# Public Disclosure and Private Decisions:
# The Case of Equity Market Execution Quality

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**Abstract**

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## Abstract

The Securities and Exchange Commission (SEC) uses public disclosure to achieve policy objectives. In 2001, the SEC required market centers to publish reports containing execution-quality statistics in an effort to spur competition for order flow between market centers. Using a sample of stocks that trade actively on several markets, we investigate whether brokers/traders appear to use these data in their order-routing decisions. Our evidence suggests that the reports are informative. Routing decisions depend on execution quality; market centers reporting low execution costs and fast fills subsequently receive more order flow. Our results are consistent with active competition for order flow that can be influenced by public disclosure and contrast to several allegations and admissions of non-competitive behavior in the recent past.

# 1 INTRODUCTION

The U.S. Securities and Exchange Commission (SEC) frequently relies on public disclosure to achieve policy objectives. In defining themselves, the Commission states that, "… *the SEC is concerned primarily with promoting disclosure of important information, enforcing the security laws, and protecting investors* …"[1] A theme appearing repeatedly in SEC activities is that well-informed individuals make decisions enhancing security-market efficiency. Recently enacted SEC Rule 11Ac1-5 is an example of this approach. Because trades frequently occur at prices other than those quoted, brokers/traders find it difficult to anticipate the execution quality they are likely to obtain when deciding where to route orders. Historically, the lack of standardized execution quality statistics on submitted orders contributed to this uncertainty. On November 17, 2000, the SEC mandated that U.S. market centers publish a broad set of standardized execution-quality statistics each month. The goal of this action was to "… *empower market forces with the means to achieve a more competitive and efficient national market system for public investors*."[2] In this paper, we investigate whether and how brokers/traders use these data when making order routing decisions. Finding that public reports can influence security market participants' actions would provide support for the SEC's reliance on disclosure as a policy tool, at least in this particular situation.

A substantial literature compares execution quality and market maker quoting behavior across U.S. equity markets. Relatively little is known, however, about whether order-routing decisions by traders or by firms with the fiduciary responsibility of executing clients' orders are sensitive to execution quality. When routing orders among markets, traders and brokers have several options when executing customer orders. For example, in actively traded securities listed on the New York Stock Exchange (NYSE), they can submit orders to the NYSE, five regional stock exchanges, several Nasdaq Intermarket dealers, and eight Electronic Communications Networks (ECNs) during our sample period. Our analysis investigates how these routing decisions are made. Specifically, we

[1] See the SEC website at http://www.sec.gov/about/whatwedo.shtml.

examine how a market center's historical execution quality appears to affect subsequent order-routing decisions. Our results help assess whether these routing decisions are consistent with competition for order flow based on execution quality. This is an important public policy issue, because it affects both the trading costs of investors and the efficiency of the equity market. More broadly, our analysis addresses whether mandatory public disclosure can affect market participants' behavior.

Rule 11Ac1-5 ("Dash-5") provides important details on execution quality and increases the visibility of quantitative execution-quality measures. The rule is intended to influence the actions of investors, brokers, and market centers. Most investors (both institutional and retail) delegate the decision of where to route orders to their broker, but some investors prefer to make this decision themselves.[3] Each market center publishes Dash-5 statistics specific to its own order flow, so individuals must possess considerable technical skills to produce comparative statistics. Commercial aggregation services are available, but the services may not be economical for small investors. Thus, Dash-5 reports probably have a limited effect on the routing decisions of small traders who make their own routing decisions. However, for investors trading larger amounts of stock and for brokers who make routing decisions on behalf of clients it might be economical to produce or purchase aggregate Dash-5 statistics.

Brokers are likely users of Dash-5 reports because they have a fiduciary responsibility to obtain best execution for customers' orders. A companion rule, 11Ac1-6, requires brokers to provide reports describing their order routing practices, including payments they receive for order flow (preferencing arrangements) and the extent to which they execute orders in-house (internalization). We expect these additional disclosure requirements to increase reliance on the standardized execution-quality statistics provided in Dash-5 reports, because customers can now identify brokers

[2] See SEC Release No. 34-43590.

[3] Systematic data on the proportion of orders where traders provide explicit routing instructions do not exist. Market participants indicate that most orders do not contain such instructions. The percentage of orders that delegate the routing decision to brokers is greater for retail orders and orders in NYSE-listed stocks, and typically exceeds 80% for institutional NYSE orders.

who route orders to high-cost market centers. While Dash-5 reports are published with a lag of four weeks, they provide brokers with a basis for routing decisions that they can easily justify to their clients. Therefore, we posit that reported changes in a market center's execution quality affect the order flow it receives in the future.

Market centers might compete for order flow using execution quality. Because quantitative measures are easier to compare across markets after Dash-5, market centers may encourage their market makers to improve these measures (to the extent possible). In addition, market centers might institute changes in trading practices to improve Dash-5 statistics. The NYSE's March 2003 decision to automate quotations, for example, may have been influenced by relatively slow execution speed revealed in the reports.

In summary, these arguments suggest that brokers/traders generally have economic incentives to consider Dash-5 reports in making their routing decisions. We also expect markets offering execution services to respond competitively by trying to improve execution quality for orders covered in these reports. Therefore, the implementation of Dash-5 could change the way order routing decisions are made and we expect market centers with better Dash-5 execution quality to receive more order flow.[4]

In this paper, we develop an empirical model of order-routing behavior for marketable orders in NYSE-listed stocks and test whether the market share of execution venues, the outcome of brokers' routing decisions, is related to historical execution quality. We control for several factors that may affect routing decisions, including execution-cost measures from the New York Stock Exchange's Trade and Quote (TAQ) data that were available before Dash-5 existed. We find that past execution costs and execution speed, as reported in Dash-5 reports, contain incremental information that appears useful in routing decisions. Market centers tend to lose order flow when

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[4] In the remainder of this paper, we refer to "brokers' routing decisions" and "routing decisions" with the understanding that most are indeed made by brokers, but that some investors make routing decisions themselves. Because these tend to be larger investors, they are likely to have the means to use Dash-5 reports, among other resources, to guide their decisions. Therefore, the arguments and inferences we make regarding brokers' decisions should generally carry over to individual traders who make their own routing decisions.

their effective spread or time-to-execution increases. These results suggest that the U.S. equity market is subject to competitive pressure to maintain high-quality executions. Brokers appear to respond to differences in market quality, implying that market centers and brokers can compete for order flow on price and speed. Our results also suggest that Dash-5 reports provide information that was unavailable (or unused) previously. Indeed, we find that the market share of trades is less sensitive to trade-based execution cost statistics after Dash-5's implementation than before. Although it is difficult to infer a causal relationship, this result suggests that the mandatory disclosure of Dash-5 statistics gives brokers an additional incentive or an additional tool for directing orders based on execution quality.

The finding that Dash-5 reports contain incremental information is not trivial, because the reports have several limitations. Only about one-third of total order flow is covered by the reports and statistics on orders routed from the receiving market to other markets are reported twice (see Boehmer, 2004). Moreover, the reports are published with a one-month lag. Industry critics also argue that Dash-5 reports are of limited use because they are not audited and are sensitive to alternative ways of aggregating the underlying order data.[5]

Our research complements a large body of research on U.S. equity market execution quality and inter-market competition. Among many others, papers by Blume and Goldstein (1992), Lee (1993), Easley, Kiefer and O'Hara (1996), Huang and Stoll (1996), SEC (1997), Bessembinder and Kaufman (1997), Bessembinder (1999), Bacidore, Ross and Sofianos (2003), SEC (2001), and Boehmer (2004) provide information about execution quality on the NYSE, Nasdaq, and the regional stock exchanges. These papers discuss measures of execution quality, compare differences in execution quality across markets, and speculate as to the causes of those differences. Other studies, e.g. Bessembinder (2003b) and Huang (2002), investigate the quoting behavior in the market for NYSE-listed and Nasdaq stocks, respectively. Bessembinder (2003b) finds that quoting competitiveness has an important relation to ex-post execution costs in NYSE-listed stocks.

Specifically, he shows that Nasdaq Intermarket execution costs tend to be higher only when its quotes are not competitive. When quotes are competitive, the differences in execution quality are negligible. This finding suggests that execution costs vary among markets and over time, and raises the question whether participants consider such variations when making order-routing decisions. Data limitations have made it difficult to answer this question previously. Our paper contributes novel evidence on this issue by focusing on how routing decisions respond to variation in execution quality at different market centers.

The remainder of this study is organized as follows. In Section 2 we discuss the sample and provide descriptive statistics from the Rule 11Ac1-5 reports. In an appendix, we extend this discussion and provide some evidence on the accuracy of execution costs from Dash-5 reports. In Section 3 we characterize the execution-quality statistics contained in Dash-5 reports. We outline our research design and econometric models in Section 4. In Section 5, we conduct an event study to investigate whether the implementation of Rule 11Ac1-5 seems to affect order-routing behavior. The results of the main analysis are presented in Section 6, and the final section concludes.

## 2 Sample and descriptive statistics

Our sample begins with 2,561 NYSE-listed securities not classified as preferred stocks, warrants, rights, derivatives, or "other" securities in the NYSE master file. To select only shares issued by domestic firms, we merge this set of securities with the Center for Research in Security Prices (CRSP) header file, resulting in 2,510 matches. Using the CRSP share code, we delete firms not incorporated in the U.S., closed-end funds, units, shares of beneficial interest, ADRs, and certificates. Finally, we exclude three stocks trading above $1,000 per share: Berkshire Hathaway Class A and B shares and Security Capital Group. This leaves 1,435 securities.

[5] In the appendix, we assess the accuracy of Dash-5 execution costs by comparing them to contemporaneous measures computed from other sources and find no evidence of systematic inaccuracies.

Panel A of Table 1 shows descriptive statistics on the 1,435 securities for the NYSE, the regional exchanges, two Nasdaq market makers, and an ECN.[6] For each market center, the table contains the daily average closing price, the daily price range relative to the closing price, daily consolidated trading volume in shares and trades, and market capitalization for securities trading at that venue. As in Bessembinder (2003a), we find that markets limiting the stocks they trade (e.g., Madoff) tend to receive order flow in high-volume, high-price stocks.

To select a sample of stocks trading on several market centers throughout the sample period (June 2001 – February 2003), we need to balance the number of market centers and the number of securities. Because our tests focus on routing decisions when several alternatives are available to brokers, we believe it is most appropriate to select a sample of securities that consistently trade in several market centers simultaneously. We achieve the broadest sample by selecting seven of the most active Dash-5 participants for our analysis. These include the NYSE, three regional exchanges (Boston, Chicago, and Philadelphia), the Nasdaq Intermarket broker-dealers Madoff and Trimark, and one ECN (Archipelago/Archipelago Exchange). These market centers form the basis for our cross-sectional analysis. Our final sample includes all 255 securities trading continuously on each of the seven markets over the 21 months for which we collect Dash-5 data (June 2001-February 2003). We additionally obtain trade and quote information from the NYSE's Trade and Quote (TAQ) data for the period from June 2000 to February 2003. These 255 securities represent about 61% of marketable Dash-5 order and trading volume reported by these seven market centers during this period. As we expect, Panel B of Table 1 shows that this sample consists of securities with above-average market capitalization and trading activity.[7]

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[6] The Instinet and Island ECNs are originally included in our sample. Subsequent analysis and conversations with market participants, however, led us to believe that part of these ECNs' Dash-5 data may be unreliable during the sample period. Thus, we excluded both from the final analyses (which, however, does not qualitatively change any results). To address potential broader concerns about the accuracy of Dash-5 data, we compare the market-center rankings implied by Dash-5 and TAQ effective spreads in the appendix.

