Competition Among Market Centers

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We examine competition among six market centers for NYSE-listed stocks using SEC Rule 11ac-5 data. We find that market centers competing with the NYSE execute orders in only a subset of stocks, order types and order sizes; that differences in effective spreads are generally much smaller than suggested by comparisons of overall averages, though reliable differences remain; that order flow routed to the NYSE is substantially more informed than order flow routed to broker-dealers and other exchanges (though less informed than marketable limit orders routed to ECNs); that prevailing quoted spreads at time of order arrival differ among market centers; and that results are less variable for orders routed to the NYSE. More importantly, we find that differences in effective spreads between the NYSE and some market centers are related to characteristics of the stocks traded.

Competition Among Market Centers

1. Introduction

Stocks listed on the New York Stock Exchange (NYSE) may be traded through a number of competing market centers, each with unique technologies and trading protocols. These include exchanges with trading floors, broker-dealers that provide execution services, and electronic communication networks (ECNs) that offer order driven markets. While the business model of each market center may rely upon innovations in market design, it may also rely upon selectively competing in a subset of order flow and/or a subset of stocks. Thus, differences in execution costs between the NYSE and these competing market centers may reflect advantages and disadvantages inherent in market center design, or may simply reflect variation in the segments market centers choose to serve. Furthermore, the ability of market centers to compete may vary depending on characteristics of the order flow and stocks that are selected.

We use data mandated by U.S. Securities Exchange Commission Rule 11Ac 1-5 (Dash5) to examine three questions related to differences in execution results between the NYSE and competing market centers.[1] First, are there differences in trading activity

[1] This rule requires market centers to make public a specified set of execution quality measures. Among other benefits, these data allow us to evaluate execution results for broker-dealers and electronic communication networks (ECNs), provide better measurements of execution results than can be constructed from trade and quote data (see Bessembinder, 2002b), allow a comparison of time to execution, and allow a breakdown and control based on order type. The purpose of the data was to promote optimal order routing for retail order flow. As a result, the rule covers only orders less than 10,000 shares and detailed data are only required for market orders and marketable limit orders. Fortunately, these orders account for approximately 36% of NYSE executed share volume and comprise the vast majority of activity at most market centers.

related to order type, order size, or the stocks that are traded at the market center.[2] Second, controlling for differences in order flow, are there persistent and reliable differences in execution results between the NYSE and competing exchanges? Third, if there are reliable differences, are the magnitudes of these differences related to characteristics of order flow or the stocks being traded? If there are differences in execution costs after controlling for trading activity, and if these are related to order characteristics or vary across stocks, then differences in execution costs are not simply an outcome of market design.[3] In this case, it is more likely that competition is imperfect and market centers vary in their ability to serve various market segments. For example, if market centers attempt to attract and retain less informed traders, this strategy may be more effective for small orders in lower volume stocks.

We find substantial variation in trading activity among market centers. As expected, the NYSE is the most active center.[4] More importantly, while the NYSE has order flow for just about every order category (a combination of stock, order size range, and order type), some market centers execute orders in only a subset of stocks, typically execute smaller orders, and/or predominantly execute a specific order type. Given the differences in trading activity, we use category-by-category comparisons to compare execution statistics for the NYSE with those of competing market centers. For marketable limit orders, NYSE effective spreads are reliably lower than those at all the

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[2] Selectivity may result from a conscious strategy, such as the purchasing of less informed order flow, or an outgrowth of decisions regarding the design of execution procedures, such as the anonymity of ECNs.
[3] See Domowitz and Steil (1999), Conrad, Johnson and Wahal (2002), and Hasbrouck and Saar (2002), among others, for discussions of alternative trading mechanisms and Stoll (2001) for a discussion of the benefits of encouraging innovation.
[4] We compare the NYSE to the broker-dealers Knight and Madoff, the ECN Archipelago, and the Boston, Cincinnati and Chicago stock exchanges. These market centers are the six most active centers for NYSE-listed securities during our study period.

market centers we examine. For market orders, NYSE effective spreads are reliably lower than spreads at four of six market centers and reliably higher than those at the remaining two. For example, effective spreads on the NYSE for very small market orders are about a half penny lower than for Knight Securities and about a half penny higher than for Madoff Securities. We note that these results are remarkably different than results based on market center averages, in which NYSE effective spreads are three to seven pennies higher than competing market centers. This illustrates the extent to which selectivity characterizes competition among market centers.

