, Table 2 reports on the average number of trades executed (on any market) in the 10 min before each trade. The main observation is that off-NYSE market makers tend to complete trades in stocks and/or at times with higher trading activity. On average, 105 trades in the same stock have been completed in the 10 min before a trade is executed on the NYSE. The number of trades completed in the 10 min before off-NYSE trades ranges from 150 for trades completed at the Pacific Exchange to 201 for trades completed at the Philadelphia Exchange.

[10] I refer to these trades as apparent violations, as some may actually be attributable to imperfect matching of the time stamps in the trade and quote databases. Errors in the time alignment of trades and quotes can make a trade that occurs just after a quote update appear executed outside the quotes when it was not. The low rate of apparent trade through violations for NYSE trades suggest that imperfections in time stamps do not cause a high error rate. Also, Ferrell (2000) cites a SEC study reporting that between 0.40% and 0.54% of trades constituted trade through violations. Although the SEC study refers to older (1980) data, it indicates that some trade through violations do occur.

3. Quote competitiveness

This section provides a description of how frequently each market posts competitive quotes. It also reports the results of an econometric analysis of the factors that determine whether or not individual quotes on each market are alone at the NBBO.

3.1. Frequency of competitive quotations

Table 3 reports several statistics concerning relations between quotations originating at each market and the intermarket best (NBBO) quotations. The status (e.g., whether the quoted price matches the NBBO price) of each individual quotation is recorded at the time each quote appears in the TAQ database and at the

Table 3

Quotations and the national best bid or offer (NBBO). Reported are sample means for characteristics of quotations placed between 9:45 a.m. and 4 p.m. for the one hundred largest NYSE-listed stocks (excluding Berkshire-Hathaway) during June 2000. Results are based on quotes reported in the TAQ (Trade and Quote) database. Results reported on Panel A are averages obtained when each quotation is weighted by elapsed time before it is updated. Results reported on Panel B are averages obtained when each quotation is weighted by the number of trades executed (on any market) while it is in effect. Quotations are at the inside if they match the NBBO quote and are alone at the inside if no other market is posting the same quote. A quotation has time priority if it is alone at the inside or if it was placed earlier than other inside quotes at the same price. Percentage active reflects the proportion of a market's inside quotes that reached the inside when that market places a new quote which improves on the existing inside, as opposed to reaching the inside passively when other markets change their quotes

Market:	NYSE	NASD	BOS	CIN	CHI	PAC	PHI
Panel A: Time-weighted averages (percent of time)							
At either inside bid or ask	99.74	90.02	12.39	11.52	17.48	9.04	6.44
At both inside bid and ask	89.11	4.08	0.60	0.78	2.01	0.42	0.47
Alone at inside bid	47.96	1.19	0.90	0.32	1.23	0.79	0.26
Alone at inside ask	36.44	1.37	0.67	0.25	1.04	0.70	0.28
Alone at both bid and ask	4.59	0.01	0.00	0.01	0.01	0.01	0.03
Time priority at bid	82.18	2.88	3.50	2.77	5.22	2.88	1.02
Time priority at ask	84.04	2.67	3.05	2.26	4.79	2.52	0.99
Percentage active	99.58	96.17	59.20	64.70	59.41	64.24	76.02
Own bid–ask spread (cents)	12.19	39.71	47.35	58.66	38.28	76.70	74.50
Panel B: Trade-weighted averages (percent of trades)							
At either inside bid or ask	99.01	85.50	21.90	21.76	27.59	13.84	9.43
At both inside bid and ask	77.38	7.52	1.50	2.61	2.71	0.85	0.70
Alone at inside bid	40.01	2.28	1.77	0.92	2.25	1.09	0.55
Alone at inside ask	35.59	2.37	1.23	0.59	1.91	0.96	0.33
Alone at both bid and ask	4.68	0.03	0.02	0.03	0.04	0.01	0.01
Time priority at bid	70.05	5.21	5.84	5.43	8.07	4.09	2.31
Time priority at ask	76.02	4.20	4.79	3.62	7.22	3.31	1.35
Percentage active	98.84	93.29	58.22	67.42	57.13	62.14	66.71
Own bid–ask spread (cents)	13.00	39.01	45.08	52.41	35.70	90.42	86.98

time of each trade. Panel A reports results that have been averaged across quotations based on the amount of time that elapsed before the quote was updated or withdrawn. Panel B reports results based on the number of trades executed (on any market) before the quote is updated or withdrawn. The trade-weighted averages on Panel B tend to indicate more off-NYSE activity than the time-weighted averages on Panel A, reflecting that off-NYSE markets quote more aggressively for stocks and at times with heavier trading activity.

The TAQ database reports quotations from the NYSE and the five regional exchanges and individual dealer quotes for NYSE stocks from the NASD market. The NBBO is recreated from this quotation data in two stages. First, the best bid and offer in effect among individual NASD dealers is assessed and is designated as the NASD bid and offer. Then, the best bid and offer in effect across the NYSE, the five regional exchanges, and the NASD are determined and are designated as the NBBO quotations. One complicating issue is that the TAQ database sometimes contains multiple quotations from the same market or NASD market maker with identical time stamps, which raises the question of which quotation is in effect going forward in time. This study adopts the convention that the quotation reported last in the TAQ database remained in effect.

Results reported on Table 3 indicate that the NYSE is virtually always (99.74% of the time and during 99.01% of trades) at the NBBO on at least one side of the market. However, off NYSE quotes are generally present on at least one side of the NBBO as well. The NYSE quote is alone at both the best bid and offer only 4.6% of the time. NASD dealers are at the NBBO on either the bid or ask side for most (90.0% time-weighted, 85.5% trade-weighted) observations. The regional exchanges are occasionally present at the NBBO. Among regional market makers, Chicago appears on at least one side of the NBBO most frequently (during 27.6% of trades and 17.5% of the time), closely followed by Cincinnati (21.8% of trades and 11.5% of the time) and Boston (21.9% of trades and 12.4% of the time). The Philadelphia Exchange is at one side of the NBBO the least (during 9.4% of trades and 6.4% of the time).

Table 3 also displays the percent of all observations where individual market quotations match *both* the best bid and the best offer. The NYSE is present at both sides of the NBBO, or equivalently, the NYSE spread is the NBBO spread, 89.1% of the time or for 77.4% of trades. Equivalently, off-NYSE quotes establish the NBBO without NYSE participation 10.9% of the time. Quotes from individual non-NYSE markets rarely match the NBBO on both sides. The distinction is most notable for NASD dealer market quotes, which are at both sides of the NBBO only 4.1% of the time, despite being present on at least one side of the NBBO 89.1% of the time. The only regional exchange that is at present at both the bid and offer as much as 1% of the time is Chicago, which matches both sides of the NBBO 2.0% of the time and during 2.7% of trades.

Table 3 reports on the percentage of observations where quotations from each market are alone at the NBBO. The NYSE quote alone establishes the best bid (ask) quote 48.0% (36.4%) of the time and during 40.0% (35.6%) of trades. Off-NYSE quotes are occasionally alone at the NBBO. An off-NYSE quote is alone at the best bid (ask) price 4.7% (4.3%) of the time, and a total of 7.4% (8.7%) of trades occur when an off-NYSE quote is alone at the best ask (bid) price.

Table 3 also reports on the percentage of sample observations where quotes from each market have time priority. A quotation has time priority if (1) it is alone at the NBBO or (2) it was posted earliest among the set of quotations that match the NBBO. If orders were always allocated across markets according to price/time priority, then every trade would be completed by the market with time priority. If so, trade market shares (as reported on Table 1) would match the trade-weighted average of quotes with time priority, as reported on Panel B of Table 3.

The NYSE quotation has time priority for the majority of sample observations. On a time-weighted basis the NYSE has time priority at the bid 82.2% of the time and at the offer 84.0% of the time. The NYSE has time priority less often on a volume-weighted basis, 70.0% at the bid and 76.0% at the offer. The NYSE market share of 51.7% of sample trades is considerably less than the proportion of the time that NYSE quotes have time priority, indicative of the fact orders are often routed according to preferencing agreements that violate price and time priority rules.