[7] While such a sample would be misleading for an inter-market comparison of execution quality, we do not believe that it is problematic for our purposes. We wish to analyze the relation between order routing and execution quality, and we are not primarily interested in the level of this quality. Therefore, we believe it is more important to select a sample that consistently trades on multiple venues than to select a sample that is representative of all securities.

Dash-5 reports distinguish order types with varying degrees of marketability. Statistics on these order types are divided into four order-size categories: 100-499 shares; 500-1,999 shares; 2,000-4,999 shares; and 5,000-9,999 shares. When aggregating the Dash-5 data across order types or sizes, we report share-weighted averages. We focus on market orders and marketable limit orders. Traders submitting non-marketable limit orders might base their routing decisions on criteria other than effective spreads and execution speed.[8]

We impose two filters on monthly records. We delete observations where the average monthly price is below $1, and where the monthly effective spread exceeds one-half the monthly average price. The second condition eliminates obvious data errors in the Dash-5 reports. These two filters together eliminate about 0.7% of the sample observations.

For each month between June 2000 and February 2003, we also compute effective spreads from TAQ. The effective spread compares the trade price to the midpoint of the national best bid and offer (NBBO) quotes in effect at the time of the trade. Specifically, the effective spread for a particular trade is twice the absolute difference between the trade price and the NBBO midpoint at the time of the trade. We exclude trades and quotes outside regular market hours and with irregular settlements, and use only trades between 100 and 9,999 shares to correspond as closely as possible to the Dash-5 order sizes. We construct the NBBO as the best quote (highest bid price and lowest offer price) among all participants in the Intermarket Trading System. For this computation, we first record all valid quotes for each market center throughout the trading day and then find the highest bid price and lowest offer price at each point in time. A market center's quote is invalid if it has suspended trading in the security, if the market center's bid (offer) price is equal to or greater (less) than the national best offer (bid) price, or if zero depth is posted. In contrast to the effective spread computed in Dash-5 reports, the TAQ estimates assume a buy (sell) order if the trade price is above

[8] A marketable limit order is a buy (sell) order with a limit price equal to or greater than (less than) the prevailing national best offer (bid) price. Orders with special handling instructions, orders that are not submitted electronically, orders for 10,000 or more shares, and limit orders with prices more than 10 cents worse than the relevant quote are excluded from Dash-5. See http://www.sec.gov/rules/final/34-43590.htm for a detailed description of rule 11Ac1-5 and the data contained in the associated monthly reports.

(below) the quote midpoint (or above (below) the most recent different trade price for midpoint trades).

Throughout our analysis, we measure the outcome of routing decisions by computing each market center's share of all Dash-5 orders placed in a particular security, in a particular order size category, and a particular order type. To compute this variable, we divide the share volume of orders placed in a market/stock/order type/order size/month combination by the aggregate order volume in this stock and month. We use share-weighted effective spreads (both for TAQ and the Dash-5 averages), because trade-weighted spreads cannot be computed from Dash-5 reports.

Table 2 provides descriptive statistics for market orders and marketable limit orders in four size categories that are routed to our sample market centers. From the Dash-5 reports, we compute the market share (for marketable orders in the sample) and share-weighted averages of effective spreads, realized spreads, and execution speed. For buy (sell) orders, effective spreads are computed as twice the (negative) difference between the execution price and the NBBO midpoint prevailing at the time an order was received. For buy (sell) orders, realized spreads are defined as twice the (negative) difference between the execution price and the quote midpoint five minutes later. Execution speed is the number of seconds elapsing between order receipt and (partial) execution.

The NYSE is the dominant market in each size category and receives about 86% of market orders and 94% of marketable limit orders submitted to the seven sample venues. Most market centers generate more volume in the two middle size categories than in either the smallest or the largest category. Madoff has the second largest market share for small market orders, but actively manages its order flow to exclude most large orders. Boston has the largest market share among the regional exchanges in the sample. Madoff has the narrowest effective spread for both order types, and realized spreads are lowest for small orders sent to the NYSE and large orders sent to Archipelago. Execution speed varies substantially across markets, reflecting their different trading protocols and business models.

## 3 CHARACTERISTICS OF DASH-5 EXECUTION QUALITY MEASURES

In this section, we characterize how the Dash-5 order-type composition and execution-cost measures vary over time and across different market centers. Because Dash-5 reports cover only a subset of orders and contain effective spreads only for marketable orders, it is helpful to discuss how incomplete coverage might affect the interpretation of results. Brokers and traders can respond to a change in execution quality by changing the execution venue, changing the order type, and/or changing order size. Our empirical tests are designed to capture changes in venue and order size as long as brokers use Dash-5 eligible orders. If brokers substitute non-marketable orders for marketable orders, or if they substitute orders not eligible for Dash-5 reports for orders that are eligible, we cannot observe the execution quality from Dash-5 reports. Interpretation of changes in market share would be more difficult in such cases, because a venue's overall market share is affected differently than its marketable-order market share. To assess the importance of these issues, we examine the time-series behavior of the order-type mixture for the sample exchanges.

Figure 1 shows each market's composition of incoming order flow. We divide Dash-5 order types into market orders (Panel A) and marketable limit orders (Panel B). The residual consists of non-marketable limit orders within ten cents of the relevant side of the prevailing quote (not shown). We measure incoming order-type volume as a percentage of each market's total Dash-5 order flow and find substantial variation across markets. For example, market orders constitute around 75% of Dash-5-eligible orders for Madoff, while non-marketable limit orders represent around 90% of orders on Archipelago. While there is some fluctuation over time, we observe a high degree of persistence. A notable exception is the shift from market orders to non-marketable limits on the Philadelphia Stock Exchange. These time series are very similar when we examine executed orders (not reported). Overall, the results suggest that traders do not dramatically alter their choices of order type over time.

We also examine whether brokers systematically switch between Dash-5 eligible and non-eligible orders. Panel C shows the ratio of executed order volume in Dash-5 reports to twice the TAQ trading volume for the sample firms. For this graph, we include both marketable and non-marketable Dash-5 orders. We find the proportion of Dash-5 eligible orders increases on all market centers over the sample period. This increase is most pronounced for the NYSE, where eligible orders increase from 30% to 44% of total volume (a 45% increase). The corresponding increases are 24% on the Nasdaq Intermarket (TAQ data are not sufficiently detailed to distinguish among individual broker/dealers), 21% on Philadelphia, 11% on Chicago, and 8% on Boston. These findings could be the result of a secular decline in order size during the sample period, but make it less likely that brokers attempt to evade the disclosure rules by substituting orders that are not eligible for Dash-5. We consider this helpful in assessing the relation between routing decisions and past execution cost.

Next, we examine the time-series behavior of each market center's effective spread. To be useful for routing decisions, Dash-5 execution cost estimates should allow a ranking of markets that is (reasonably) consistent over time. That is, the most recently available Dash-5 effective spread (from two months ago) should contain some information about current expected execution costs. The left side of Figure 2 presents market-specific mean effective spreads for the sample securities, separated into market and marketable limit orders. Consistent with Lipson (2003), we find that differences between markets exist and rankings tend to be persistent over time, especially for market orders. We attribute this to the fact that market orders are a more homogenous group than marketable limit orders. For example, in contrast to market orders, not all marketable limit orders execute immediately.

It is important to note that a consistent ranking of effective spreads does not trivialize order-routing decisions. For example, suppose that brokers consistently route their most difficult order flow to one market and their easiest to another. Under these circumstances, we would expect that the reported average effective spread is consistently greater in one of the markets, but this would not make the routing decision irrelevant. Effective spreads reflect the total price impact of an executed order, which depends on order difficulty. Order difficulty, in turn, may vary with market conditions and order characteristics. Therefore, effective spreads are useful for routing decisions only conditional on order difficulty. This argument is consistent with the time series of realized spreads presented on the right side of Figure 2. Realized spreads represent the temporary price impact of an order execution, which can be viewed as the portion of execution costs not due to order difficulty. In contrast to effective spreads, realized spreads do not exhibit a persistent ranking across markets. Therefore, conditional on order difficulty, routing decisions appear to matter. In our empirical tests, we attempt to control for order difficulty by taking into account order size and different measures of market conditions.

In summary, we find that the mix of order types across market centers and execution quality across market centers is relative stable over time and we find no evidence that brokers attempt to evade disclosure requirements by submitting orders that are not eligible for Dash-5. This suggests that brokers might be able to use and benefit from historical execution quality statistics for routing decisions.

## 4 ECONOMETRIC MODEL OF ORDER ROUTING BEHAVIOR

In this section, we specify an econometric model of routing decisions. We wish to test whether order-routing decisions depend on information published in Rule 11Ac1-5 reports. Unfortunately, we cannot observe individual routing decisions. Rather, we observe each market center's order flow, which represents the aggregate outcome of individual decisions. To make inferences about the determinants of the underlying choices, we follow an extensive marketing literature that addresses the modeling of market shares. Econometric models of market share require specific assumptions to make the estimation logically consistent. For example, predicted values for market shares should lie between zero and one for each market center, and the sum of market shares across market centers should be equal to one. In addition, brokers' responses to changes in certain explanatory variables may differ across markets, and we need to consider possible heterogeneity across different securities. This section addresses each of these issues.

After receiving a customer order or after making the decision to place a proprietary order in security $i$, we assume that brokers choose a market center $m \in \{1,2,\ldots,M\}$ and an order size $s \in \{[100-$

499];[500-1,999];[2,000-4,999];[5,000-9,999]}. Alternatively, one could aggregate order flow across all sizes at each market center. This creates inference problems, however, if different market centers have a comparative advantage in processing certain order sizes (evidence in Bessembinder 2003a, Boehmer 2004, and Lipson 2003 supports this claim). Therefore, we believe it is appropriate to endogenize order size by treating each market center-order size combination as a different choice. This approach allows the effect of execution quality to differ systematically across markets and allows brokers to respond to changes in costs with changes in submitted order size categories, changes in venue, or both. Where appropriate, we use $j \in \{1,2,\ldots,J\}$ to index these $J \equiv 4M$ elements that represent brokers' choice set (we limit our analysis to orders below 10,000 shares because Dash-5 reports exclude larger orders).

We ask how the choice of $j$ is related to observable characteristics of the different market centers and securities. To model this relationship, we assume that the choice depends on the attraction (or utility) $A_{ij}$ of sending an order for stock $i$ of size $s$ to market center $m$. Bell, Keeney, and Little (1975) show that the following relationship between market share $S_{ij}$ and attraction holds under reasonable assumptions:[9]

$$S_{ij} = \frac{A_{ij}}{\sum_{j=1}^{J} A_{ij}} \tag{1}$$

Equation (1) states that the market share of choice $j$ for stock $i$ depends on its relative attraction to brokers. This relationship can vary across securities and $S_{ij}$ can be interpreted as the result of individual choices. If individuals choose $j$ according to a multinomial logit model, the aggregation of their choice probabilities is consistent with equation (1).[10]

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[9] Alternative sets of assumptions are sufficient. One possible set is the following: (1) $A_j$ is non-negative; (2) the attraction of a subset of all available choices equals the sum of the attractions of the elements in this subset; (3) $A_j$ is finite for all $j$ and non-zero for at least one element; (4) if two subsets of choices have equal attractions, then their market shares are also equal.

[10] See Cooper and Nakanishi (1988, Section 2.9.3), who present alternative derivations of this result.