We find that order flow routed to the NYSE is substantially more informed than order flow routed to broker-dealers and other exchanges. For ECN Archipelago, on the other hand, there is no difference in information for market orders, though marketable limit orders routed to Archipelago are typically more informed than those routed to the NYSE. For example, after the arrival of very small market or marketable limit orders at the NYSE, prices move about twice as much as they do following similar orders at broker-dealers or other exchanges. Furthermore, NYSE order flow is sufficiently more informed than order flow routed to competing market centers, that the NYSE has substantially lower realized spreads than all other market centers except Archipelago.[5] We also examine quoted spreads at the time of order submission. In general, prevailing quoted spreads are larger at the time small orders arrive at the NYSE than they are when small orders arrive at competing market centers. The reverse is true for larger orders.

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[5] While the effective spread is the difference between execution prices and value of a security at the time of order placement, the realized spread is the difference between the execution price and a subsequent value of the security. The difference in the spread measures is due to price movements subsequent to order placement and reflects order difficulty due either to characteristics of the order or market conditions around the time of order execution. For this reason, realized spreads can be considered a measure of the gross

More importantly, those market centers with effective spreads smaller than the NYSE are those that execute orders when prevailing spreads are narrower. These results suggest that order difficulty and order timing are important dimensions along which competing market centers may chose to specialize.

The potential benefits of catering to more profitable market segments have been well documented.[6] In particular, Easley, Keifer and O'Hara (1996) note that market centers capturing less-informed trading volume (cream skimming) can earn substantial profits.[7] Given the potential benefit from selective competition in equity markets and given our earlier results suggesting that specialization occurs, we provide evidence on the following question: when is selective competition actually more effective? We find that differences in effective spreads between the NYSE and some competing market centers vary systematically in the cross-section of stocks. For example, the quintile of firms for which the difference in effective spreads between Madoff Securities and the NYSE is greatest in July 2001, remains the quintile with the greatest difference each month over the remaining year. We find that factors related leading to successful competition vary across market centers. However, competition generally appears to be more effective for lower volume stocks, stocks with higher volatility, stocks where the NYSE provides less

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revenue to providers of liquidity and are indicative of the expected cost of execution when order characteristics are controlled for.

[6] Much of the literature extends Rothschild and Stiglitz (1976), who note that insurance companies can benefit from offering contracts that attract lower risk individuals. Similar arguments have subsequently been made for capital market institutions, including banks making loans, venture funds selecting investments, and brokerage firms purchasing order flow.

[7] Chordia and Subrahmanyam (1995) and Battalio, Greene and Jennings (1997), describe the arrangements and agreements that route order flow to various market centers. Related evidence and discussions can be found in Battalio, Greene and Jennings (1997), Bloomfield and O'Hara (1998), Battalio and Holden (2001). Consistent with the effects of order routing, Blume and Goldstein (1997) find that orders do not always flow to the market center posting the best prices and Bessembinder (2002a) links higher trading costs on the regional exchanges to orders being routed to regional exchanges when their quotes are not competitive.

price improvement, and for smaller orders.[8] These results are consistent with predictions based on models of strategic competition in which successful entrants focus on smaller markets.[9] Thus, while our earlier results suggest that market centers may compete by selectively executing orders based on order and stock characteristics, these results suggest that whatever strategies are chosen are not equally effective for all order flow and for all stocks.