Off-NYSE market makers have time priority for a non-trivial number of observations. Focusing on the percentage of trades, time priority at the bid is held by the Chicago Stock Exchange for 8.1% of observations, by the Boston Exchange for 5.8% of observations, followed by the Cincinnati Exchange (5.4%), a NASD dealer (5.2%), the Pacific Exchange (4.1%), and the Philadelphia Exchange (2.3%). The pattern for time priority at the ask is similar. The divergence between trade market share and the proportion of trades for which the market has time priority is most notable for the NASD dealer market, which has a 19.4% trade market share, compared to time priority during 4% to 5% of trades. This result suggests that NASD market makers obtain the bulk of their trades in NYSE securities by preferencing agreements.

A quote can arrive at the NBBO actively, because the market maker posts a new bid or offer that improves on at least one side of the existing NBBO, or passively because other market makers post new quotes that move away from an existing bid or offer. Table 3 also reports on the percentage of each market's observations at the NBBO that are attributable to the active posting of a new quote by the Exchange, as opposed to passive arrival (i.e., due to movement in quotes at other markets).

Virtually all (99.6%) of the NYSE time at the NBBO is attributable to the active posting of quotes that improve on either the existing best bid or best offer. The NASD dealer market also arrives actively at the NBBO almost all (96.2%) of the time. The regional exchanges, in contrast, often reach the NBBO passively, due to updates in other markets' quotations. The percentage of the time at the NBBO attributable to passive arrival ranges from 24.0% for the Philadelphia Stock Exchange to 30.8% for the Boston Stock Exchange. Many of the off-NYSE quotes that arrive at the NBBO passively appear to be autoquotes, which are computer generated quotes for one hundred shares that are placed just outside the NYSE quotes, and are updated automatically (but not instantaneously) after NYSE quote changes. I repeat the analysis in Table 3 when any quote with bid and ask sizes both equal to one hundred shares and bid and ask prices both inferior to the standing

NYSE quote is treated as a withdrawal from the market. This filter eliminates 26.8% of all quote updates in the sample, ranging from 8.2% of NASD quotes to 89.7% of Philadelphia quotes. With autoquotes excluded, the percentage of the remaining time at the NBBO that is attributable to passive arrival falls for all off-NYSE markets, ranging from 1.4% for Philadelphia to 7.3% for Chicago.

To summarize, the NYSE posts the most aggressive quotes on average, participating in at least one side of the NBBO quotations 99.7% of the time, and in both sides of the NBBO quotations 89% of the time. However, off-NYSE market-makers are active suppliers of posted liquidity a non-trivial portion of the time, establishing both sides of the NBBO without NYSE participation 11% of the time and participating in at least one side of the NBBO quotes over 95% of the time.

3.2. The determinants of quote competitiveness

The results reported above concern the average competitiveness of quotations posted by each market. This section presents results of an empirical analysis of the factors that determine whether individual quotes from each market are competitive. If all trades are routed based on preferencing agreements or other fixed arrangements, then there is little reason for market makers to vary their quotation placement in strategic or systematic ways. If, in contrast, competitive quotations can attract order flow, then quotation strategies should vary systematically as a function of the profitability and likelihood of attracting additional order flow.

Quote competitiveness is evaluated using a pair of logistic regression specifications. The first considers quotes throughout the trading day. Characteristics of the quotes in effect at each market are recorded at the time of every quote observation in the TAQ database, and the logistic analysis is conducted while weighting each observation by the elapsed time until the next quote for the same stock appears in the database. The dependent variable for this specification equals one for quotations that are alone at the NBBO and zero for all other quotations. The second specification focuses specifically on quotation update decisions, including in the analysis only quote updates where either the bid or the ask price differs as compared to that markets' preceding quote for the same stock. For this specification, the dependent variable equals one if the quote update establishes a new NBBO and equals zero if the market alters its quote but does not improve on the existing NBBO. Each logistic analysis is also conducted when competitive quotations are defined as those that either match or improve on the existing NBBO. Results are qualitatively similar to those reported.

The interpretation of coefficient estimates potentially differs across these two specifications. Posting a new quote at a price that differs from the preceding quote is an act of commission, and the new quote will improve on the existing NBBO quote only as a result of a conscious decision by the liquidity provider. In contrast, the competitiveness of quotes in effect through the trading day can change in the absence of any decision or action on the part of the market maker, as a result of quote changes on other markets.

Logistic regression models are estimated for each market in turn. To be consistent with the trade analysis reported in Section 4, this analysis excludes quotes posted before 9:45 a.m. Since the sign of some coefficient estimates are expected to differ across bid and ask quotes, results are reported separately for bid- and ask-quote updates.

The following explanatory variables are used in the logistic analysis to assess whether quote competitiveness varies systematically with market conditions. Individual observations on each explanatory variable are standardized by a divisor constructed to facilitate interpretation and render the standardized variables comparable across stocks. The explanatory variables are:

1. The relative order imbalance. This variable is constructed for each market based on the accumulated difference since open between customer buy and customer sell trades on that market.[11] The order imbalance on a relative basis is measured as the difference between the order imbalance measure for the individual market and the same measure averaged across all seven markets. Each relative order imbalance observation is standardized to allow for time of day and normal trading activity by dividing by the product of the elapsed time (in 10 min intervals) since market open and the full sample average number of trades (per 10 min) in that stock.
2. The width of the NBBO spread, relative to the average NBBO spread for the stock.
3. Market volatility during the prior 10 min, based on the absolute percentage change in the transaction price from the last trade more than 10 min before the quote update to the last trade before the quote update. The volatility measure is standardized by the sample mean for that stock.
4. The number of trades during the immediately preceding 10 min, relative to the average number of trades per 10 min in the stock.
5. The quote size in shares, relative to the average NBBO quote size for the stock.
6. One hundred separate indicator variables for the one hundred stocks in the sample.

Numerous authors, beginning with Amihud and Mendelson (1980) and Ho and Stoll (1983), suggest that market-makers' quote-placement strategies should be affected by accumulated inventory. The relative order imbalance variable is included in the logistic regression to determine whether inventory considerations affect the competitiveness of quotations. An excess of customer buy (sell) orders leads to reductions (increases) in market-maker inventory. If market makers perceive that competitive quotations will attract orders, then reductions (increases) in inventory should lead to the posting of more aggressive quotations at the bid (ask) to attract customer sell (buy) orders and restore inventory. Order imbalances spread across all liquidity providers would presumably affect quotes from each market symmetrically.

[11] Trades are designated as customer buys or sells using the Ellis et al. (2000) algorithm. All results were also estimated using the Lee and Ready (1991) algorithm, and using a trade imbalance variable that weights each trade by the number of shares transacted. All conclusions are the same as those reported.

The analysis therefore focuses on order imbalances relative to the market-wide average. The analysis that considers all quotes in effect during the trading day includes the relative order imbalance in levels. The analysis that focuses only on quote changes relies on the change in the order imbalance measure since the previous quote update.

If market makers use quotations to manage inventory we anticipate a positive (negative) coefficient on the relative order imbalance variable when explaining whether the bid (ask) quote is competitive. If, in contrast, orders are routed for reasons unrelated to quote competitiveness, then there is no reason to expect order imbalances to affect quote placement.

The width of the NBBO spread is included in the logistic regression to assess whether quote competitiveness is affected by potential profitability. The specification that focuses on quote updates includes the NBBO spread just prior to the quote update. If competitive quotes attract orders then we would expect to see positive coefficient estimates on the existing NBBO spread in this specification, since the additional order flow would be more profitable when spreads are wider. The specification that considers all quotes through the trading day includes the contemporaneous NBBO spread, to assess whether each market tends to be alone at the NBBO during periods of wide or narrow spreads.

The market volatility measure is included to assess whether individual markets tend to quote aggressively or to post cautious, non-competitive, quotes at times of greater uncertainty. The number of trades in the prior 10 min is included to assess whether market makers are more likely to post competitive quotes at times of greater trading activity and liquidity.

Liquidity suppliers select quotation size and price simultaneously. As a consequence, it is not useful to think of quotation size as an external determinant of whether quotes are placed at competitive prices. Quotation sizes are included in the logistic regression to document the manner in which endogenous selections of quotation prices and sizes covary on each market. Empirically, coefficient estimates on the other explanatory variables are little altered by the inclusion or exclusion (results not reported) of quotation sizes in the logistic regression, so no information regarding the effects of other variables on quote competitiveness is lost. Finally, the one hundred firm-specific indicator variables are included to control for stock-specific effects and to allow for valid statistical inference in the pooled time-series cross-sectional data.