Next, we wish to model $A_{ij}$ in a way that is economically meaningful. We consider the following general model of attraction (see Cooper and Nakanishi 1988):

$$A_{ij} = \prod_{k=1}^{K} f_k \left( X_{kij} \right)^{\beta_{kij}} \tag{2}$$

In this specification, the attraction of the broker's choice for a specific security depends on a set of $k$ variables (the columns of $X$), possibly including characteristics of market quality, the security, or other issues important to brokers. The coefficients $\beta_{kij}$ measure the sensitivity of attraction to these variables, and can, in principle, vary across market center-order size combinations and securities. The link function $f_k$ is a monotone transformation of $X$, where $f_k(\bullet)>0$. For estimation, both the identity and the exponential functions have desirable properties and yield models that are linear in all parameters. We choose an exponential function for our estimation, because it has the additional property that the resulting model is consistent with a multinomial choice model at the (unobservable) broker level. Adding constant and error terms,

$$A_{ij} = \exp\left( d_{ij} + \sum_{k=1}^{K} \beta_{kij} X_{kij} + u_{ij} \right) \tag{3}$$

where the $d_{ij}$ represent different levels of attraction for different securities and market center-order size combinations. To estimate this model, we use time series observations for each variable. Substituting into equation (1) and taking logs yields the estimable form:

$$\log \frac{S_{ijt}}{\tilde{S}_{it}} = \sum_{j=1}^{4M-1} \gamma_j I_j + \sum_{i=1}^{N} \alpha_i I_i + \sum_{k=1}^{K} \sum_{j=1}^{4M} \beta_{kj} I_j (X_{kijt} - \bar{X}_{kit}) + \varepsilon_{ijt} \tag{4}$$

where $\tilde{S}_{it}$ is the geometric mean of market shares in period $t$ for security $i$, $\bar{X}_{kit}$ is the arithmetic mean of the $k^{th}$ independent variable in period $t$ for security $i$, the $I_i$ are security fixed effects, and the $I_j$ are choice fixed effects (representing market centers and order sizes). The fixed effects are included to control for unobservable effects that differ systematically across securities and choices, respectively. Because the available time series is relatively short (19 months), we impose certain restrictions on the slope coefficients to estimate the model. We generally restrict slope coefficients to be equal across securities, although we perform sensitivity tests permitting slopes to vary across securities. This allows us to focus on how slope coefficients vary across market centers or market center-order size categories.

By construction, model (4) produces predicted market shares that are logically consistent (Cooper and Nakanishi 1988). This model, which is based on security-specific deviations from the mean across choices set at time *t*, is equivalent to a model of unadjusted variables that includes a set of time-series fixed effects (Nakanishi and Cooper 1982). The deviation-from-means form is more flexible, however, because we can include controls that do not vary across the choice set (such as market-wide trading volume) in model (4). We use such variables to control for security-specific characteristics such as trading volume, volatility, and share price. In a model with fixed time effects, such variables would be linearly dependent on the effects.

## 4.1 Variables

### *4.1.1 Dependent variable*

We compute two measures of market share; one using Dash-5 data and another using TAQ data. Dash-5 market shares are order based, while TAQ market shares are trade based. From Dash-5 data, we compute the market share of orders placed, $S_{ijt}$, as the share volume of Dash-5-eligible orders placed in security *i* in month *t* that are sent to the $j^{th}$ market center-order size combination, divided by all marketable order volume in security *i* and month *t* across the sample venues. From TAQ data, we compute the market share as the share volume of trades between 100 and 9,999 shares, divided by the aggregate of such volume across the sample venues. For Dash-5 variables, we have individual observations for each of the seven market centers in our sample. Because Nasdaq market centers are not separately identified in TAQ, we group the three markets that print their trades on Nasdaq (Archipelago, Madoff, and Trimark) together for all TAQ measures.

*4.1.2 Independent variables*

The independent variables come from three different sources: the Dash-5 reports, TAQ, and CRSP. From Dash-5 reports, we obtain *Dash5ES*, the share-weighted effective spreads, and *Dash5Speed*, the time between order arrival and execution in seconds. Each of these variables is computed for each stock, month, order type, order size category, and market center. We are mainly interested in whether two alternative dimensions of Dash-5 execution quality, effective spreads and execution speed, have incremental influences on market shares.

All regressions also include *TaqES*, the trade-based effective spread from TAQ for each observation (combined for the three sample market centers reporting trades to Nasdaq). *TaqES* is included for several reasons. First, we wish to understand whether individual routing decisions are associated with TAQ-based measures of execution quality that are publicly available before Dash-5 is effective. Second, we are interested in the incremental information, in addition to that available in TAQ data, which Dash-5 reports appear to provide. Finally, *TaqES* provides a control for a market's general liquidity because this measure includes all order types below 10,000 shares and not just Dash-5-eligible orders.

We also wish to control for the extent to which routing decisions in one security are associated with routing decisions made for other securities. While we cannot observe order flow for individual decision makers, we can construct an indirect test in the following way.[11] In model (4), the variable *TaqES* is transformed into the deviation from its mean across market center-order size choices *j*, so that $TaqES'_{ijt} = TaqES_{ijt} - 1/J \sum_{j=1}^{J} TaqES_{ijt}$ measures how much TAQ effective spreads for choice *j* deviate from those for the other choices for the same security in month *t*. This deviation measures the benefit of sending an order to market center-order size category *j*, relative to other choices available for this security. We then compute the mean deviation across all securities except the security of interest. We include the result, $TaqOtherES_{ijt} = \frac{1}{N-1} \sum_{\substack{l=1 \\ l \neq i}}^{N} TaqES'_{ljt}$ , as an independent

[11] We thank an anonymous referee for this suggestion.

variable to assess how a market's order flow in security *i* is related to the relative performance of choice *j* in all other securities.

Finally, we employ three variables intended to control for monthly market conditions and security-specific characteristics: the log of the average daily closing price (*ClosePrc*), the log of average daily share volume (*ADV*), and the average of the daily price range standardized by the closing price (*RelRange*). These variables are identical across market center-order size observations and therefore, in contrast to all others, not represented as deviations from the mean.

In additional sensitivity tests, we use an alternative specification that yields qualitatively identical results throughout the analysis and is therefore not reported. One may argue that realized spreads are a more appropriate determinant of routing decisions than effective spreads, because realized spreads do not depend on the information content of an order. On the other hand, realized spreads are not a measure of execution costs, and because traders may not be able to quantify the information content of their order, past realized spreads may be of limited use for routing decisions. We nevertheless address this issue empirically by adding price impact as an independent variable. Price impact, computed as one-half the difference between effective and realized spreads, approximates the information content of an order. In this specification, the coefficient on *Dash5ES* captures variation in effective spreads beyond that caused by information content and can be interpreted as market share sensitivity to changes in realized spreads. We obtain virtually identical estimates for all variables, although the relationship between market share and Dash-5 spreads becomes somewhat stronger in most regressions. We omit these results to conserve space.

*4.1.3 Timing issues*

To specify an economically meaningful model of market shares, we must understand the timing of all variables. We model routing decisions (and thus market shares) during month *t*, so the independent variables must be available to the decision maker at that time. Data on the control variables and the measures constructed from TAQ are available for the previous month, so these variables enter the model with a one-month lag. In contrast, Dash-5 reports are published by the end of the subsequent month (e.g., the January report must be published by the end of February). Therefore, we lag Dash-5 independent variables by two months.

### 4.2 Estimation

In Tables 3 to 6, we present ordinary least squares estimates and *p*-values based on robust (hetereroskedasticity-consistent) standard errors for the pooled model (4). We address four issues that require slightly different specifications. In Section 5, we use TAQ data to conduct an event study that compares routing behavior before and after Dash-5 reports are available (Table 3). We intend to test whether brokers use trade-based measures of execution quality prior to having Dash-5 data available and whether they continue to use these measures after Rule 11Ac1-5 is implemented. This model does not include any Dash-5 variables and is based on a maximum of 30,600 observations (5 market centers, 24 months, and 255 securities).[12]

The models in Section 6 use Dash-5 market shares and examine the incremental sensitivity of market shares to Dash-5 market-quality data. We estimate this model for market orders and marketable limit orders separately. Because this estimation uses seven market centers and four order-size categories, the maximum number of observations is 135,660. Tables 4 to 6 differ in the restrictions imposed on the slope coefficients. In Table 4, we restrict slope coefficients of past Dash-5 variables to be equal across all observations. In Tables 5 and 6, the Dash-5 coefficients vary across market centers and across market center-order size categories, respectively. We find that the association between market share and execution quality is generally robust to model specification.

In additional unreported sensitivity tests, we use a two-step procedure to remove the restriction of equal slope coefficients across securities. In the first step, we estimate 255 security-specific regressions where control variables are restricted to be equal across market centers. We first hold the slope coefficients of the Dash-5 variables fixed, but later relax this restriction and allow

[12] In contrast to the Dash-5 regressions, order-size information is not available for this model. Because trade sizes are less informative about the underlying order sizes, we compute market shares for all sizes between 100 and 9,999 shares together.

them to vary by market center. In the second step, we aggregate coefficients across securities and perform tests on the cross-sectional mean and median. This alternative specification produces estimates that are qualitatively similar to the ones presented for the pooled model presented in this paper, although both the power of this alternative test and the precision of the estimates are lower.

Theory provides little guidance whether variation across stocks or variation across order sizes and market centers is more important for routing decisions. In this paper, our primary interest is the variation across market centers and order sizes. Estimating security-specific models allows coefficients to vary across securities, but the precision of the estimates is greatly reduced once we let slope coefficients also vary across markets and order sizes. Moreover, we have little guidance on how to aggregate coefficients across stocks. For these reasons, we believe the pooled model provides a more appropriate specification for our purposes. In the pooled approach, we restrict slope coefficients to be equal across securities, but security-specific fixed effects allow us to focus on within-security variation and to test restrictions across markets and order sizes. Additionally, we use a control variable to explicitly allow routing decisions in one security to depend on the execution quality of the other sample securities.

## 5 ORDER FLOW SENSITIVITY TO EXECUTION COST BEFORE AND AFTER RULE 11AC1-5

In this section, we explore whether the implementation of Rule 11Ac1-5 appears to affect the data brokers use to make order-routing decisions. Before Dash-5 reports, the primary publicly available sources of execution-quality data were the Consolidated Trade System (CTS) and the Consolidated Quote System (CQS), i.e., the record of trade prices and quotes. These data are sold by several providers (e.g., as TAQ by the NYSE). To compute traditional execution quality statistics with CTS and CQS data, users must merge the two sources and perform the calculations using trade-time quotes.[13] Dash-5 data contain order-time spread statistics (and provide statistics on fill rates and execution speed) that are arranged by order type and size. Compared to TAQ, Dash-5 data require less data manipulation and provide additional and (arguably) more accurate information. The disadvantages include a lower reporting frequency and only partial coverage of order flow. The tests in this section are designed to examine whether routing decisions appear consistent with trade-based execution quality before the implementation of Rule 11Ac1-5 and whether this changes afterwards.