Finally, we note that there are significant differences in the time to execution among market centers and that execution results vary less on the NYSE than on most other market centers. Speed and predictability are factors that might attract specific trading clienteles and provide a basis for market center differentiation.[10]

Taken together, our results suggest that competition for execution services in NYSE-listed stocks is often characterized by specialization and selective competition. In fact, selective execution may be necessary for effectively competing against the NYSE: the two market centers that have reliably lower effective spreads than the NYSE are the two that execute orders in the fewest stocks while the two market centers with reliably higher effective spreads are those that execute orders in almost all the stocks in our sample.[11] In addition, the low spreads on broker-dealer Madoff seem to reflect their

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Easley, Keifer and O'Hara (1996) and Bessembinder and Kaufman (1997) provide empirical evidence of cream skimming while Battalio (1997) does not.

[8] The phrase "competing more effectively" is used here as a comment on the comparative ability of one market center over another, not the absolute ability. For example, effective spreads on the Chicago Stock Exchange are typically higher than effective spreads on the NYSE. However, for those stocks with lower volume, the difference between the market centers is lower. In this case we would say the Chicago Stock Exchange competes more effectively in lower volume stocks.

[9] Porter (1985) outlines a number of strategies which were subsequently refined by Wright (1987).

[10] Boehmer (2002) and Hasbrouck and Saar (2002) discuss issues related to time to execution.

[11] We do not draw any conclusions in this study about the desirability of selective execution. Less informed traders will certainly prefer to pool only with other uniformed traders (Admati and Pfleiderer (1988)). On the other hand, fragmentation of order flow may degrade price discovery (see Mendelson (1987), Madhavan (1995), Stoll (2001), and Huang (2002), among others).

ability to select less informed order flow. If we view competition among market centers as a search for market segments in which a market can compete more effectively, our results suggest that competition focuses on subsets of order flow and stocks and that competition varies predictably in effectiveness across stocks.

Our results are related to a number of studies comparing market centers. In contrast to Lee (1993) and Blume and Goldstein (1997), we find that the regional exchanges are not uniformly more costly than the NYSE. Our results also contrast those of Conrad, Johnson and Wahal (2002), who find that institutional orders routed to ECNs are less costly to execute than orders routed to the listing market. On the other hand, our results are consistent with Barclay, Hendershott and McCormick (2002) and Huang (2002) who find that ECN spreads are higher than those at the listing exchange and that ECNs appear to attract more informed order flow. We augment this line of inquiry by updating earlier results and adding results on broker-dealers, which are organized quite differently than exchanges or ECNs. The importance of examining broker-dealers is apparent in the case of Madoff, whose performance differs most remarkably from that of the NYSE.

Studies of cream skimming have focused on whether reliable differences in the informativeness of order flow exist and whether these are related to agreements for the purchase of order flow. We extend this literature by adding results on when these agreements augment the competitiveness of market centers. For example, Easley, Keifer and O'Hara (1996) point out that cream skimming can be especially profitable when market centers match the spreads on markets where trading volume is more informed. Consistent with this argument, we find that competition is more effective when there is

less price improvement by the NYSE. Furthermore, given the limited ability of the NYSE trading floor to treat small orders differently than large orders, it is not surprising that competition is more effective for smaller orders.

The paper is organized as follows. Section 2 discusses the market centers we examine and describes the Dash5 statistics. Section 3 discusses our data. Section 4 examines issues related to the calculation and appropriate use of Dash5 statistics and uses the statistics to evaluate execution quality. Section 5 provides a brief conclusion.

2. Market Centers and Dash5 Data Details

The landscape for execution services has been evolving at a rapid pace. A decade ago the central question was whether the regional exchanges were sufficient competition for the NYSE. Now there is a proliferation of trading venues and these venues employ vastly differing technologies and execution procedures. Even these details are changing at every moment. Below we discuss the market centers examined in this study. Following that we discuss the Dash5 data that are required by the SEC and used in this study.