Panel A of Table 4 reports results of the logistic analysis that considers all quotes in effect throughout the trading day, Panel B of Table 4 reports results that consider only the new quotes posted by each market. The tables report coefficient estimates, as well as Chi-square statistics for the hypothesis that each coefficient equals zero. In light of the large sample sizes, I denote the few coefficient estimates that are *not* significantly different from zero (p-value>0.01) with asterisks. Because of the logistic transformation, the coefficient estimates cannot be interpreted as the change in probability that a quote update will be competitive for a unit change in the explanatory variable. I calculate this effect, denoted probability slope on Table 4 Panels A and B, as probability slope $= \alpha(B, X)[1 - \alpha(B, X)]B$, where B is the vector

Table 4

Logistic analysis of quotations alone at the NBBO. Displayed are results of estimating logistic regressions where the dependent variable equals one for quotes that alone comprise the NBBO and zero otherwise. For Panel A, observations are recorded at the time that a quote from any market enters the TAQ database, and coefficient estimates are obtained while weighting each observation by the elapsed time until the next quote. For Panel B the analysis includes only quote updates where the bid or offer differs from the preceding same-market quote. Probability slope denotes the estimated change in the probability of a competitive quote for a unit change in the explanatory variable, evaluated at the sample mean. Several explanatory variables are standardized to facilitate interpretation. The quote size is divided by the average NYSE quote size in the same stock. The inside bid–ask spread is standardized by the average NBBO spread for the stock. Trades during the prior 10 min are standardized by the average number of trades per 10 min in that stock. Volatility in the prior 10 min is standardized by the average 10 min volatility in that stock. The relative order imbalance is measured since the beginning of the trading day, but is scaled by the product of elapsed time since open and average trading activity. The regression includes separate intercepts for each of the one hundred sample stocks. An asterisk indicates a point estimate that is not significantly different from zero at the 0.01 level. A Chi-square statistic greater than 100,000 is denoted 100 k +

Panel A: Quotations throughout the trading day

Quotes on:	NYSE		NASD		BOS		PHI		CIN		CHI		PAC	
	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask
Percent alone at NBBO	50.6	43.8	4.1	6.2	1.6	1.2	0.5	0.5	0.8	0.7	1.8	1.5	1.3	1.2
Trades during prior 10 min														
Regression coefficient	−0.083	−0.210	0.254	0.288	0.294	0.247	0.301	0.344	0.401	0.316	0.197	0.188	−0.011	0.243
Probability slope	−2.1	−5.2	1.0	1.6	0.5	0.3	0.2	0.2	0.3	0.2	0.3	0.3	−0.0	0.3
Chi-square statistic	10,778	70,603	12,825	18,645	14,375	8,173	4,865	5,708	18,461	7,606	6,714	5,194	10.8	6,854
Volatility during prior 10 min														
Regression coefficient	−0.026	−0.028	0.184	0.181	0.079	0.184	0.181	0.087	0.290	0.275	0.160	0.157	0.291	0.166
Probability slope	−0.6	−0.7	0.7	1.0	0.1	0.2	0.1	0.0	0.2	0.2	0.3	0.2	−0.4	0.2
Chi-square statistic	4,904	4,788	17,028	19,189	12,215	10,478	4,063	810.4	22,953	14,657	11,728	9,992	36,424	8,005
Inside spread														
Regression coefficient	−0.066	−0.104	−0.777	−0.675	−1.103	−0.771	−0.599	−0.689	−0.032	0.174	−1.012	−0.899	−0.012	−0.431
Probability slope	−1.6	−2.6	−3.0	−3.9	−1.8	−0.9	−0.3	−0.4	−0.0	0.1	−1.8	−1.4	−0.0	0.5
Chi-square statistic	10,617	25,714	75,228	65,693	98,401	42,045	9,810	13,050	600.8	5,425	100k +	75,354	91.8	14,279
Relative order imbalance														
Regression coefficient	0.395	−0.451	0.082	0.077	0.110	0.069	0.110	−0.225	0.045	−0.019	0.035	−0.025	0.045	−0.125

Table 4. (*Continued*)

Panel A: *Quotations throughout the trading day*

Quotes on:	NYSE		NASD		BOS		PHI		CIN		CHI		PAC	
	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask
Probability slope	9.9	−11.1	0.3	0.4	0.2	0.1	0.1	−0.1	0.0	−0.0	0.1	−0.0	0.1	−0.2
Chi-square statistics	85,278	100k +	561.0	636.3	2,883	787.5	1,377	7,646	210.7	35.7	302.0	104.8	305.7	2,107
Quote size														
Regression coefficient	−0.803	−0.781	0.070	0.040	0.097	0.113	0.176	0.180	0.064	0.061	0.104	0.062	0.159	0.127
Probability slope	−20.1	−19.2	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.2
Chi-square statistics	100k +	100k +	43,061	24,749	40,095	57,753	92,291	100k +	4,824	3,464	100k +	66,969	100k +	100k +

Panel B: *Quote updates only*

Quote updates on:	NYSE		NASD		BOS		PHI		CIN		CHI		PAC	
Number of quote updates	578,704		744,923		274,151		542,737		215,413		305,113		471,375	
	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask	Bid	Ask
Percent improving NBBO	62.7	60.5	2.1	2.2	3.0	2.2	0.3	0.3	5.4	4.2	2.0	1.6	0.7	0.7
Trades during prior 10 min														
Regression coefficient	−0.161	−0.098	0.323	0.251	0.258	0.160	0.358	0.257	0.340	0.213	0.230	0.067	0.145	0.109
Probability slope	−3.8	−2.3	0.7	0.5	0.8	0.3	0.1	0.1	1.7	0.9	0.5	0.1	0.1	0.1
Chi-square statistic	614.9	251.4	730.3	412.1	251.1	61.2	98.9	35.3	677.0	203.9	129.8	7.4	26.9	15.6
Volatility during prior 10 min														
Regression coefficient	−0.143	−0.132	−0.048	−0.012	−0.118	−0.138	−0.089	−0.185	−0.107	−0.149	−0.149	−.0135	−0.027	−0.051
Probability slope	−3.3	−3.2	−0.1	0.0	−0.3	−0.3	0.0	−0.1	−0.5	−0.6	−0.3	−0.2	0.0	0.0
Chi-square statistic	1,816	1,674	31.2	2.2*	96.1	94.4	11.8	38.3	137.0	194.2	105.3	70.8	2.3*	7.5
Existing inside spread														
Regression coefficient	1.433	1.328	0.789	0.693	0.840	0.857	0.979	0.882	0.831	0.759	0.940	0.925	0.657	0.656
Probability slope	33.5	31.7	1.6	1.4	2.4	1.8	0.3	0.3	4.2	3.1	1.8	1.5	0.5	0.5
Chi-square statistic	49,856	47,189	5,029	4,150	2,592	2,028	777.9	578.3	4,628	3,257	2,627	2,108	812.6	759.9

Change in relative order imbalance														
Regression coefficient	0.758	−0.898	0.079	−0.115	0.027	−0.080	0.065	−0.028	0.001	−0.020	0.061	−0.062	0.068	−0.062
Probability slope	17.7	−21.5	0.2	−0.2	0.1	−0.2	0.0	−0.0	0.0	−0.1	−0.1	−0.1	0.0	−0.0
Chi-square statistic	733.5	1,010	12.5	25.7	4.8*	83.9	21.0	25.3	0.0*	15.6	21.3	23.5	31.7	32.4
Quote size														
Regression coefficient	−0.154	−0.123	0.115	0.073	0.189	0.186	0.242	0.275	0.047	0.064	0.125	0.119	0.222	0.204
Probability slope	−3.6	−2.9	0.2	0.2	0.5	0.4	0.1	0.1	0.2	0.3	0.2	0.2	0.2	0.1
Chi-square statistic	4,119	2,871	2,123	1,370	1,135	968.2	847.7	1,443	71.9	118.8	973.7	1,047	1,771	1,562

of coefficient estimates, X is the vector of means of the explanatory variables, and $\alpha(B, X) = \exp(BX)/(1 + \exp(BX))$.