We choose June 2000 to May 2001 as the pre-Dash-5 period, and December 2001 to November 2002 as the post-Dash-5 period. We end the pre-event period in May 2001, because Rule 11Ac1-5 became effective in June 2001. The post-event period starts in December 2001 because some venues provided their first reports only in November 2001 and so that it is not affected by the aftermath of the market closure following September 11, 2001. Specifically, we estimate the following model based on deviations from means across market centers *m*:

$$\begin{aligned}\log\frac{S_{imt}}{\widetilde{S}_{it}} &= \sum_{m=1}^{M-1}\gamma_m I_m + \sum_{i=1}^{N}\alpha_i I_i + \delta After_t + \beta_1\left(TaqES_{im,t-1} - \overline{TaqES_{i,t-1}}\right) \\ &+\beta_2 After_t * \left(TaqES_{im,t-1} - \overline{TaqES_{i,t-1}}\right) + \beta_3 TaqOtherES_{im,t-1} \\ &+\beta_4 After_t * TaqOtherES_{im,t-1} + \sum_{k=5}^{K}\sum_{m=1}^{M}\beta_{km} I_m (X_{kim,t-1} - \overline{X}_{ki,t-1}) + \varepsilon_{imt}\end{aligned} \tag{5}$$

where notation is as in equation (4) and $X_k$ includes the closing price, the average daily price range standardized by the closing price, and the average daily volume. *After* is a dummy variable that equals one in the post-Dash-5 period and zero otherwise. Using this specification, we can examine (1) whether TAQ information affects routing decisions before Dash-5 by testing whether $\beta_1=0$; (2) whether it is important after Dash-5 by testing whether $\beta_1+\beta_2=0$; and (3) whether the change is statistically significant by testing $\beta_2=0$. We perform similar tests to determine whether the importance of execution quality in other securities changes by examining the coefficients $\beta_3$ and $\beta_4$.

We first estimate the model without *TaqOtherES* (Panel A in Table 3) and then include this variable and the corresponding interaction term (Panel B). We report only the coefficients $\beta_1$- $\beta_4$ and the associated tests. In both specifications, the pre-Dash-5 market share of trades is significantly negatively related to effective spreads estimated from TAQ for the previous month. This suggests

[13] We do not mean to suggest that brokers necessarily compute effective spreads. They might simply form

that market participants respond to wider spreads (larger execution costs) in a given stock on a given market by routing fewer orders in that stock to that market center in the future. Specifically, for every one-cent increase in effective spreads, a market center's market share falls by 1.2%. After the implementation of Dash-5 the magnitude of this coefficient is 49% smaller. While it is still significantly negative, we find that this decline in the sensitivity to *TaqES* is significant. Thus, the implementation of Rule 11Ac1-5 appears to significantly alter the information brokers use to make their routing decisions.

Adding *TaqOtherES* to the model does not affect this conclusion materially, but it shows that the average market center performance in other stocks also is relevant for routing decisions. As other stocks become relatively more costly to execute in market center *m*, brokers appear to be less inclined to submit orders in any stock in the future. This relationship is not significantly affected by the implementation of the Dash-5 rule.

## 6 ANALYSIS OF ORDER MARKET SHARE SENSITIVITY TO EXECUTION QUALITY REPORTS

Having shown evidence consistent with a change in how public trade and quote information is used in order routing decisions, we now estimate the sensitivity of routing decisions to past Dash-5 execution quality statistics. We estimate the following general model based on deviations from means across market center-order size choices *j*:

$$\log \frac{S_{ijt}}{\widetilde{S}_{it}} = \sum_{j=1}^{4M-1} \gamma_j I_j + \sum_{i=1}^{N} \alpha_i I_i + \sum_{j=1}^{4M} \beta_{1j} \left( Dash5ES_{ij,t-2} - \overline{Dash5ES_{i,t-2}} \right)$$
$$+ \sum_{j=1}^{4M} \beta_{2j} \left( Dash5Speed_{ij,t-2} - \overline{Dash5Speed_{i,t-2}} \right) + \sum_{m=1}^{M} \beta_{3m} \left( TaqES_{im,t-1} - \overline{TaqES_{i,t-1}} \right) \quad (6)$$
$$+ \sum_{m=1}^{M} \beta_{4m} TaqOtherES_{ij,t-1} + \sum_{k=5}^{K} \sum_{m=1}^{M} \beta_{km} I_m (X_{kim,t-1} - \overline{X}_{ki,t-1}) + \varepsilon_{ijt}$$

where notation is as in equation (4) and the $X_k$ again include closing price, relative range, and volume. For regressions involving marketable limit orders, we add the cancellation rate as a control

impressions of which venues provide favorable and which provide unfavorable prices.

variable. We do not observe the opportunity costs associated with non-executed orders (see, for example, Peterson and Sirri 2002), and the cancellation rate is a readily-available proxy to control for these costs. Finally, in unreported sensitivity tests, we include the dependent variable lagged by one period (or, alternatively, two periods) as an additional regressor. This specification addresses the possibility that market-share deviations from the mean may be autocorrelated, which could affect inferences and the causal structure assumed in model (6). We obtain qualitatively identical results for all versions of model (6) that we estimate below with and without lagged dependent variables.

### 6.1 Results for all sample market centers combined

Table 4 presents estimation results for equation (6), with additional restrictions on the variation of slope coefficients. In Model 1, all coefficients are held constant across market centers. Model 2 allows the coefficients on control variables to vary across market centers, and Model 3 allows the coefficients on both the control variables and the TAQ variables to vary across market centers. This comparison allows us to investigate how these restrictions affect the Dash-5 coefficients. We provide separate results for market orders and marketable limit orders and do not report the coefficients on the control variables.

We find that the Dash-5 reports provide information that appears useful for routing decisions. Future market share declines as effective spreads or execution time increase. We also find that market share is still significantly negatively related to *TaqES*, as shown in Table 3. These results suggest that Dash-5 statistics provide incremental information over that available from TAQ. Using the unconditional standard deviations, the coefficients indicate that a one-standard deviation increase in *Dash5ES* (3.4 cents) decreases the future share of market orders by 1.33%. Similarly, a one-standard deviation decrease in *Dash5Speed* (40.8 seconds) corresponds to a decrease of 1.22%. These estimates imply economically significant penalties for poor execution quality. Given an average daily volume of three million shares (see Table 1), our estimates suggest that a one-standard deviation increase in effective spreads reduces daily order flow by 39,900 shares for each stock traded. The corresponding decline for a one-standard deviation decrease in speed is 36,600 shares per stock. Given that Dash-5 eligible market orders represent about 15% of total volume, this translates into sizeable effects on order flow.[14]

When we allow coefficient estimates to vary across market centers for the control variables (Model 2) and, additionally, for the TAQ variables (Model 3), the coefficients on *TaqES* are negative regardless of specification. Sensitivity to the Dash-5 variables remains negative for market orders, but diminishes for marketable limit orders in Models 2 and 3. This suggests that past Dash-5 execution quality is more important for the routing of market orders than for that of marketable limit orders.

Market shares do not decline systematically when the relative execution quality of other sample securities at that market center is poor. This suggests that, in a multivariate setting, routing decisions are driven primarily by past execution quality of a specific security, rather than a market center's average performance. However, Model 3 shows that this relationship varies across markets. For example, average past other-stock execution costs have a strong negative effect on market orders sent to Philadelphia and Trimark, and on marketable limit orders sent to the NYSE, Philadelphia, and Archipelago. However, we obtain the opposite result for market orders sent to Chicago and for marketable limit orders sent to Chicago and Madoff. One potential explanation for a positive coefficient on *TaqOtherES* is that brokers may have arrangements that promise a certain order volume for specific markets. These brokers would allocate more of their order flow in stocks for which an execution venue offers relatively low execution costs and less of the order flow in stocks with high execution costs on that venue. For example, consider a case where a broker allocates order flow in stocks A and B between two venues and has agreed to a minimum volume to both venues in exchange for order-flow payment. If venue one offers low execution costs for stock A and high execution costs for stock B, then the broker routes all of the order flow in stock A to venue one and

[14] The finding that Dash-5 reports provide additional information over that contained in TAQ is also supported by a comparison of effective spreads from TAQ and Dash-5, as reported in the appendix.

all of the order flow in stock B to venue two.[15] Finally, the mixed results on the role of execution costs for other securities may reflect differences in business models and routing algorithms across brokerage firms.

### 6.2 Results by market center

One implicit assumption in the previous analysis is that brokers use the same market-quality criteria regardless of target venue. However, some aspects of market structure imply that this might not be true. For example, some market centers paid for order flow during the sample period. In addition, markets differ with respect to the dimension of execution quality they emphasize. For example, ECNs tend to provide fast executions, so traders might send orders there when speed is important. Exchanges traditionally emphasize the auction process, which promises price improvement at the expense of execution speed. Nasdaq market makers, such as Trimark and Madoff, operate automatic execution systems that are fast and can provide price improvement for selected orders. Thus, we might expect a different sensitivity of routing decisions to execution quality measures across venues.

To address this issue empirically, we again estimate equation (6), but allow the Dash-5 execution-quality coefficients to vary across market centers. In Table 5, we provide separate results for market and marketable limit orders (and do not report fixed-effects and the coefficients on control variables and *TaqOtherES*, which vary across market centers). Removing the equality restriction from the Dash-5 coefficients allows several new insights. First, we find that changes in effective spreads have the greatest effect on the NYSE's market share for both order types. In fact, the sensitivity of NYSE market share to *Dash5ES* is about twice as large as its sensitivity to *TaqES*. This illustrates that the aggregate results in Table 4 understate the economic importance of Dash-5 information, because the NYSE receives about 80% of the orders in our sample. The NYSE also receives more market orders when past execution speed has slowed (i.e., time to fill has lengthened).

[15] The second-largest positive coefficient (market orders to Archipelago) represents little volume. As shown in Figure 1, Archipelago receives only a negligible fraction of its order flow as market orders.

Because the NYSE is not generally considered a venue for fast executions, this may simply indicate that traders do not send orders to this market when speed is important and that execution speed and price improvement are inversely related on the NYSE (see Boehmer 2004). Alternatively, it is consistent with the NYSE being a "market of last resort," which receives more order flow in difficult market conditions. Such difficult conditions may be characterized by slower execution, and our control variables may not fully capture such adverse conditions.

For market orders, most other market centers also have negative coefficients on both Dash-5 variables and all have negative coefficients on *TaqES*. The *Dash5ES* coefficients are not significant for Philadelphia, Madoff, and Trimark, potentially reflecting the prevalence of preferencing. In preferencing agreements, a broker prefers one market center to the others either because of monetary payments (payment for order flow) or because of other considerations. Recent SEC regulation allows us to determine whether the sample market centers systematically enter preferencing agreements. Specifically, SEC Rule 11Ac1-6, promulgated at the same time as Dash-5, requires that brokers disclose payment for order flow and other preferencing arrangements. According to Rule 11Ac1-6 reports published during the sample period, Boston, Chicago, Philadelphia, Madoff, and Trimark pay for order flow. We find that poor past execution quality in Boston and Chicago reduces their future order flow, although to a lesser extent than on the NYSE. Thus, despite preferencing, brokers appear to place value on execution quality in these market centers.

Archipelago, which receives only a small fraction of its order flow as market orders (see Figure 1), has a positive coefficient on *Dash5ES*, which attenuates the larger, negative *TaqES* coefficient. However, the *Dash5Speed* coefficient is significantly negative. This suggests that either speed is more important for traders routing orders there, or that Archipelago's practice of routinely routing orders to other markets when they post better quotes makes traders less sensitive to reported effective spread measures.

For marketable limit orders, we find that Dash-5 statistics generally are less important, but again document a strong effect on NYSE order flow. Both *Dash5ES* and *Dash5Speed* have a significantly negative relationship with market share on the NYSE. As with market orders, the Dash-

5 effect is large relative to the TAQ effect. Other market centers' order flow either is not sensitive to Dash-5 information, or, on Boston and Archipelago, has a weak positive relationship with *Dash5ES*. Marketable limit orders, however, are relatively unimportant on these markets (see Figure 1), so that traders may route such orders there for reasons other than past execution quality.