2. 1 Market Centers

The NYSE is a centralized continuous auction market. All orders are routed to a single specialist who is responsible for maintaining an orderly market in the traded stock. The NYSE has both a physical trading floor and an electronic order routing system

(SuperDot).[12] The orders routed through SuperDot are the only NYSE orders subject to Dash5 reporting. The NYSE is the listing exchange for the stocks we examine. It is also, as we shall see, the dominant venue for order routing. For this reason, and to simplify the analysis, we will evaluate results at other market centers relative to the NYSE.

We examine six market centers in addition to the NYSE. Below is a description of each over the time period studied, classified by type of market center:

Broker-Dealers	
Knight	Knight Trading Group - A broker-dealer that provides execution services.
Madoff	Madoff Investment Securities - A discount brokerage that provides automated execution services.
ECN	
Archipelago	Archipelago ECN - An electronic communications network that has become the equity trading group for the Pacific Stock Exchange.
Exchanges	
Boston	Boston Stock Exchange – A floor based continuous auction market, originally specializing in New England based companies
Cincinnati	Cincinnati Stock Exchange - An electronic auction market
Chicago	Chicago Stock Exchange – An electronic auction market.

Each of the above market centers is unique in their organization and design.[13] Knight, and Madoff are broker-dealers who provide execution services specifically for their clients. We note that one contribution of this study to examine broker-dealers and that these market centers have the greatest degree of flexibility in limiting the services they provide. Archipelago is an ECN and is essentially an order driven electronic market that also accepts all orders in the stocks for it makes markets. The NYSE, Boston,

[12] There can be many providers of liquidity for NYSE listed stocks other than the specialist. In fact, the floor of the exchange encourages competition for liquidity provision. When we refer to the specialist in their general role as a liquidity provider, such statement applies all providers of liquidity.
[13] Since we do not attempt to link any specific features to differences in performance among market centers, we do not attempt to fully characterize the protocols at each market center.

Chicago and Cincinnati are stock exchanges and accept all orders in the stocks for which they make markets. Of these four, the NYSE and Boston retain traditional trading floors.

2. 2 The Details of SEC Rule 11Ac 1-5

This section discusses the critical features of the Dash5 data. From the many measures of execution quality that are available, Dash5 rules require the following:

- **Effective Spread.** The effective spread is equal to twice the difference between the price at which an order is executed and the midpoint of a benchmark quote, multiplied by -1 for sell orders.[14] The benchmark mid-quote should represent the price that would be obtained in the absence of transaction costs. Since the Dash5 statistics are based on orders (not transactions), the benchmark quote for Dash5 data is the prevailing quote at the time the order arrives at the market center.[15]
- **Realized Spread.** The realized spread is twice the difference between the execution price and the mid-quote five minutes after execution, multiplied by –1 for sell orders. The mid-quote represents the subsequent value of the security and the realized spread, therefore, reflects the gross trading profit to a liquidity provider from taking the other side of an order. The difference between effective and realized spreads reflects is the permanent price impact of the order. This impact reflects the difficulty of the order – essentially the expected information content of the order.[16]
- **Time to Execution.** The time from order arrival until it is executed.[17]
- **Price Improvement.** Price improvement measures the execution price relative to the quoted bid price for sell orders or the quoted ask for buy orders. In other words, it describes the execution relative to the execution price that would have occurred against the quoted spread at the time of order arrival.[18]

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[14] The combination of the best bid and the best offer across all quotes is referred to as the National Best Bid and Offer (NBBO). This is the quote that is used to benchmark Dash5 data. Unless otherwise indicated, any reference to quoted spreads means the NBBO.

[15] The order arrival benchmark is more appropriate than an execution time benchmark because the effective spread will reflect any price movements that occur while an order is being executed. These price movements reflect real costs to traders and may differ across market centers. As mentioned previously, one advantage of Dash5 data is the accuracy of the results.

[16] Glosten and Milgrom (1985) and Easley and O'Hara (1987) describe how the information implicit in order flow is reflected in the spread. For a comprehensive discussion of these issues, the reader is referred to O'Hara (1997) and Harris (2002).