The results reported on Table 4 Panels A and B indicate that inventory considerations affect NYSE quote placements in a highly significant manner. Results reported on Table 4 Panel A indicate that an excess of customer buy orders at the NYSE since the open substantially increases (decreases) the likelihood that the NYSE quote is competitive on the bid (ask) side of the market, and vice versa. Results reported on Table 4 Panel B indicate that NYSE quote updates are significantly affected by inventory changes since the prior quote update, again in the direction predicted by inventory control theories. Madhavan and Sofianos (1998) survey earlier studies of relations between inventory measures and quote placement, and note that empirical results are generally weak. The results presented here appear to comprise the first statistically significant finding that inventory affects quote placement for US equities. (That inventory affects the quote behavior of London Stock Exchange dealers has been documented by Hansch et al., 1998).

Relative order imbalances also affect quotes posted by liquidity providers at the six off-NYSE markets and most often in the direction predicted by inventory control theory. Considering first the results reported in Table 4 Panel A for all quotations, 10 of the 12 coefficient estimates are of the correct sign (positive when explaining the competitiveness of bid quotes and negative when explaining the competitiveness of ask quotes) and statistically significant. The two exceptions are for ask quotes posted by the NASD dealer market and the Boston Stock Exchange. When explaining quote updates (Table 4 Panel B) all twelve estimated coefficients on the change in the relative order imbalance are of the predicted sign, although two (bid quotes in Boston and Cincinnati) are not statistically significant.

Although the evidence supports inventory control as a determinant of quote placement both on and off the NYSE, the estimated effects are substantially stronger for the NYSE. An order imbalance (per 10 min) that equals the average number of trades (per 10 min) alters the probability that the next NYSE quote update will establish a new NBBO by approximately 18–20%. In contrast, a similar order imbalance off the NYSE alters the probability that the next quote update from the market experiencing the imbalance will establish a new NBBO by only 0.1–0.2%. The weaker support for inventory-based theories of quote placement off the NYSE could reflect that individual market-making firms can be active in more than one market, implying that the order imbalance on any individual market may not be relevant. For example, Battalio (1997) reports that the market-making firm Madoff Securities completes trades on both the NASD dealer market and on the Cincinnati stock exchange.

The effect of market volatility on quote competitiveness differs markedly depending on whether the focus is on quotes throughout the day or quote updates. All of the 14 coefficient estimates reported on Table 4 Panel B for the effects of market volatility on the likelihood that a quote update will establish a new NBBO are negative, and 12 are statistically significant. New quotes posted by liquidity providers both on and off the NYSE are less likely to improve on the existing best quote during times of increased market volatility. This result likely reflects risk aversion on the part of liquidity providers and is the process by which the NBBO spread tends to widen when markets are volatile. When considering quotes in effect through the trading day as reported on Table 4 Panel A, in contrast, we see positive coefficient estimates on volatility for quotes originating off the NYSE. This implies that standing non-NYSE quotes are more likely to alone comprise the NBBO at times when markets are volatile. This likely reflects in part that quotes can passively reach the NBBO if a market maker is slow to update quotations.

Quote updates that occur when the existing NBBO spread is wide are more likely to improve on the existing quote. All 14 of the individual coefficient estimates for the NBBO spread reported on Table 4 Panel B are positive and statistically significant. This result is to be expected if quotations attract order flow, since those orders can be executed more profitably when the spread is wider. The estimated effects of existing spread widths on the likelihood that new quotes will be competitive are quite large. For example, an increase in the inside spread by the average for the stock increases the probability that the next NYSE quote update will improve on the existing bid (ask) by 33.5% (31.7%). The corresponding figures for the Cincinnati Stock exchange are increases in the probability that the next quote update will improve on the existing NBBO quote by 4.2% at the bid and 3.1%. These estimates are large compared to the overall sample percentages with which Cincinnati quote updates improve on the NBBO, which are 5.4% at the bid and 4.2% at the ask.

In contrast to results for quote updates, the likelihood that quotes throughout the trading day will be alone at the NBBO is negatively related to the NBBO spread. All 14 coefficient estimates for the inside spread reported on Table 4 Panel A are negative, a result which would be expected if narrow spreads reflect more competitive markets when more than one quote is tied at the NBBO. This result is somewhat sensitive to the exclusion of autoquotes. I repeat the analysis when autoquotes (see Section 3.1) are treated as withdrawals from the market. The coefficient estimates on the inside bid ask spread are then mixed in sign and those that remain negative are closer to zero. The exclusion of autoquotes also reduces the magnitude, but not the statistical significance of relations between quote competitiveness and quote size, as discussed below. A table that reports results corresponding to those in Table 4 Panel A when autoquotes are excluded is available from the author on request. Empirical results reported elsewhere in the paper are generally insensitive to the exclusion of autoquotes.

Relations between the competitiveness of quote updates and both volatility and spread widths are quite uniform across the NYSE and the other markets that enter quotes for NYSE-listed stocks. In contrast, relations between trading activity, quote size, and quote competitiveness differ across the NYSE and other market makers. More active trading increases the likelihood that quote updates originating off the NYSE will be competitive. Each off-NYSE coefficient estimate on trading activity reported on Table 4 Panel B is positive and statistically significant. Noting that return volatility and spread widths are also included in the regressions, the likely interpretation of this result is that off-NYSE liquidity providers are more likely to post competitive quotes at times when markets are more liquid, both because there are more orders to capture and because unwanted positions can be readily unwound in active markets. In contrast to results for off-NYSE market makers, more active trading is associated with a decreased likelihood that NYSE quote updates will match or better the NBBO quote. Results for quotes in effect throughout the trading day are similar, in that off-NYSE quotes are more likely to be at the NBBO during times of rapid trading.

Estimates reported on Table 4 Panel A for quotes through the trading day and Table 4 Panel B for quote updates both indicate that quotes originating off the NYSE are more likely to be competitive if they are also for large sizes. This effect is observed for all six non-NYSE markets, for both bid and ask quotes and is always statistically significant. In contrast, larger NYSE quote sizes are associated with a decreased likelihood that either standing quotes or quote updates are alone at the NBBO. Offering less shares at more attractive (to liquidity demanders) prices is consistent with the reasoning that NYSE quotes reflect an upward sloping liquidity supply schedule. In contrast, offering more shares at more attractive (to the liquidity demander) prices is not consistent with the reasoning that off-NYSE quotes simply reflect an upward-sloping liquidity supply function.

If orders are allocated across markets on the basis of preferencing agreements or other predetermined criteria then there is no motivation for liquidity providers to quote strategically. The results here indicate that quote placement strategies depend systematically on market conditions, in a manner that would be expected if market makers can attract orders through their quotations. In particular, the findings are consistent with the reasoning that off-NYSE market makers employ quotations as a selective signaling device. Under some circumstances the off-NYSE markets are content to receive the orders routed to them for non-quotation reasons, e.g., through preferencing agreements. In other circumstances, for example during times when spreads are unusually wide or when markets are unusually active (both implying increased profits to liquidity provision), when markets are tranquil, when unwanted inventory has accumulated, or when customer limit orders have been directed to the market, off-NYSE liquidity providers use more aggressive quotation prices and larger quote sizes to indicate an interest in attracting additional market orders. Section 4 below assesses empirically whether the posting of more aggressive quotes succeeds in attracting more order flow, and Section 5 focuses on whether markets that use aggressive quotations give better trade executions.

4. The empirical determinants of execution market

Orders are routed by brokerage firms to market makers for execution. I next examine the factors that govern order-routing decisions. The empirical specification includes both quotation and trade characteristics. If all orders were routed by price/time priority rules, quotation characteristics would fully explain execution venue, and trade characteristics would have no explanatory power. In contrast, if all orders were routed on the basis of preferencing agreements, quote characteristics would have no explanatory power.