### 6.3 Results by market centers and order size

As execution costs for a specific order increase in one market, traders may either send the order elsewhere or split/bundle their trading interest into different order sizes. Table 6 extends the analysis by allowing Dash-5 coefficients to vary across market center-order size categories, explicitly allowing for endogenous order-size choices. This corresponds to estimating equation 6 without additional restrictions. As in Table 5, the TAQ and control-variable coefficients vary across market centers and are not reported.

We find that the NYSE's share of market orders is strongly related to *Dash5ES* in all but the second-smallest order size category. This contrasts to all other markets (except Archipelago), where the sensitivity to execution costs is concentrated in the smallest orders. This finding illustrates a further difference between the NYSE and other markets: not only is NYSE order flow more sensitive to execution quality, the sensitivity is also more consistent across order sizes. The sensitivity to execution speed varies less across order sizes. Generally, the markets where presumably speed matters more (see Table 5) show more significant coefficients, but we find little systematic variation across order sizes.

For marketable limit orders, the NYSE's market share increases when past *Dash5ES* and *Dash5Speed* decline (i.e., time to execution decreases) in three out of four size categories. In the other markets, routing decisions for marketable limit orders appear to be less sensitive to past execution quality both compared to the NYSE and to the routing decisions for market orders.

## 7 CONCLUSIONS

We use execution-quality reports required by SEC Rule 11Ac1-5 to investigate whether order-routing decisions for marketable orders are sensitive to two dimensions of historical execution quality, execution costs and execution speed. We document a systematically negative relationship between the share of order flow received by an execution venue and that venue's historical effective spread and time between order receipt and execution. This finding suggests that market centers, including those that pay for order flow, can compete on execution quality, because order routers pay attention to past performance. It further suggests that broker-dealers face competitive pressures to route orders to low-cost and/or fast execution venues. These findings are in contrast to several allegations and admissions of non-competitive behavior in the recent past.

We document substantial variation in the sensitivity of market share to execution quality depending on order type, market center, and order size. For market orders, better Dash-5 execution quality measures (order-based effective spreads and execution speed) and better TAQ effective spreads consistently are associated with greater future market share. This result is consistent with competition for order flow and suggests that Dash-5 reports contain additional information that is not revealed even by more timely TAQ measures. Except for the NYSE, the association between Dash-5 measures and subsequent market shares is strongest for small orders, which are more likely to be within the quoted size and the size guarantees provided by Nasdaq market makers. Among the market centers we examine, the NYSE order flow is by far the most sensitive to past execution costs, and this relationship is not limited to the smallest order size category. Execution speed, however, does not appear to play a role in attracting order flow to the NYSE. Although we find that traders appear to use other publicly available data for routing decisions prior to the SEC's enactment of the rule, the reliance on these trade-based statistics decreases after Rule 11Ac1-5 becomes effective.

For marketable limit orders, we also document a systematic negative relationship between market shares and TAQ effective spread. In addition, NYSE order flow is again systematically related to Dash-5 execution costs and speed. Results for other markets, however, suggest that past execution quality (as measured by effective spreads and execution speed) appears to be less important for marketable limit orders than for market orders. This result makes economic sense, because traders exert some control over the execution costs of marketable limit orders by setting limit prices. The results for marketable limit orders are also harder to interpret because we cannot observe the costs of unfilled orders, and because marketable limit orders may serve a different purpose than market orders (see Peterson and Sirri 2002 for a discussion).

An important implication of our findings is that the reports based on SEC Rule 11Ac1-5 appear to have value beyond other publicly-available trade and quote information. Our empirical tests explicitly control for execution-cost measures computed from previously available data sources, and show that Dash-5 reports provide additional information that appears to be used in routing decisions. This is despite a lack of audits and the alleged sensitivity of Dash-5 statistics to the computational details employed at the different market centers. Our results qualify industry complaints about the high cost of producing these data, because the additional price competition should benefit market participants.

Finally, our study suggests that the Securities and Exchange Commission's emphasis on disclosure as a means of effecting public policy can produce beneficial effects. We find that publishing standardized execution quality statistics encourages brokers and investors to consider these statistics in their routing decisions. Moreover, the data are used in a way that increases competition based on execution quality, and should therefore make the allocation of resources in the market for equity trading more efficient.

## APPENDIX: ESTIMATING THE ACCURACY OF DASH-5 REPORTS

Market centers compute Dash-5 reports from large databases of orders and quotes that must be filtered, aggregated, and manipulated regularly. This is complex task that is costly to market centers and the SEC does not require external verification. Moreover, it is possible that the data quality differs across market centers. Therefore, an important question is whether there are sufficient incentives for markets to produce accurate reports. There are examples of problems with Dash-5 accuracy. MSI recently notes that the Archipelago Exchange erroneously calculated the National Best Bid and Offer, on which execution cost measures are based, for its NASDAQ stocks from April 2003 to October 2003. Their published reports were based on the Nasdaq BBO rather than the Consolidated NBBO as required by Rule 11Ac1-5. MSI also states that Island reports are erroneous for March and April of 2004. Finally, Trimark submitted an inaccurate report for March 2004 that was later replaced by a corrected version.[16]

Deliberate, repeated misrepresentation of execution quality, however, would probably prompt legal action by the SEC. Moreover, if brokers use Dash-5 reports for order routing decisions, then repeated relationships should encourage accurate reporting because brokers can verify Dash-5 reports using internal execution-cost reports. While proprietary reports cover only the broker's orders, larger firms could generate meaningful comparisons between Dash-5 reports and their actual experience. Because larger firms are also more important for the market centers, competition may in fact encourage accurate reporting.

In this appendix, we provide evidence on the reliability of Dash-5 effective spreads. Unfortunately, it is difficult to find an appropriate benchmark. Ideally, one would use order data from each market center, but these data are not publicly available. We therefore compare Dash-5 effective spreads to those computed from TAQ. This comparison suffers from several shortcomings.

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[16] All examples were reported on www.marketsystems.com during 2004.

- First, while TAQ is comprehensive, Dash-5 reports cover only orders that are smaller than 10,000 shares and have no special execution instructions. Because TAQ trade sizes do not correspond to Dash-5 order sizes and because order instructions are not reported in TAQ, the subset of Dash-5 eligible orders cannot be reconstructed based on only TAQ information.
- Second, because order type, order side, and order arrival time are not reported in TAQ, effective spreads in the two databases measure different price impacts. While Dash-5 measures the total price impact of an order, effective spreads based on TAQ ignore changes in the quote midpoint between order arrival and execution. The costs of difficult executions, which might take longer to execute, are especially likely to be misrepresented in TAQ, as are orders that are rerouted from one market center to another.[17]
- Third, the comparability of Dash-5 and TAQ effective spreads may vary across market centers and depend on market conditions.
- Fourth, TAQ does not provide separate trade reports for the different Nasdaq market centers.

These issues make it difficult to directly compare the levels or the magnitude of month-to-month changes of Dash-5 and TAQ effective spreads. Instead, we focus on a non-parametric analysis based on rankings across market centers. For each month and stock, we compute share-weighted effective spreads from TAQ and Dash-5. We use all marketable orders for the Dash-5 computation, but the results are unchanged when we use only market orders. Then we create a ranking of the five market centers in our sample (NYSE, Boston, Chicago, Philadelphia, and Nasdaq Intermarket) for both measures, ranging from 1 (lowest effective spread) to 5 (highest effective spread). Based on these rankings, we compute the differences Rank (Dash-5) – Rank (TAQ) for each stock and month. Thus, a positive difference implies that, on average, Dash-5 effective spreads are greater than TAQ effective spreads for a market center. The frequency distribution of these differences is presented in Table A1.

We find that the two measures produce identical rankings 28% of the time, and differ by at most one ranking position 66% of the time. The ranking difference is 3 or greater only 13% of the time. The distribution also reveals differences across markets. On the NYSE, Dash-5 tends to produce wider spreads (and a lower ranking) than TAQ. The opposite is true for Nasdaq, and the regional exchanges are relatively balanced. Subject to the qualifications above, these results suggest

[17] For example, for a sample of 227 NYSE stocks, Boehmer (2004) documents that the average time between order receipt and execution is 22 seconds. Therefore, at least for actively traded stocks, it is feasible that quotes change during this period.

that the two measures tend to produce similar, but not identical rankings. Because we do not know which measure is most accurate, we cannot, however, assess whether the differences are due to data errors. They may result from different sets of included orders, reflect the estimation error of TAQ computations, or inaccuracies in Dash-5 reports.

A different way of examining the differences between rankings is to ask what happens in month $t+1$ if the two measures disagree in month $t$. Conditional on the ranking difference in month $t$, Table A2 shows the average subsequent (one-month) change in the respective rankings, and the average change in the difference of rankings. If ranking differences are small, neither measure changes much by the next month. However, as the disagreement increases, the two measures subsequently tend to converge. Importantly, the more the measures disagree, the stronger is the subsequent change in both measures, and we observe that both rankings change. For example, consider the extreme case where the Dash-5 ranking difference in month $t$ is 4, implying a Dash-5 rank of 5 (worst) and a TAQ rank of 1 (best). In the subsequent month, the ranking difference tends to decrease by 2.92 ranking positions on average (so the ranking difference in month $t+1$ is about 1). This convergence is due to changes in both measures: on average, the TAQ rank deteriorates by 1.25 (to about 2), and the Dash-5 rank improves by 1.68 (to about 3).

Although effective spreads from Dash-5 and TAQ represent different concepts, our results suggest that disagreements between TAQ and Dash-5 measures are temporary. We also find that the rate of convergence is greater when the disagreement is greater. More importantly, we show that *both* measures change subsequent to a disagreement. If disagreements were mostly due to Dash-5 errors, one would expect that the TAQ rank remains relatively constant, while the Dash-5 rank adjusts to correct the error. In summary, these results suggest that both TAQ and Dash-5 provide reasonable measures of effective spreads. Moreover, they are consistent with the finding in the main analysis that Dash-5 data provide additional information over that contained in TAQ data.