[17] The arrival time is technically the time that an order is captured by the market center's automated handling system. Also, as with many statistics, the execution time is the share-weighted time of execution if the order is executed in parts.

[18] This assumes, implicitly, that there is enough depth at quote to execute the order in full. The depth available at quote may vary across market centers. Bacidore, Battalio and Jennings (2001) examine issues related to depth and the ability of markets to provide more depth than what is displayed in quotes.

From the price improvement and effective spread data, one can infer the prevailing quote at the time of order arrival. We examine quoted spreads since they reflect market and order flow conditions at the time of order arrival.[19] Note that effective spreads not only reflect prevailing market conditions, but also reflect characteristics of the order, such as order size, that cannot be reflected in the quoted spread (see Blume and Goldstein (1992)).

Both effective and quoted spreads will change depending on market conditions at the time of an order. It should be stressed that spreads are not a perfect measure of trading costs for many reasons. For example, many trading decisions are worked over time and spreads cannot capture the change in prices brought about by earlier executions as part of the same decision. Furthermore, spreads ignore commissions and any other market center fees or costs. However, spreads are simple to measure, readily available, and are usually reasonable indicators of actual trading costs for very small orders.

Any comparison of spreads needs to condition, to whatever extent possible, on characteristics of the order and market conditions at the time of order placement. While the Dash5 data do not explicitly condition on prevailing market conditions, they do partition orders along two dimensions.

- **Order Size.** Orders are classified into four order size groups. These are indicated below along with the designation we use to describe the order size category. Note that Dash5 does not require statistics for order sizes below 100 shares (odd lots) or for 10,000 shares or more.

[19] The reason market participants use price improvement as a measure of market quality is precisely because the quoted spread may control for some characteristics of market conditions. For example, two market centers may provide the same price improvement, but one market center executes orders under more difficult conditions. The *realized* effective spreads would differ across the market centers, but price improvement would be the same. In this case, price improvement is a better reflection of the *expected* result of routing an order to a given market center.

Designation	*Order Size*
Very Small	100-499 shares
Small	500-1,999 shares
Medium	2,000-4,999 shares
Large	5,000-9,999 shares

- **Order Type.** Order conditions can dramatically affect how an order is executed and also reflect differing degrees of urgency on the part of customers. The more patient a customer, the lower the expected cost of execution (and the longer it will likely take to execute). The following categories require Dash5 statistics. The definitions below apply to buy orders; sell orders are defined analogously. The applicable quote is the quote prevailing at the time of order arrival.

Buy Order Type	*Description*
Market	No limiting price
Marketable Limit	Limit price equals or exceeds the ask
Inside the Quote Limit	Limit price is between the bid and ask
At the Quote Limit	Limit is equal to the bid
Near the Quote Limit	Limit is within 10 pennies below the bid

We refer to a combination of stock, order size, and order type as a category. Dash5 rules require statistics for any category for which an order was placed. We focus our analysis on market and marketable limit orders since the data required more other order types is limited (it does not included effective spreads, for example). Dash5 statistics are share-weighted within each category.[20] Dash5 statistics for each category also report the number of orders placed (the number of orders received by the market center), the number of shares placed (the number of total shares in the orders received by the market center), and the number of shares executed.

[20] Note that categories are determined by order size, while the share weighting is based on executed shares. For example, an order for 3,000 shares might execute in two equal parts, each part with a different execution result. The results would be weighted by the shares executed and reported in the medium size order category even though it executed in two parts each of which would be classified as a small order. The purpose is to represent the expected execution results for the *order* submitted. It is also the order characteristics, not execution sizes, which reflect the difficulty of executing an order.

Dash5 guidelines contain many provisions designed to prevent the statistics from being distorted by unusual orders. For example, orders that require special handling or have unusual restrictions are excluded. Stopped orders are excluded. Also, the portion of an order executed on a day different from when the order was placed is excluded. Orders that meet all the requirements for inclusion in the statistics are referred to as "eligible orders".