Logistic regression models are estimated for each market in turn, using the full sample of 4.93 million trades. When examining the determinants of NYSE trading, the dependent variable is set to one for NYSE trades and zero for off-NYSE trades. When examining NASD trading, the dependent variable is set to one for NASD trades and zero for off-NASD trades, etc. Explanatory variables reflect characteristics of the quotations in effect on the market under consideration, as well as trade characteristics. Quote characteristics are matched to trade direction. For customer buys the analysis focuses on characteristics of the ask quote while for customer sells the analysis focuses on characteristics of the bid quote. The explanatory variables are:

1. An indicator variable that equals one if the quote from the indicated exchange matches the NBBO quote and zero otherwise.
2. An indicator variable that equals one if the quote from the indicated exchange has time priority and zero otherwise.
3. An indicator variable that equals one if the quote from the indicated exchange is alone at the NBBO and zero otherwise.
4. A passive quote indicator that equals one if the quote matches the NBBO quote and arrived at the inside passively (due to changes in quotes on other markets) and zero otherwise.
5. The quote size in shares, relative to the average NYSE quote size for the stock.
6. The width of the spread between the ask and bid quotes posted by the indicated exchange, relative to the average NBBO spread for the stock.
7. Trade size, relative to the average trade size for the stock.
8. The number of trades during the immediately preceding 10 min, relative to the average number of trades per 10 min in the stock.
9. The trade's price impact in dollars per share.
10. One hundred separate indicator variables for the one hundred stocks in the sample.

The four indicator variables are used to ascertain whether brokers are more likely to route orders to a market when it posts a more competitive quote. Note that the definitions of the indicator variables overlap. All quotes that are alone at the inside have time priority, and all trades that have time priority must match the NBBO. As a consequence, coefficient estimates on the indicator variables are additive. The coefficient estimated for the "Quote at NBBO indicator" measures the effect of the quote being at the NBBO, without time priority and without being alone at the NBBO. The coefficient estimate for the "Quote has time priority indicator" measures the incremental effect of having time priority, so that the effect of a quote with time priority relative to a quote away from the NBBO is obtained as the sum of the "at NBBO" and "time priority" estimates. Similarly, the "quote alone at the NBBO" coefficient measures the marginal effect of being alone at the NBBO relative to the effect of having time priority but not being alone at the NBBO.

The passive quote indicator is included to allow the data to distinguish between two possibilities. Such a quote could be viewed as a free option to trade against a liquidity provider at a stale price. If so, the passive arrival of quote at the inside would be expected to immediately attract orders. However, order execution is generally not automatic, and brokers might be skeptical as to whether a competitive but passive quote is good.

The quote size variable is included to assess whether market makers can successfully signal a willingness to trade by increasing the quote size as well as by improving price. The own bid–ask spread variable measures whether proximity of the opposite (bid for buy orders, ask for sell orders) quote can also attract trades. When examining NYSE trades I estimate the logit regression both with and without the own bid–ask spread variable. Since the NYSE is often at the NBBO on both sides of the market, the indicator variables and the NYSE spread are highly collinear, and inference with respect to the indicator variables is somewhat sensitive to inclusion of the bid–ask spread variable in the regression. In contrast, inference in the other markets is not sensitive to exclusion of the spread variable, and corresponding results are not reported.

The three trade variables are included to assess whether trade characteristics affect brokers' order-routing decisions. If orders were always routed to the best quotations in terms of price and size, then trade characteristics would not add explanatory power. Trade size is included in light of the strong evidence that it dominates univariate comparisons, as in Table 2. Price impact is included in light of the cream-skimming hypothesis. The number of trades in the prior 10 min is included to assess whether trades are routed to or away from the indicated market during times of fast trading. As in the analysis of quotation placement strategies the logistic regressions also include indicator variables for the one hundred sample stocks, and a coefficient estimate that is *not* significantly different from zero (p-value > 0.01) is denoted with an asterisk. The results of estimating the logistic regressions for execution venue are reported on Table 5.

The overall message that can be drawn from the results reported on Table 5 is that execution venue is strongly linked to *both* the characteristics of the trades involved and to the competitiveness of a market's quotations. Coefficient estimates on the "Quote at NBBO indicator" are positive and statistically significant for all seven markets. Coefficient estimates on the "Quote has time priority" indicator are positive for five of the seven markets, but smaller in magnitude. Coefficient estimates on the "Quote alone at NBBO indicator" are also positive and generally are the largest in magnitude of the three quote-related indicator variables.

The effect of competitive quotations in attracting order flow is substantial. The estimated impact of the NYSE quote being at the NBBO is an increase in trade probability of 6.6%. If the NYSE quote has time priority the probability rises by another 1.1%, and if the NYSE quote is alone at the NBBO the likelihood of a NYSE execution rises another 3.5%. The combined change in the probability of a NYSE trade when the NYSE quote is alone at the inside relative to a NYSE quote away from the inside is 11.2%. By comparison, the unconditional sample probability of a trade at the NYSE is 52.5%.

The proportional impact on trade execution probabilities is generally larger for off-NYSE trades. Consider the Boston Exchange, where the estimated marginal effects of a quotation at the inside, a quotation with time priority, and a quotation

Table 5
Logistic analysis of execution market. Displayed are results of estimating logistic regressions for the probability a trade will be executed at the indicated market. Quote characteristics are for quotes originating at that market. Probability Slope denotes the estimated change in execution probability for a one-unit change in the explanatory variable, evaluated at the explanatory variable mean. Chi-square statistics reported at the bottom of the table are for the hypothesis that the indicated coefficients are jointly zero. Chi-square statistics that are not significant at the 0.01 level are indicated with an asterisk. Several explanatory variables are standardized to facilitate interpretation. The quote size variable is divided by the average NYSE quote size in the same stock. The own bid–ask spread variable is standardized by the average NBBO spread for the stock. The trade size variable is standardized by the average trade size for the stock. Trades during the prior 10 min are standardized by the average number of trades per 10 min in that stock. The regression includes separate intercepts for each of the one hundred sample stocks

Trades on:	NYSE	NYSE	NASD	BOS	PHI	CIN	CHI	PAC
Proportion of sample trades	0.5247	0.5247	0.1917	0.0784	0.0625	0.0794	0.0415	0.0218
Own quote related variables:								
Quote at NBBO indicator								
Regression coefficient	0.145	0.266	0.233	0.144	0.178	0.261	0.172	0.322
Probability slope	0.036	0.066	0.036	0.010	0.010	0.019	0.007	0.007
Chi-square statistic	1,288.0	4626.2	8741.8	552.1	133.6	1878.6	1046.7	1212.4
Quote has time priority indicator								
Regression coefficient	0.019	0.046	0.256	0.046	−0.073	−0.072	0.049	0.062
Probability slope	0.005	0.011	0.040	0.003	−0.004	−0.005	0.002	0.001
Chi-square statistic	36.1	208.9	1421.2	25.1	8.3	61.4	35.7	22.7
Quote alone at NBBO indicator								
Regression coefficient	0.141	0.142	0.313	0.864	0.588	0.547	0.542	0.834
Probability slope	0.035	0.035	0.049	0.062	0.034	0.040	0.022	0.018
Chi-square statistic	3,090.3	3,149.3	1,225.1	5,353.8	269.8	1,177.3	3,373.6	2,677.7
Passive quote indicator								
Regression coefficient		−0.503	−0.010	−0.025	−0.054	0.081	−0.021	−0.068
Probability slope		−0.125	−0.002	−0.002	−0.003	0.006	−0.001	−0.002
Chi-square statistic		1,901.2	4.1*	17.9	12.00	151.5	15.1	52.8
Quote size								
Regression coefficient	−0.061	−0.059	0.466	0.175	0.170	0.216	0.125	0.067
Probability slope	−0.015	−0.015	0.072	0.013	0.010	0.016	0.005	0.002
Chi-square statistic	7,811.5	7,336.6	5,358.9	517.1	11.2	322.1	302.5	11.3
Own bid–ask spread								
Regression coefficient	−0.224		0.005	−0.009	0.002	−0.028	−0.005	−0.021
Probability slope	−0.056		0.001	−0.001	0.000	−0.002	0.000	0.000
Chi-square statistic	13,522.8		310.8	80.9	6.9*	399.5	11.8	517.4
Trade related variables:								
Trade size								
Regression coefficient	0.881	0.877	−0.521	−0.767	0.684	−0.635	−0.348	−1.056
Probability slope	0.220	0.219	−0.081	−0.055	−0.040	−0.046	−0.014	−0.023
Chi-square statistic	262,387.5	260,625.2	68,481.2	33,676.3	8,495.6	24,097.9	20,631.3	22,985.6
Trades during prior 10 min								
Regression coefficient	−0.458	−0.490	0.183	0.151	0.099	0.110	0.199	0.187
Probability slope	−0.114	−0.122	0.028	0.011	0.006	0.008	0.008	0.004
Chi-square statistic	49,857.2	58,816.9	11,108.7	4,216.6	522.6	1,675.9	7,350.2	3,491.8