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## Table 1: Descriptive statistics for sample securities

The table shows monthly means for the period from June 2001 to February 2003. The table uses all 2561 securities not classified as preferred stocks, warrants, rights, derivatives, or "other" securities in the NYSE master file. To select only shares issued by domestic companies, we merge this set of securities with the CRSP header file, resulting in 2510 matches. Based on the CRSP share code, we further delete firms incorporated outside of the U.S., closed-end funds, units, shares of beneficial interest, certificates, and ADRs. Finally, we exclude three stocks trading above $1000, Berkshire Hathaway Class A and B shares and Security Capital Group. This procedure leaves 1435 securities in the sample. The final sample includes 255 stocks that are continuously traded over the sample period on seven market centers.

| Market Center | Number of stocks traded for at least one month | Average daily closing price ($) | Average daily price range (% of closing price) | Average daily volume (shares) | Average daily number of trades | December 2002 market capitalization ($ million) |
|---|---|---|---|---|---|---|
| **Panel A: All sample securities** | | | | | | |
| New York Stock Exchange | 1,435 | 25.93 | 3.87 | 941,226 | 708 | 4,605 |
| Chicago Stock Exchange | 1,396 | 26.17 | 3.91 | 967,011 | 727 | 4,726 |
| Boston Stock Exchange | 1,077 | 27.51 | 4.10 | 1,222,840 | 906 | 5,978 |
| Philadelphia Stock Exchange | 1,057 | 28.01 | 4.07 | 1,247,693 | 919 | 6,095 |
| Trimark | 1,435 | 25.93 | 3.87 | 941,226 | 708 | 4,605 |
| Archipelago ECN | 1,430 | 25.95 | 3.86 | 944,407 | 711 | 4,620 |
| Madoff | 535 | 32.75 | 4.13 | 2,201,134 | 1,508 | 11,242 |
| **Panel B: Final sample** | | | | | | |
| NYSE, Chicago, Boston, Philadelphia, and Nasdaq | 255 | 34.42 | 4.31 | 3,037,390 | 2,032 | 18,924 |

**Table 2: Descriptive statistics on execution quality for marketable orders**

The sample consists of order information (for 4 order-size categories) in 255 stocks that continuously trade on each of seven market centers (NYSE, Boston Stock Exchange, Chicago Stock Exchange, Philadelphia Stock Exchange, Archipelago ECN and Exchange, Madoff, and Trimark) between June 2001 and February 2003. The table reports share-weighted means for marketable orders based on SEC Rule 11Ac1-5 reports. We impose two filters on monthly records. We delete observations if the mean daily closing price for the month is less than $1 or if the mean monthly effective spread exceeds one-half of the share price. Market shares are computed as a percentage of the shares in all marketable orders in the sample.

| | Market orders | | | | Marketable limit orders | | | |
|---|---|---|---|---|---|---|---|---|
| Market center | Shares placed market share (%) | Dash-5 effective spread ($) | Dash-5 realized spread ($) | Dash-5 execution speed (seconds) | Shares placed market share (%) | Dash-5 effective spread ($) | Dash-5 realized spread ($) | Dash-5 execution speed (seconds) |
| **Panel A: Orders between 100 and 499 shares** | | | | | | | | |
| NYSE | 24.16% | 0.032 | 0.000 | 18.4 | 15.65% | 0.017 | -0.007 | 14.9 |
| Boston | 0.82% | 0.022 | 0.018 | 8.4 | 0.06% | 0.020 | 0.016 | 11.3 |
| Chicago | 0.82% | 0.024 | 0.017 | 5.8 | 0.11% | 0.033 | 0.010 | 13.6 |
| Philadelphia | 0.23% | 0.026 | 0.022 | 6.1 | 0.01% | 0.039 | 0.021 | 17.1 |
| Archipelago | 0.07% | 0.043 | 0.010 | 30.2 | 0.51% | 0.030 | -0.006 | 10.8 |
| Madoff | 1.34% | 0.018 | 0.014 | 0.2 | 0.05% | 0.016 | 0.014 | 1.2 |
| Trimark | 0.78% | 0.025 | 0.013 | 2.6 | 0.08% | 0.022 | 0.012 | 7.8 |
| **Panel B: Orders between 500 and 1,999 shares** | | | | | | | | |
| NYSE | 35.85% | 0.041 | 0.003 | 19.5 | 40.41% | 0.019 | -0.008 | 18.8 |
| Boston | 1.26% | 0.031 | 0.022 | 18.2 | 0.27% | 0.023 | 0.014 | 26.4 |
| Chicago | 1.21% | 0.037 | 0.025 | 20.1 | 0.56% | 0.038 | 0.011 | 23.7 |
| Philadelphia | 0.31% | 0.037 | 0.027 | 28.6 | 0.07% | 0.028 | 0.011 | 36.0 |
| Archipelago | 0.13% | 0.049 | 0.007 | 28.3 | 1.07% | 0.030 | -0.013 | 13.5 |
| Madoff | 1.75% | 0.022 | 0.013 | 1.6 | 0.20% | 0.018 | 0.004 | 4.9 |
| Trimark | 1.35% | 0.029 | 0.014 | 7.8 | 0.40% | 0.022 | 0.005 | 20.2 |
| **Panel C: Orders between 2,000 and 4,999 shares** | | | | | | | | |
| NYSE | 17.63% | 0.054 | 0.014 | 21.5 | 21.22% | 0.020 | 0.004 | 38.5 |
| Boston | 0.67% | 0.044 | 0.028 | 35.5 | 0.28% | 0.027 | 0.019 | 60.7 |
| Chicago | 0.58% | 0.057 | 0.037 | 44.4 | 0.53% | 0.043 | 0.016 | 42.6 |
| Philadelphia | 0.17% | 0.049 | 0.033 | 56.1 | 0.11% | 0.038 | 0.029 | 63.1 |
| Archipelago | 0.09% | 0.057 | 0.011 | 29.3 | 0.45% | 0.024 | -0.008 | 23.5 |
| Madoff | 0.71% | 0.031 | 0.013 | 12.8 | 0.19% | 0.020 | 0.004 | 32.6 |
| Trimark | 0.70% | 0.045 | 0.025 | 30.5 | 0.48% | 0.021 | 0.011 | 59.9 |
| **Panel D: Orders between 5,000 and 9,999 shares** | | | | | | | | |
| NYSE | 8.60% | 0.074 | 0.026 | 24.4 | 16.37% | 0.026 | 0.007 | 56.1 |
| Boston | 0.41% | 0.057 | 0.032 | 51.2 | 0.28% | 0.029 | 0.025 | 86.6 |
| Chicago | 0.29% | 0.068 | 0.041 | 61.2 | 0.46% | 0.041 | 0.014 | 68.8 |
| Philadelphia | 0.13% | 0.051 | 0.030 | 68.4 | 0.14% | 0.028 | 0.029 | 123.1 |
| Archipelago | 0.08% | 0.057 | 0.014 | 30.8 | 0.41% | 0.022 | -0.009 | 30.6 |
| Madoff | 0.21% | 0.047 | 0.020 | 31.0 | 0.16% | 0.022 | 0.013 | 77.9 |
| Trimark | 0.39% | 0.060 | 0.032 | 47.1 | 0.48% | 0.022 | 0.017 | 105.8 |

## Table 3: Changes in routing behavior around the implementation of Rule 11Ac1-5

The sample consists of order information (for 4 order-size categories) in 255 stocks that continuously trade on each of five market centers (NYSE, Boston Stock Exchange, Chicago Stock Exchange, Philadelphia Stock Exchange, and Nasdaq) between June 2001 and February 2003. We use OLS to estimate monthly panel regressions that include fixed effects for each stock and each market center except Nasdaq. Rule 11Ac1-5 became effective in June 2001, but various market centers began publishing Dash-5 reports between June and September 2001. The estimation period includes 12 months before June 2001 (pre-Dash-5 period) and 12 months after November 2001 (post-Dash-5 period). The dummy variable *After* equals one in the post-Dash-5 period and zero otherwise. The regressions also include the *After* dummy and controls for the average closing price, average daily volume, and the average daily price range scaled by the closing price in month t-1, whose coefficients vary across market centers. Coefficients on fixed effects, *After*, and the controls are not reported. The dependent variable is the month *t* market share of trades between 100 and 9,999 shares from TAQ, expressed as the deviation from the geometric mean across market centers. *TaqES* is the share-weighted effective spread from TAQ trades between 100 and 9,999 shares. It is expressed as deviations from the arithmetic mean across market centers. *TaqOtherES* is the average deviation of *TaqES* across securities, excluding the security in the current observation, for the market center in the current observation. The 'joint tests' refer to tests of the hypothesis that the indicated coefficients are jointly equal to zero. We use robust standard errors to compute p-values.

| | TaqES<br>I | TaqES * After<br>II | TaqOtherES<br>III | TaqOtherES * After<br>IV | N | Adj. R squared |
|---|---|---|---|---|---|---|
| **Panel A** | | | | | | |
| Coefficient | -1.165 | 0.566 | | | 30,160 | 0.90 |
| p-value | (0.00) | (0.02) | | | | |
| Test that both coefficients are jointly zero: | I+II=0 | | | | | |
| Chi-square p-value | (0.00) | | | | | |
| **Panel B** | | | | | | |
| Coefficient | -1.064 | 0.514 | -8.887 | 0.495 | 30,160 | 0.90 |
| p-value | (0.00) | (0.03) | (0.00) | (0.82) | | |
| Test that both coefficients are jointly zero: | I+II=0 | | III+IV=0 | | | |
| Chi-square p-value | (0.01) | | (0.00) | | | |

## Table 4: The sensitivity of order-routing decisions to execution quality

The sample consists of order information (for 4 order-size categories) in 255 stocks that continuously trade on each of seven market centers (NYSE, Boston Stock Exchange, Chicago Stock Exchange, Philadelphia Stock Exchange, Archipelago ECN and Exchange, Madoff, and Trimark) between June 2001 and February 2003. We use OLS to estimate monthly panel regressions that include fixed effects for each stock and all market center-order size permutations except the largest order size on Trimark. Each regression also includes controls for the average closing price, average daily volume, and the average daily price range scaled by the closing price in month *t* -1. Marketable limit order regressions also include the cancellation rate in month *t* -2 from Dash-5 reports. Coefficients on control variables and fixed effects are not reported. The ***, **, and * indicate significance at the 1%, 5%, and 10% level based on robust standard errors. The dependent variable is the month *t* market share of orders placed, expressed as the deviation from the geometric mean across market center-order size categories. Variables from Dash-5 reports, effective spreads (*Dash5ES*) and execution speed (*Dash5Speed*), are based on share-weighted monthly averages and recorded in month *t* -2. They are expressed as deviations from the arithmetic mean across market center-order size categories. All other independent variables are recorded in month *t* -1. *TaqES* is the share-weighted effective spread from TAQ trades between 100 and 9,999 shares (this measure does not vary across the three market centers reporting to Nasdaq). It is expressed as deviations from the arithmetic mean across market center-order size categories. *TaqOtherES* is the average deviation of *TaqES* across securities, excluding the security in the current observation, for the market center-order size category in the current observation.

| | | Market orders | | | Marketable limit orders | | |
|---|---|---|---|---|---|---|---|
| Variable (unit, timing) | Market center | Model 1 | Model 2 | Model 3 | Model 1 | Model 2 | Model 3 |
| Dash5ES ($, t-2) | All | -0.39 *** | -0.46 *** | -0.45 *** | -0.29 *** | -0.03 | -0.04 |
| Dash5Speed (seconds, t-2) | All | -0.0003 ** | -0.0002 ** | -0.0002 ** | -0.00003 ** | -0.00002 | -0.00002 * |
| TaqES ($, t-1) | All | -1.58 *** | -1.24 *** | | -1.69 *** | -1.49 *** | |
| TaqES ($, t-1) | NYSE | | | -3.28 *** | | | -4.19 *** |
| TaqES ($, t-1) | Boston | | | -0.69 *** | | | -0.59 *** |
| TaqES ($, t-1) | Chicago | | | -1.24 *** | | | -1.15 *** |
| TaqES ($, t-1) | Philadelphia | | | -1.29 *** | | | -0.87 *** |
| TaqES ($, t-1) | Archipelago | | | -2.63 *** | | | -2.25 *** |
| TaqES ($, t-1) | Madoff | | | -1.27 *** | | | -2.32 *** |
| TaqES ($, t-1) | Trimark | | | -1.21 *** | | | -1.60 *** |
| TaqOtherES ($, t-1) | All | 1.08 ** | 0.13 | | 2.22 *** | -1.40 ** | |
| TaqOtherES ($, t-1) | NYSE | | | 0.94 | | | -4.75 *** |
| TaqOtherES ($, t-1) | Boston | | | -0.55 | | | -1.69 |
| TaqOtherES ($, t-1) | Chicago | | | 9.31 *** | | | 25.08 *** |
| TaqOtherES ($, t-1) | Philadelphia | | | -5.98 *** | | | -12.27 *** |
| TaqOtherES ($, t-1) | Archipelago | | | 24.66 *** | | | -9.01 *** |
| TaqOtherES ($, t-1) | Madoff | | | 0.86 | | | 4.04 ** |
| TaqOtherES ($, t-1) | Trimark | | | -4.30 *** | | | 0.17 |
| Restrictions on control variable coefficients | | All equal | Equal within markets | Equal within markets | All equal | Equal within markets | Equal within markets |
| adj. R-squared | | 0.84 | 0.86 | 0.86 | 0.87 | 0.88 | 0.88 |
| Observations | | 110,405 | 110,405 | 110,405 | 105,408 | 105,408 | 105,408 |