In general, requiring results by category attempts to create groups of orders that are essentially identical. These orders can then be compared to evaluate execution quality. However, these categories cannot capture all the characteristics that might affect order execution. For example, institutional orders are more likely to be motivated by price relevant information than orders originating from individuals. A market center whose order flow predictably originates from a given type of trader will have Dash5 statistics that disproportionately reflect the results that type of trader might expect. Furthermore, the categories do not acknowledge any differences in prevailing market conditions at the time an order is executed. For example, it is possible that orders are routed to a given market center when conditions for execution are most favorable and this market center's reported Dash5 statistics will be disproportionately determined by easy executions.[21]

3. Sample and Summary Statistics

This study examines 350 NYSE listed stocks over a one-year period spanning July 2001 through June 2002. We constructed the sample as follows. We began with all

stocks available in the NYSE Trade and Quote (TAQ) data set for June 2001 that were matched to the Center for Research in Security Prices (CRSP) data set. We used the CRSP data to exclude from our study all securities that were not regular U.S. common equities (we excluded ADRs, funds, REITS, and unit rights offerings). Finally, we restricted our sample to those stocks with a June 2001 trade-weighted average price of at least $5.00.

From this initial sample, the 100 stocks with the largest share volume in June 2001 were selected (the most active stocks). The remaining firms were sorted into quintiles based, again, on June 2001 volume and 50 stocks were selected at random from each of the quintiles, providing an additional 250 stocks (less active stocks). In general, the results differed little between these two samples, so we present results for the combined sample of 350 firms except for sample summary statistics, which are presented in Table 1. [22]

The first section of Table 1 describes the characteristics of the companies whose stocks are studied. Not surprisingly, the most active stocks are substantially larger firms and firms with a slightly higher share prices than the less active firms. The second section of Table 1 describes the trading activity in the stocks, including the activity for orders subject to Dash5 statistics that are directed to the market centers we study. By construction, the most active stocks have substantially higher consolidated trading volume than the less active stocks – more than ten times more volume, on average.

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[21] Additional categories would, of course, yield better comparisons. However, the realized spread does provide implicit controls on market conditions and order difficulty.

[22] We should note that for the less active stocks there are more cases where results are statistically insignificant. In many cases, this is simply a result of having few observations. For example, there are very few observations for marketable limit orders in the less active sample.

As for Dash 5 activity, for the most active stocks, there are 2,511 market orders and 1,392 marketable limit orders placed, on average, each day. For the less active stocks, trading activity is much lower: there are 227 market orders and 226 marketable limit orders placed each day.[23] Shares placed, as expected, follow the pattern in orders placed.

Table 1 also presents summary statistics for shares executed. As expected, virtually all the market orders are executed. Interestingly, about 20% of marketable limit orders are unexecuted. This reflects the fact that the determination of status of a limit order as "marketable" is made at the time of order arrival. Between that time and the time the order is made available for execution (e.g. the time at which it is displayed to the specialist), prices may have moved away from the limit order.

Table 2 presents summary statistics of trading activity for the market centers in this study. As might be expected, the NYSE is the most active market center with shares executed equal to over four times the total of all the other market centers combined and almost twenty times the next most active market center. More important, the NYSE has observations in more categories and stocks than other market centers. For example, the NYSE has observations in about 32 thousand categories while the next highest value is about 26 thousand for Knight. The lowest is Cincinatti with observations in just under 10 thousand categories. Similarly, while the NYSE has at least one observation in every

[23] For non-marketable limit orders, there are 4,363 and 1,078 orders placed each day, on average, for the two samples, respectively. To evaluate the activity subject to Dash 5 reporting to total trading activity, note that the order and share values are one-sided (buys and sells counted separately) whereas aggregate trading volume is two-sided (reflects both a buy and a sell).

stock in the sample, some market centers have observations in far fewer stocks. For example, there are results for Madoff in only 184 of the 350 stocks in our sample.[24]

These results show that there are clear differences in the samples for each of the market centers and we explore this further below. At this point, we note that the stocks in which competing market centers tend to have observations are the lower volume stocks, and that competing market centers tend to have smaller average order sizes.[25] For example, the total consolidated volume in the 184 stocks for which Madoff has observations is about 10% lower than for the NYSE, while the average order size for Madoff order flow is about 20% lower than order flow at the NYSE.