Table 5. (*Continued*)

Trades on:	NYSE	NYSE	NASD	BOS	PHI	CIN	CHI	PAC
Price impact ($)								
Regression coefficient	0.139	0.134	−0.020	−0.080	−0.254	−0.099	−0.060	−0.163
Probability slope	0.035	0.033	−0.003	−0.006	−0.015	−0.007	−0.002	−0.003
Chi-square statistic	1,103.1	1,035.9	17.5	142.9	311.9	143.5	86.9	280.9
Test: quote coefficients zero	42,555.9	28,780.8	30,396.8	11,811.4	469.8	5,668.7	9,227.2	10,186.8
Test: trade coefficients zero	302,397	307,360.8	79,733.4	38,346.0	9,422.9	26,129.2	28,182.3	26,984.3

alone at the inside are 1.0%, 0.3%, and 6.2%, respectively. These imply that the probability a trade will occur at Boston rises by 7.5% when the Boston quote is alone at the inside as compared to when the Boston quote is away from the inside. This change is large compared to Boston's sample trade market share of 7.84%. Similar increases in the probability of trade execution are observed when other markets post quotes at the NBBO.

Coefficient estimates on the passive quote indicator are negative for six of the seven markets and are statistically significant for all markets except the NASD. Trades are less likely to be routed to markets whose quote is competitive but arrived passively than to markets whose quotes are competitive as a result of an overt decision to post an aggressive quote. This is consistent with the reasoning that market participants view competitive but passive quotes as unreliable indicators of market makers willingness to trade. The lone exception is the Cincinnati Stock Exchange, where competitive but passive quotes attract more orders. The Cincinnati Exchange is fully computerized, which may facilitate the "picking off" of stale quotes, without an opportunity for the liquidity provider to back away.

These results are generally consistent with those of Blume and Goldstein (1997), who compare market shares conditional on posting a quote that is alone at the inside to unconditional market shares, reporting substantially higher shares when quotes are better than other markets. This analysis shows that the inferences drawn by Blume and Goldstein from their univariate comparisons are substantiated when additional variables are included in a multivariate analysis. The results here also allow the total effect of quotes alone at the NBBO to be decomposed into portions attributable to tying other markets at the NBBO, to having time priority, to having a quote than is strictly better than other markets, and to actively posting rather than passively reaching the NBBO. Further, this analysis quantifies the incremental effect on trade venue of variables other than quote competitiveness.

The coefficient estimate on quote size is positive and statistically significant for the NASD market and for each of the regional exchanges. This result indicates that off NYSE market makers can use larger quote sizes to attract more trades, even after allowing for the empirical observation that larger quote sizes are on average associated with more aggressive prices, which themselves attract trades. Curiously, though, the coefficient estimate on quote size is negative at the NYSE, indicating that larger NYSE quotes are not helpful in attracting trades.

The coefficient estimate on the own-market bid–ask spread is negative and highly significant at the NYSE. Increasing the NYSE spread by an amount equal to the average NBBO spread for the stock decreases the probability that a trade will be completed at the NYSE by 5.6%. In contrast, own bid–ask spreads have little explanatory power for whether trades are routed to the off-NYSE markets. This likely reflects that non-NYSE markets are typically competitive on only one side of the market, and suggests that their non-competitive quote on the opposite side is largely irrelevant to order-routing decisions.

The trade size variable has tremendous explanatory power for trade execution venue. The coefficient estimate on trade size when examining NYSE trades is positive and large. Increasing the size of an individual trade by the average trade size for the stock increases the probability of a NYSE execution by 22.0%. Coefficient estimates on trade size for the off-NYSE markets are uniformly negative and significant. Increasing trade size by the average for the stock decreases the probability of off-NYSE executions, the estimated decline being 8.1% on the NASD, 5.5% on Boston, 4.0% on Philadelphia, 4.6% on Cincinnati, 2.3% on the Pacific Exchange, and 1.4% on the Chicago Exchange. These decreases are all large relative to market shares for these venues.

A increase in the number of trades in the prior 10 min from the normal level for the stock to twice the normal level decreases the probability of an NYSE trade by 11.4%, while significantly increasing the probability of a trade at each of the off-NYSE markets. Since the regression also includes separate indicator variables for each of the one hundred stocks that accommodate cross-sectional variation in average trading, the estimates obtained on the recent trading variable captures time series variation in trading activity. Off-NYSE market makers attract more trades at times when trading in stocks is high relative to that stock's normal activity.

Coefficient estimates on the price impact variable indicate that trades which contain more information are significantly more likely executed at the NYSE, and are less likely executed at all of the six off-NYSE markets. This is consistent with the univariate evidence reported Table 2 and with the reasoning that off-NYSE market makers are able to cream-skim uninformed order flow. Since trade size is also included in the logistic regression the coefficient estimates on price impact obtained here indicate that the cream skimming goes beyond the diversion of smaller orders that tend to contain less information. Brokers and market makers apparently use some order-flow characteristics in addition to size to ascertain whether order flow originates from informed investors and route the orders containing less information away from the NYSE to a statistically significant degree. Note, though, that the coefficient estimates are rather small in economic terms. An increase in price impact of $1 (compared to sample average price impact of 2.2 cents) increases the probability of a NYSE trade by 3.5%.

The empirical results reported here indicate that the routing of trades in NYSE stocks is affected to a significant extent by quote-based competition for orders. Markets with quotes that match the NBBO receive more trades, particularly if the quote is alone at the NBBO. And, the posting of quotes with larger sizes attracts more trades to non-NYSE markets. However, trade characteristics are also very relevant to execution venue, and a large proportion of sample trades is still completed at markets posting noncompetitive quotes.

5. Trading costs and quote competitiveness

The results of the logistic regression indicate that order flow is responsive to the competitiveness of quotations on each market to a significant degree. But what does a competitive quote signal, and why should it attract order flow? If all markets execute orders at the NBBO then trading costs are no different at the market posting the best quote than elsewhere. In practice some trades are completed at prices better or worse than the NBBO quotes, allowing the possibility of differing execution costs. Despite the finding that order flow is responsive to quotation competitiveness, many sample trades (37.1% of the total sample and 65.9% of off-NYSE trades) are completed when the executing market is posting a non-competitive quote.

5.1. Trades executed at markets posting competitive and noncompetitive quotes

I next investigate whether trading costs vary systematically with the competitiveness of quotations. Table 6 reports average trading costs and trade characteristics for trades that are completed at a market posting a quote that matches the NBBO as compared to trades completed on the same market when quotes are inferior to the NBBO quote. Rows labeled "When completed at NBBO market" provide means for the subsample of trades completed when the executing market quote matches the NBBO. Cursory examination indicates that trade characteristics vary systematically across those trades completed at or away from the market posting the best quote. For example, Table 6 shows that trades executed at the NBBO market average 2,056 shares. In contrast, sample trades completed on a market whose quote does not match the NBBO market (not reported) average 1,207 shares.

To obtain a clean comparison I construct a matched sample. For each trade completed at a market posting a competitive quote I select a matching trade by sampling with replacement from eligible trades completed when the executing market quote is not competitive. To be eligible as a match, both trades must (1) be in the same stock, (2) be completed on the same market, and (3) be drawn from the same trade size bucket. The sample is divided into ten trade size buckets with the goal of matching trades reasonably closely by size while having enough trades in each bucket so that matching trades can be identified for every stock and market. The ten trade size buckets are: less than 300 shares, 300–500 shares, 600–900 shares, 1,000–1,500 shares, 1,600–2,500 shares, 2,600–4,900 shares, 5,000–9,900 shares, 10,000–19,900 shares, 20,000–30,000 shares, and over 30,000 shares. The intent is that matched trades should be essentially identical, except for the competitiveness of the quote on the executing market. Means computed from the sample of matched trades are reported on Table 6 in rows labeled "Away from NBBO, matched sample."