## Table 5: Differences across market centers in the sensitivity of order-routing decisions

The sample consists of order information (for 4 order-size categories) in 255 stocks that continuously trade on each of seven market centers (NYSE, Boston Stock Exchange, Chicago Stock Exchange, Philadelphia Stock Exchange, Archipelago ECN and Exchange, Madoff, and Trimark) between June 2001 and February 2003. We use OLS to estimate monthly panel regressions that include fixed effects for each stock and all market center-order size permutations except the largest order size on Trimark. Each regression also includes controls for the average closing price, average daily volume, and the average daily price range scaled by the closing price in month *t* -1. Their coefficients are allowed to vary across market centers. Marketable limit order regressions also include the cancellation rate in month *t* -2 from Dash-5 reports. Coefficients for fixed effects and controls are not reported. The ***, **, and * indicate significance at the 1%, 5%, and 10% level based on robust standard errors. The dependent variable is the month *t* market share of orders placed, expressed as the deviation from the geometric mean across market center-order size categories. Variables from Dash-5 reports, effective spreads (*Dash5ES*) and execution speed (*Dash5Speed*), are based on share-weighted monthly averages and recorded in month *t* -2. They are expressed as deviations from the arithmetic mean across market center-order size categories. All other independent variables are recorded in month *t* -1. *TaqES* is the share-weighted effective spread from TAQ trades between 100 and 9,999 shares (this measure does not vary across the three market centers reporting to Nasdaq). It is expressed as deviations from the arithmetic mean across market center-order size categories. *TaqOtherES* is the average deviation of *TaqES* across securities, excluding the security in the current observation, for the market center-order size category in the current observation.

| | Market orders | | | Marketable limit orders | | |
|---|---|---|---|---|---|---|
| | Dash5ES ($, t-2) | Dash5Speed (seconds, t-2) | TaqES ($, t-1) | Dash5ES ($, t-2) | Dash5Speed (seconds, t-2) | TaqES ($, t-1) |
| NYSE | -4.09 *** | 0.00131 *** | -2.05 *** | -5.71 *** | -0.00069 *** | -3.59 *** |
| Boston | -0.39 ** | -0.00014 | -0.69 *** | 0.41 * | 0.00001 | -0.60 *** |
| Chicago | -0.59 *** | -0.00125 *** | -1.19 *** | 0.10 | -0.00004 | -1.16 *** |
| Philadelphia | -0.10 | -0.00007 | -1.30 *** | -0.16 | 0.00004 | -0.87 ** |
| Archipelago | 0.58 *** | -0.00030 *** | -2.67 *** | 0.48 * | 0.00000 | -2.26 *** |
| Madoff | 0.25 | -0.00024 | -1.28 *** | 0.31 | 0.00002 | -2.33 *** |
| Trimark | -0.21 | -0.00078 *** | -1.22 *** | -0.13 | -0.00003 | -1.60 *** |
| adj. R-squared | | 0.86 | | | 0.88 | |
| Observations | | 110,405 | | | 105,408 | |

## Table 6: Differences across market centers and order size in the sensitivity of order-routing decisions

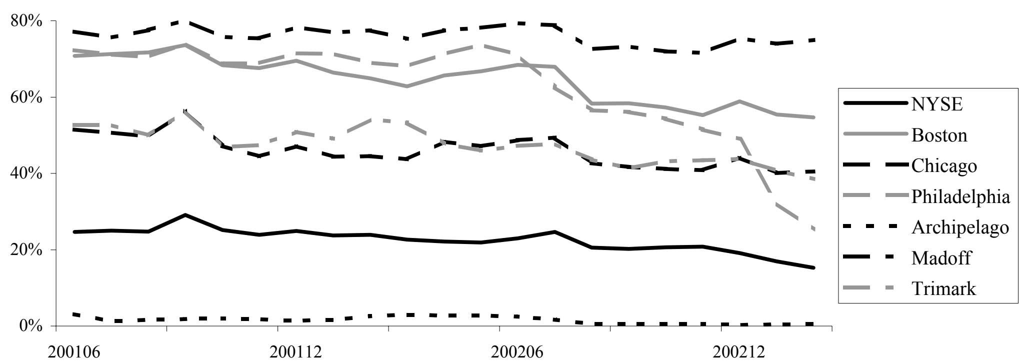
The sample consists of order information (for 4 order-size categories) in 255 stocks that continuously trade on each of seven market centers (NYSE, Boston Stock Exchange, Chicago Stock Exchange, Philadelphia Stock Exchange, Archipelago ECN and Exchange, Madoff, and Trimark) between June 2001 and February 2003. We use OLS to estimate monthly panel regression that include fixed effects for each stock and all market center-order size permutations except the largest order size on Trimark. Fixed effect coefficients are not reported. Each regression also includes controls for the average closing price, average daily volume, and the average daily price range scaled by the closing price in month *t* -1. Their coefficients are allowed to vary across market centers. Marketable limit order regressions also include the cancellation rate in month *t* -2 from Dash-5 reports. The ***, **, and * indicate significance at the 1%, 5%, and 10% level based on robust standard errors. The dependent variable is the month *t* market share of orders placed, expressed as the deviation from the geometric mean across market center-order size categories. Variables from Dash-5 reports, effective spreads (*Dash5ES*) and execution speed (*Dash5Speed*), are based on share-weighted monthly averages and recorded in month *t* -2. They are expressed as deviations from the arithmetic mean across market center-order size categories. All other independent variables are recorded in month *t* -1. *TaqES* is the share-weighted effective spread from TAQ trades between 100 and 9,999 shares (this measure does not vary across the three market centers reporting to Nasdaq). It is expressed as deviations from the arithmetic mean across market center-order size categories. *TaqOtherES* is the average deviation of *TaqES* across securities, excluding the security in the current observation, for the market center-order size category in the current observation. The table reports only the coefficients for the two Dash 5 variables.

| | Market orders | | | | Marketable limit orders | | | |
|---|---|---|---|---|---|---|---|---|
| | 100-499 shares | 500-1,999 shares | 2,000-4,999 shares | 5,000-9,999 shares | 100-499 shares | 500-1,999 shares | 2,000-4,999 shares | 5,000-9,999 shares |
| Dash5ES ($, t-2) | | | | | | | | |
| NYSE | -3.35 *** | 0.46 | -4.90 *** | -4.36 *** | -9.47 *** | -3.19 *** | 0.04 | -8.07 *** |
| Boston | -8.37 *** | -1.33 ** | -0.03 | 0.02 | 0.85 * | -0.46 | 0.11 | 1.06 ** |
| Chicago | -8.27 *** | 0.46 | -0.32 | -0.29 ** | -0.63 | 1.00 *** | 0.33 | -0.22 |
| Philadelphia | -1.50 ** | 0.04 | -0.22 | -0.08 | -0.23 | -0.07 | -0.50 | 0.12 |
| Archipelago | 0.72 | 0.71 ** | 0.73 *** | -0.36 | 0.24 | 1.61 ** | 0.05 | 0.53 |
| Madoff | -4.33 *** | 0.57 | 0.52 | 0.61 *** | -3.94 *** | -0.47 | 1.34 *** | 1.20 ** |
| Trimark | -9.23 *** | -0.86 * | 0.11 | 0.11 | -0.68 | -0.03 | -0.26 | 0.05 |
| Dash5Speed (seconds, t-2) | | | | | | | | |
| NYSE | 0.00213 *** | 0.00121 ** | 0.00099 ** | 0.00061 | -0.00032 * | 0.00001 | -0.00056 *** | -0.00117 *** |
| Boston | -0.00532 *** | -0.00219 *** | -0.00030 | -0.00001 | -0.00027 | 0.00007 | -0.00006 | 0.00005 |
| Chicago | -0.00264 *** | -0.00240 *** | -0.00199 *** | -0.00044 ** | -0.00013 * | -0.00021 | -0.00022 *** | 0.00003 |
| Philadelphia | -0.00402 *** | 0.00001 | -0.00028 | -0.00010 | -0.00030 | 0.00014 | 0.00007 | 0.00002 |
| Archipelago | -0.00001 | -0.00040 *** | 0.00092 | -0.00003 | -0.00010 | -0.00014 *** | 0.00001 | 0.00008 |
| Madoff | -0.00036 | 0.00017 | -0.00049 | 0.00002 | 0.00051 ** | -0.00025 * | 0.00002 | 0.00004 |
| Trimark | -0.00071 | -0.00033 | -0.00128 *** | -0.00039 * | -0.00023 | -0.00022 | -0.00006 | -0.00001 |
| adj. R-squared | 0.86 | | | | 0.89 | | | |
| Observations | 110,405 | | | | 105,408 | | | |

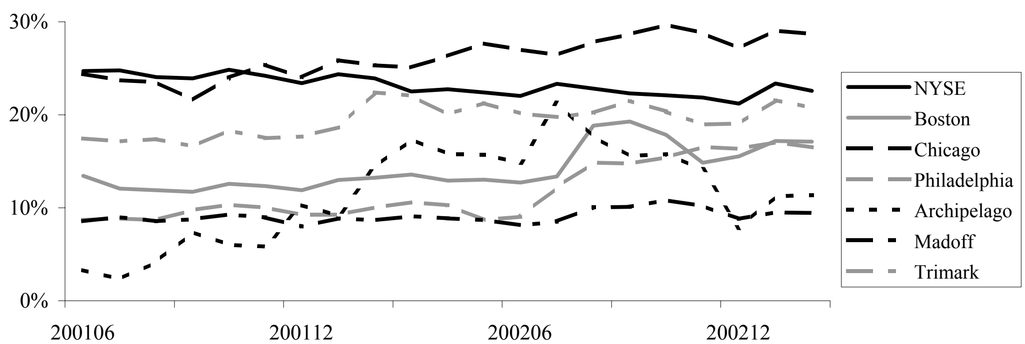
## Figure 1: Composition of order flow over time

The sample consists of order information in 255 stocks that continuously trade on each of seven market centers (NYSE, Boston Stock Exchange, Chicago Stock Exchange, Philadelphia Stock Exchange, Archipelago ECN and Exchange, Madoff, and Trimark) between June 2001 and February 2003. Panels A and B show the percentage of different order types to total share order flow as reported in the Dash-5 statistics for each individual market center. Panel C shows the ratio of executions reported in Dash-5 reports, which include separate records for buy and sell orders, to twice the trading volume reported to the Consolidated Trade System.