The columns of Table 6 labeled "All Trades" present results of this analysis without considering which market completed the trade. A notable result is that effective spreads are greater when trades are completed at markets posting quotes inferior to the NBBO. The mean effective half-spread for trades completed at markets with competitive quotes is 3.50 cents, compared to 5.58 cents for matched

Table 6

Trades at or away from NBBO market. Trades are at the NBBO market if the executing exchange bid (ask) matches the best bid (ask) at the time of a customer sell (buy). Rows labeled "When completed at NBBO market" report means for trades completed at a market whose quote matches the NBBO. Rows labeled "Away from NBBO, Matched Sample" report means for a sample of trades completed at the same market when it is posting inferior quotes. Matching trades are of similar size and are in the same stock. Columns labeled "difference" report the difference from the "When at NBBO" mean. The *t*-statistic for the hypothesis that the mean difference is zero is reported in parentheses

	All Trades		Trades at NYSE		Trades Off NYSE	
Number trades when quote equals NBBO	3,100,110		2,300,790		799,320	
Number trades when quote inferior to NBBO	1,832,895		287,620		1,545,275	
	Mean	Difference	Mean	Difference	Mean	Difference
Inside bid–ask spread (cents)						
When completed at NBBO market	11.18	−1.24	11.56	−1.65	10.07	−0.04
Away from NBBO, matched sample	9.94	(−325.9)	9.91	(−380.7)	10.03	(−5.9)
Trade size (shares)						
When completed at NBBO market	2,056	75	2,584	99	536	−3.00
Away from NBBO, matched sample	2,131	(13.8)	2,683	(13.6)	533	(−0.8)
Effective half-spread (cents)						
When completed at NBBO market	3.50	2.08	3.32	2.73	4.01	0.29
Away from NBBO, matched sample	5.58	(843.0)	6.05	(1,020.9)	4.30	(44.9)
Realized half-spread (cents)						
When completed at NBBO market	1.19	−0.38	1.02	−0.91	1.66	1.19
Away from NBBO, matched sample	0.81	(−23.3)	0.11	(−48.3)	2.85	(35.1)
Price impact (cents)						
When completed at NBBO market	2.31	2.47	2.30	3.64	2.35	−0.91
Away from NBBO, matched sample	4.78	(150.2)	5.94	(192.6)	1.44	(−27.8)
Percent price improved						
When completed at NBBO market	28.42	−17.66	31.95	−23.95	18.24	0.48
Away from NBBO, matched sample	10.76	(683.4)	8.00	(−786.3)	18.72	(11.3)
Percent at prices outside NBBO						
When completed at NBBO market	0.86	15.93	0.18	20.29	2.79	3.44
Away from NBBO, matched sample	16.79	(1864.8)	20.47	(2,631.8)	6.23	(185.5)
Percent trades small and price outside NBBO						
When completed at NBBO market	0.43	3.19	0.06	3.47	1.51	2.37
Away from NBBO, matched sample	3.62	(775.2)	3.53	(1,208.0)	3.88	(172.0)

trades completed when the executing market quote is inferior. Note that the NBBO spread is actually narrower at times when trades are completed away from the NBBO, indicating that larger execution costs when quotes are away from the NBBO cannot be attributed to a selection bias where these trades occur when the market is less competitive overall.

The higher trade execution costs for trades completed away from the NBBO market are attributable to both higher rates of outside-the-quote executions and lower rates of price improvement. When trades are executed at a market with a competitive quote the price improvement rate is 28.4%, compared to an improvement rate of just 10.8% in the matched away-from-NBBO sample. Only 0.9% of trades completed at a market with a competitive quote are executed at prices outside the quotes. In contrast, 16.8% of the matched trades completed away from the NBBO market are executed outside the NBBO quotes. Note, though, that only 3.6% of the matched trades are apparent trade through violations. Most of the outside-the-quote executions involve trades that are larger than the size of the NBBO quote.

There is, however, evidence that trades executed at the NBBO market differ from those completed at markets not posting competitive quotes in terms of trades' information content. The average price impact of trades completed at the NBBO market is 2.31 cents, while the average price impact of trades in the matched sample is 4.78 cents. As a consequence, realized half-spreads for the full sample are actually smaller by 0.38 cents when trades are completed at a market not posting a competitive quote.

Separating the sample into trades executed at and away from the NYSE reveals that the effect of quote competitiveness on execution costs depends in an important way on the exchange involved. The higher effective spreads observed when trades are executed at a market with noncompetitive quotes is primarily due to NYSE trades. The full sample differential of 2.08 cents is attributable to a difference of 2.73 cents for NYSE trades compared to a differential of just 0.29 cents for off-NYSE trades. Price impact differentials also vary greatly across markets. For off-NYSE trades the price impact of trades completed when posting noncompetitive quotes is 0.9 cents per share *less* than when posting competitive quotes. For NYSE trades, the price impact of trades completed while the NYSE quotes are noncompetitive is 3.6 cents per share *greater* than when the NYSE is posting competitive quotes. As a consequence realized spreads on the NYSE are 0.9 cents per share *less* when quotes are noncompetitive, while realized spreads off the NYSE are 1.2 cents *greater* when quotes are noncompetitive.

These results are consistent with the reasoning that trades executed when posting non-competitive quotes contain different selection biases on different markets, such that these trades are particularly desirable for liquidity providers off the NYSE, but are unattractive to NYSE liquidity providers. Off-NYSE liquidity providers are able to attract trades (over 1.5 million in the present sample) even without posting competitive quotes, due to preferencing agreements and payment for order flow. These agreements generally target order flow from uninformed investors, and the resulting trades contain little information, allowing for relatively large realized half-spreads averaging about three cents per share.

At times off-NYSE market makers become interested in attracting more market orders. They then post competitive quotes and receive more order flow. However, this additional order flow is not screened, and contains more adverse information on average. Consistent with this reasoning, the average price impact of trades occurring when the executing market is posting competitive quotes is almost identical (2.30 cents on the NYSE, 2.35 cents off the NYSE) across markets in the present sample.

Liquidity providers at the NYSE face a different tradeoff. NYSE quotes typically match or solely comprise the NBBO quote, and the NYSE receives the order flow that is not diverted to the regional markets or the NASD. A specialist who infers the presence of material new information about stock value can move quotes away from the inside, but is obligated by NYSE price continuity rules to limit the magnitude of price movements and to execute trades at each tick. (See Hasbrouck et al., 1993). The smaller size of off-NYSE quotes also precludes the forwarding of larger orders to the market posting the best quote.

Empirically, trades executed at the NYSE when the NYSE quote is noncompetitive contain far more information (average price impact of 5.9 cents per share compared to 2.3 cents when quotes are competitive) than other trades. The NYSE floor provides these trades far less price improvement (8.0% of trades, compared to 32.0% when quotes are competitive) and more frequently (20.5%, compared to 0.2% when quotes are competitive) executes them at prices outside the quotes. These outside the quote executions generally do not comprise trade through violations, since the size of NBBO quotes that originate off the NYSE tends to be small. Despite these measures, realized half-spreads for NYSE trades executed when quotes are noncompetitive are reduced to only 0.1 cents per share.

To summarize, trades completed at a market posting noncompetitive quotes involve larger effective half-spreads as compared to trades in the same stock at the same market that are executed when the market posts competitive quotes. This finding with respect to effective half-spreads is largely attributable to executions that occur on the NYSE when its quotes are not competitive. These trades move subsequent quote midpoints by an unusually large distance, suggesting that they contain a large amount of information, and resulting in very small realized half-spreads. In contrast, trades executed off the NYSE when the local quote is noncompetitive (i.e., trades resulting from preferencing agreements) contain less information and are associated with larger realized bid-ask spreads as compared to trades completed away from the NYSE when the local quote is competitive. Finding that realized spreads for off-NYSE executions are smaller when the executing market quote is competitive as compared to when the local quote is not competitive is consistent with the reasoning that quote-based competition reduces trade execution costs.

5.2. NYSE versus off-NYSE executions

Finally, to provide an additional perspective and a point of comparison to the related literature, I report on measures of execution costs for trades on and off the NYSE. Unlike the results provided by Bessembinder and Kaufman (1997) or Lee (1993) the results here distinguish between trading costs when the off-NYSE market does or does not use competitive quotes to attract orders.

The rows of Table 7 labeled "Off-NYSE Mean" report average trade characteristics and trade execution costs for the 2.34 million sample trades completed away from the New York Stock Exchange. A matching NYSE trade is selected for each off-NYSE trade by drawing at random with replacement from the set of NYSE trades in the same stock and in the same trade size category. The rows labeled "Matched NYSE Sample Mean" report averages computed across trades in the matched NYSE sample.

Trade execution costs for the full sample are about one cent per share greater when trades are executed off the NYSE. Results are very similar for effective half-spreads (1.03 cents higher) and for realized half-spreads (1.02 cents higher). The differential is due to a higher rate of NYSE price improvement (26.0% versus 19.7%) and a lower rate of outside-the-quote executions (1.7% versus 4.6%).

The differential between average NYSE and off-NYSE effective half-spreads when the off-NYSE market maker is posting a competitive quote is reduced to 0.85 cents. As noted above, the trades diverted from the NYSE by competitive quotes contain more information than those diverted by use of preferencing agreements (i.e., those executed off the NYSB when the local market is non-competitive quotes). After allowing for the greater information content there is essentially no difference across trading venues in average realized half-spreads (1.66 cents off the NYSE and 1.70 cents on the NYSE) for those off-NYSE trades occurring while the local market quote is competitive.

In contrast, for trades occurring when the local quote is noncompetitive the average realized half-spread is 1.56 cents larger off the NYSE. Trades completed off the NYSE while the local quote is noncompetitive result from orders diverted on the basis of various preferencing agreements. This analysis therefore supports the conclusions that (1) the higher average trade execution cost for trades off the NYSE is attributable to those trades diverted from the NYSE based on preferencing agreements, and (2) trade execution costs are lower when liquidity providers use aggressive quotes to attract order flow as compared to when liquidity providers receive order flow passively.

6. Conclusions

This paper provides empirical evidence relevant to the ongoing debate regarding market fragmentation and the routing of market orders across execution venues. The empirical analysis focuses on quotation strategies by the various markets that trade large capitalization NYSE-listed securities, the factors that govern order-routing decisions in NYSE stocks, and relations between quotation competitiveness, trade venue, and trade execution costs.

The evidence presented here indicates that there is substantial quote-based competition for order flow. If all orders were allocated according to preferencing agreements there would be little reason for quotations to vary strategically, and order routing would not respond to quotation characteristics. In contrast to this reasoning, quotation strategies are shown to vary systematically with market

Table 7
Off-NYSE trades compared to matched NYSE trades. The sample consists of off-NYSE trades in the one hundred largest NYSE-listed stocks (excluding Berkshire-Hathaway) during June 2000. A matching NYSE trade is assigned to each off-NYSE trade by sampling with replacement from the set of NYSE trades. Each matching trade is of similar size and is in the same stock. The t-statistic for the hypothesis that the mean difference is zero is reported in parentheses

	All off-NYSE trades		Trades when executing market quote matches NBBO		Trades when executing market quote is inferior to NBBO	
Number trades	2,334,595		799,320		1,545,275	
	Mean	Difference	Mean	Difference	Mean	Difference
Inside bid–ask spread (cents)						
Off-NYSE mean	10.46	−0.49	10.07	−0.42	10.66	−0.52
Matched NYSE sample mean	9.97	(−80.6)	9.65	(−58.1)	10.14	(−62.4)
Trade size (shares)						
Off-NYSE mean	540	1	536	4	542	−1
Matched NYSE sample mean	541	(0.4)	540	(1.4)	541	(−0.5)
Effective half-spread (cents)						
Off-NYSE mean	4.22	−1.03	4.01	−0.85	4.33	−1.12
Matched NYSE sample mean	3.19	(−241.0)	3.16	(−163.4)	3.21	(−190.1)
Realized half-spread (cents)						
Off-NYSE mean	2.69	−1.02	1.66	0.04	3.22	−1.56
Matched NYSE sample mean	1.67	(−51.3)	1.70	(1.2)	1.66	(−62.8)
Price Impact (cents)						
Off-NYSE mean	1.53	−0.01	2.35	−0.89	1.10	0.45
Matched NYSE sample mean	1.52	(0.71)	1.46	(−27.5)	1.55	(17.6)
Percent price improved						
Off-NYSE mean	19.68	6.33	18.24	6.25	20.42	6.37
Matched NYSE sample mean	26.01	(248.5)	24.49	(145.5)	26.79	(201.5)
Percent at prices outside NBBO						
Off-NYSE mean	4.55	−2.90	2.80	−1.20	5.45	−3.78
Matched NYSE sample mean	1.65	(−214.0)	1.60	(−64.9)	1.67	(−207.9)
Percent trades small and price outside NBBO						
Off-NYSE mean	2.80	−2.11	1.51	−0.83	3.47	−2.77
Matched NYSE sample mean	0.69	(−195.6)	0.68	(−60.8)	0.70	(−188.2)

conditions, and order routing is found to respond systematically to quote placement. Although the majority of trades that are executed off the NYSE occur when the local market quote is not competitive (i.e., due to order preferencing agreements), off-NYSE liquidity providers can successfully attract more trades by posting competitive quotes of larger size. Off-NYSE market makers are more likely to post competitive quotes when existing spreads are wide and when markets are active, which are times when increased market share is likely to be more profitable. The evidence also indicates that the previously-documented finding of higher average execution costs for trades completed off the NYSE is attributable to the trades that are routed to these markets when they are displaying noncompetitive quotes. In contrast, execution costs for trades completed off the NYSE when the local market posts competitive quotes are virtually the same as for matched NYSE trades.

Collectively, these results are consistent with (1) off-NYSE liquidity providers using quotations as a selective signaling device to indicate when they are prepared to give better than normal trade executions, (2) there is substantial but imperfect quote-based competition for order flow in NYSE-listed stocks, and (3) the use of quotations to compete for order flow is associated with lower trade execution costs as compared to the use of preferencing agreements to obtain order flow.

Whether investors are harmed by the fact that many orders are still routed to markets displaying inferior quotes depends in pan on whether their brokerage commission is reduced sufficiently to compensate for the higher average execution cost on these trades. The model developed by Parlour and Rajan (2003) predicts that in equilibrium commissions will not be reduced enough to offset the higher trade execution costs. It is difficult to address this issue empirically, because no comprehensive commission databases appear to be available, and even if commission data were available, it would be difficult to fully control for other services such as stock research that may accompany higher commissions.

The finding that execution quality is better when markets use quotations to compete for order flow is supportive of the notion that market quality can be improved by enforcing priority rules across market centers. However, strict price/time priority enforcement can also limit incentives for market centers to innovate, could encourage the creation of small and illiquid individual markets, and could make it difficult for market centers to meet the needs of those (primarily institutional) customers who prefer to not reveal their trading interest publicly.

Stoll (2001) argues that policy should focus on brokers'order-routing decisions, rather than mechanical linkages across markets. He notes that enforcing strict time priority across markets is not feasible without formal linkages enabling automatic execution. Stoll advocates the enforcement of price, but not time, priority across markets. His proposed "best price" rule would require that market orders be routed to the market posting the best price (conditional on order size) and would eliminate "price matching" by a market posting an inferior quote, thereby improving incentives for market makers to post competitive quotes. Another possibility is to require brokerage firms to internalize the cost of poor trade executions. Ferrell (2000), for example, recommends a requirement that brokers always credit customer accounts with the NBBO quote, so that the incremental cost or benefit of obtaining a different execution price is borne by the broker. It is, however, unclear how these proposals would affect traders who value aspects of order handling in addition to price, such as speed of execution or care in order exposure.

Agency problems arise in order-routing decisions in part because investors know the commission they pay, but typically do not know the actual trade execution cost. The SEC has recently enacted new regulation requiring individual market centers to report *average* trade execution costs by stock and by calendar month. A potentially more effective and perhaps less costly solution would be to require brokers to indicate on trade confirmation reports the actual execution cost, perhaps measured by the effective half-spread, paid on each individual trade. Traders would then consider both commissions and trade execution costs, along with any other criteria of interest to them, in assessing whether their needs are being well met.

The results reported here indicate substantial, but incomplete, quote-based competition for order flow, and that trade execution costs are lower when liquidity providers use quotes to compete. Improved disclosure of trading costs would likely stimulate increased competition and improve the efficiency of order routing, without the need for extensive new regulation.

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