**Panel A: Dash-5 market orders as percentage of all Dash-5 eligible orders placed in market center**




**Panel B: Dash-5 marketable limit orders as percentage of all Dash-5 eligible orders placed in market center**




**Panel C: Dash-5 order executions (all types) as a percentage of twice consolidated volume**

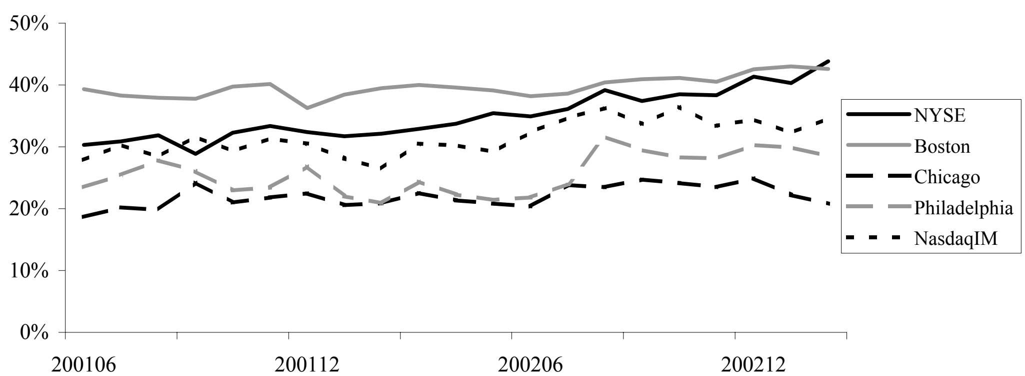
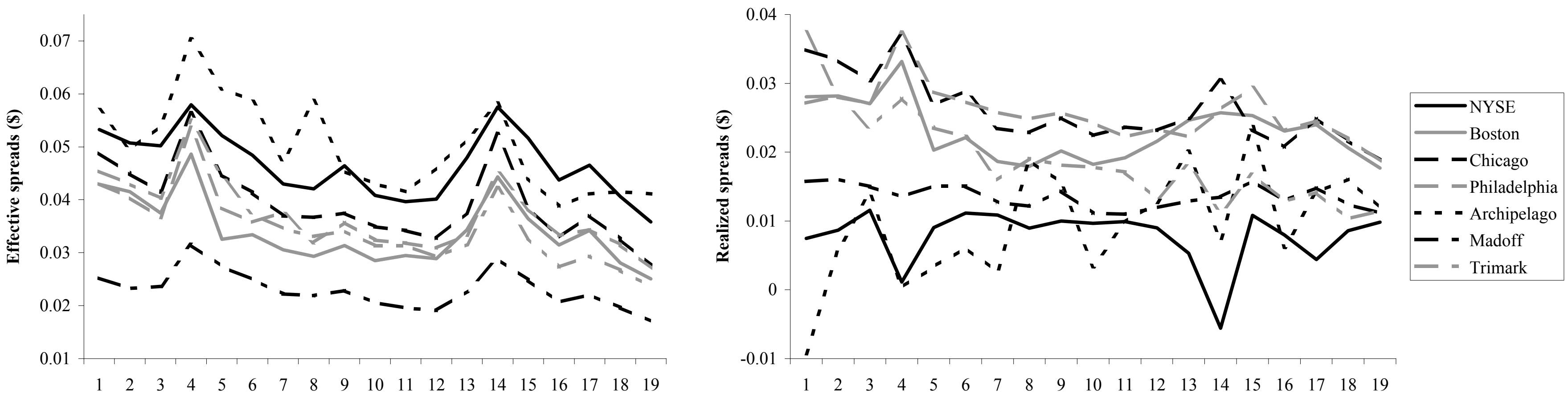


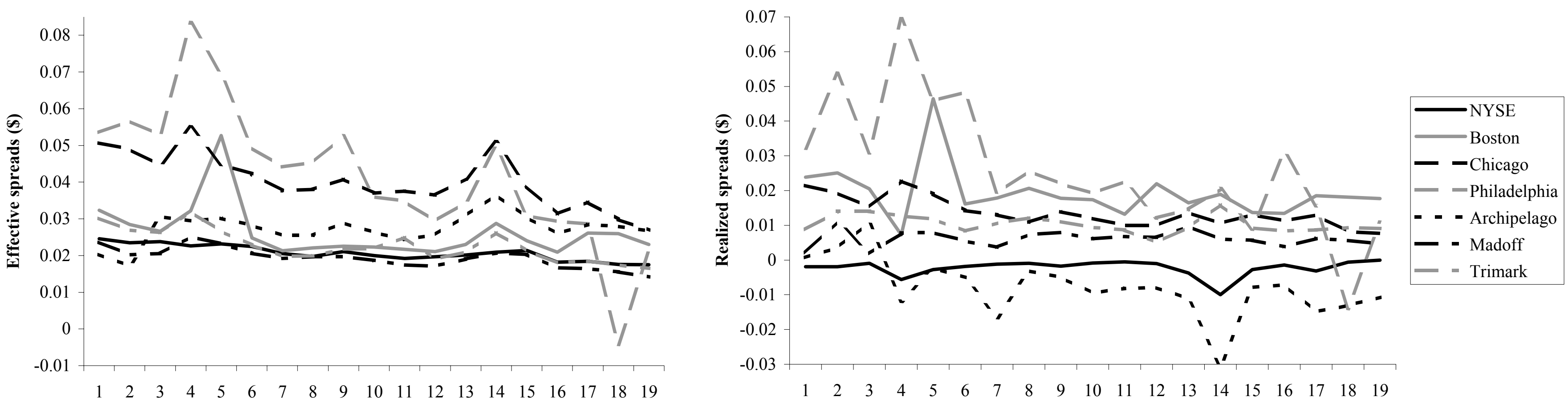
**Figure 2: Effective spreads over time**

The sample consists of order information in 255 stocks that continuously trade on each of seven market centers (NYSE, Boston Stock Exchange, Chicago Stock Exchange, Philadelphia Stock Exchange, Archipelago ECN and Exchange, Madoff, and Trimark). The figures show share-weighted average effective and realized spreads from Dash-5 reports between August 2001 and February 2003.

**Panel A: Market orders**




**Panel B: Marketable limit orders**



## Table A1: Frequency distribution of differences between effective-spread rankings from Dash-5 and TAQ

The sample consists of 255 stocks that continuously trade on each of seven market centers (NYSE, Boston Stock Exchange, Chicago Stock Exchange, Philadelphia Stock Exchange, Archipelago ECN and Exchange, Madoff, and Trimark) between June 2001 and February 2003. For each month and stock, we compute share-weighted effective spreads from TAQ and Dash-5. For the Dash-5 calculations, we use all marketable orders. Then we create a ranking of the five market centers (NYSE, Boston, Chicago, Philadelphia, and Nasdaq Intermarket) for both measures, ranging from 1 (lowest effective spread) to 5 (highest effective spread). Based on these rankings, we compute the differences Rank (Dash-5) – Rank (TAQ) for each stock and month. The table shows the frequency distribution of these differences.

| Dash-5 rank - TAQ rank | NYSE | Boston | Chicago | Philadelphia | Nasdaq | All market centers |
|---|---|---|---|---|---|---|
| -4 | 0% | 2% | 1% | 5% | 5% | 3% |
| -3 | 0% | 3% | 4% | 6% | 14% | 5% |
| -2 | 1% | 7% | 7% | 10% | 23% | 9% |
| -1 | 4% | 15% | 18% | 17% | 29% | 17% |
| 0 | 28% | 28% | 34% | 30% | 18% | 28% |
| 1 | 38% | 23% | 22% | 17% | 8% | 21% |
| 2 | 21% | 15% | 10% | 10% | 3% | 12% |
| 3 | 7% | 6% | 3% | 4% | 1% | 4% |
| 4 | 2% | 2% | 0% | 1% | 0% | 1% |
| | 100% | 100% | 100% | 100% | 100% | 100% |

## Table A2: Ranking changes after disagreements between Dash-5 and TAQ effective spread

The sample consists of 255 stocks that continuously trade on each of seven market centers (NYSE, Boston Stock Exchange, Chicago Stock Exchange, Philadelphia Stock Exchange, Archipelago ECN and Exchange, Madoff, and Trimark) between June 2001 and February 2003. For each month and stock, we compute share-weighted effective spreads from TAQ and Dash-5. For the Dash-5 calculations, we use all marketable orders. Then we create a ranking of the five market centers (NYSE, Boston, Chicago, Philadelphia, and Nasdaq Intermarket) for both measures, ranging from 1 (lowest effective spread) to 5 (highest effective spread). Based on these rankings, we compute the differences Rank (Dash-5) – Rank (TAQ) for each stock and month. The table shows how rankings change in month *t* when there is a disagreement between Dash-5 and TAQ rankings in month *t* -1.

| Rank difference in month t-1 | Ranking change in month t | NYSE | Boston | Chicago | Philadelphia | Nasdaq | All market centers |
|---|---|---|---|---|---|---|---|
| -4 | Average change in TAQ rank | | -1.99 | -1.46 | -1.58 | -1.40 | -1.55 |
| | Average change in Dash-5 rank | | 2.16 | 2.30 | 1.96 | 0.84 | 1.61 |
| | Average change in rank difference | | 4.15 | 3.76 | 3.54 | 2.24 | 3.15 |
| -3 | Average change in TAQ rank | -2.00 | -1.48 | -0.64 | -1.04 | -1.02 | -1.03 |
| | Average change in Dash-5 rank | 1.50 | 1.62 | 1.95 | 1.42 | 0.59 | 1.09 |
| | Average change in rank difference | 3.50 | 3.10 | 2.59 | 2.45 | 1.61 | 2.12 |
| -2 | Average change in TAQ rank | -1.33 | -0.88 | -0.43 | -0.48 | -0.34 | -0.48 |
| | Average change in Dash-5 rank | 0.76 | 1.10 | 1.13 | 1.12 | 0.32 | 0.73 |
| | Average change in rank difference | 2.09 | 1.98 | 1.56 | 1.59 | 0.66 | 1.20 |
| -1 | Average change in TAQ rank | -0.86 | -0.47 | -0.43 | -0.34 | 0.27 | -0.20 |
| | Average change in Dash-5 rank | 0.75 | 0.68 | 0.54 | 0.43 | 0.06 | 0.39 |
| | Average change in rank difference | 1.61 | 1.15 | 0.97 | 0.77 | -0.21 | 0.58 |
| 0 | Average change in TAQ rank | -0.07 | -0.19 | -0.35 | -0.09 | 0.49 | -0.09 |
| | Average change in Dash-5 rank | 0.67 | 0.11 | -0.27 | -0.28 | -0.49 | -0.03 |
| | Average change in rank difference | 0.74 | 0.30 | 0.08 | -0.19 | -0.97 | 0.06 |
| 1 | Average change in TAQ rank | 0.05 | 0.29 | 0.44 | 0.53 | 0.83 | 0.32 |
| | Average change in Dash-5 rank | 0.03 | -0.30 | -0.42 | -0.54 | -0.94 | -0.30 |
| | Average change in rank difference | -0.03 | -0.60 | -0.86 | -1.07 | -1.77 | -0.62 |
| 2 | Average change in TAQ rank | 0.11 | 0.71 | 1.10 | 0.96 | 1.21 | 0.63 |
| | Average change in Dash-5 rank | -0.66 | -0.64 | -0.66 | -1.05 | -1.39 | -0.76 |
| | Average change in rank difference | -0.77 | -1.35 | -1.75 | -2.02 | -2.61 | -1.38 |
| 3 | Average change in TAQ rank | 0.13 | 1.11 | 1.79 | 1.60 | 1.63 | 1.02 |
| | Average change in Dash-5 rank | -1.18 | -1.32 | -0.99 | -1.40 | -1.98 | -1.27 |
| | Average change in rank difference | -1.31 | -2.43 | -2.79 | -3.00 | -3.60 | -2.29 |
| 4 | Average change in TAQ rank | 0.22 | 1.69 | 2.63 | 1.75 | 1.75 | 1.25 |
| | Average change in Dash-5 rank | -1.36 | -1.68 | -1.44 | -2.22 | -2.25 | -1.68 |
| | Average change in rank difference | -1.59 | -3.37 | -4.06 | -3.96 | -4.00 | -2.92 |