4. Differences Between the NYSE and Competing Market Centers

4. 1 Method of Comparison

Since market centers do not execute orders in every category and/or every firm, one has to be careful using Dash5 data to evaluate differences between any two market centers. In this section we highlight the magnitude of potential errors from inappropriate comparisons, illustrate the approach taken for the remainder of our analyses, and provide summary statistics for the magnitude of effective spreads (measured in various ways) at each market center. We consider three ways to make comparisons:

- *Simple Average*: Average the statistic across all categories and stocks and compare means.

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[24] The maximum number of categories is 84,000 (350 stocks × 12 months × 4 order sizes × 5 order types). Thus, there are many cases of categories without observations. Even the NYSE has observations in only about 78% of the categories. These null observations, as might be expected, are predominantly in the larger order sizes and less active stocks.

[25] As expected, but not reported, the competing market centers therefore have more observations in the smaller order size categories.

- *Paired Differences by Stock*: Create a volume weighted average for each stock, and then calculate the difference between pairs of market centers for a given stock when there is an observation for both market centers. The distribution of paired differences can used to compare market centers.
- *Paired Differences by Category*: Calculate the difference between pairs of market centers for every category where there is an observation for both market centers. The distribution of the paired differences can be used to compare market centers.

The first approach is most simple, but will be distorted the most by variations in executed volume among market centers. For example, a market center that trades only high volume stocks will have a much lower average spread than a market center that also trades low volume stocks – regardless of actual execution quality. The next approach accounts for volume differences by volume weighting statistics and accounts for stock selection by comparing only stocks with observations. The final approach most closely adheres to the concept of holding all things constant – it looks at category-level differences (which includes the stock). Note that the last two approaches do not provide a simple single statistic that characterizes a given market center, though they do summarize the difference across any two market centers.

Table 3 presents our analysis of effective spread differences for market orders using the approaches outlined above. For each method, there is a column labeled "NYSE vs Other" which shows the inferred difference between the NYSE and the given market center using each approach. Consider the simple average across all category observations. The effective spread on the NYSE averages 11.50 pennies across all categories/stocks. The effective spread for other market centers varies from a low of 3.81 pennies (Madoff) to a high of 8.40 pennies (Knight). The NYSE effective spread is

higher in every case and almost three times higher in some cases. All these differences are significant.[26]

Next we calculate volume weighted average spreads by stock and look at the distribution of stock-pair differences. This approach yields conclusions that are remarkably different from the simple average comparison. In particular, the only reliable differences are for three of the market centers and the magnitude of the differences is substantially attenuated relative to the simple average. Note (again) the variation across market centers in the number of observations – while many market centers have observations for virtually all stocks, others do not.

The final approach makes the most complete use of the data. This approach calculates the difference across market centers for every category/stock. Here we find that differences across some market centers just about vanish. For example, the difference between the NYSE and Cincinnati is about 2 hundredths of a penny. In this study, NYSE effective spreads are higher than two market centers and lower than three. Once again, it is important to note the variation across market center comparisons in the number of observations (categories) - from a low of 5,111 (Cincinnati) to a high of 13,752 (Knight). Given that we are examining market orders only, the maximum number of categories is 16,800 (350 stocks × 4 order sizes × 12 months).

In general, these results identify statistically reliable differences among market centers, though the magnitude is substantially smaller than what is suggested by looking

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[26] One could also generate a share-weighted average. The results are not reported. However, we find that effective spreads are much lower: the NYSE effective spread drops precipitously to 4.57 pennies and the effective spread for other market centers ranges from a low of 1.99 pennies (Madoff again) to a high of 6.00 pennies (Instinet). More importantly, the inferences are changed. The NYSE has a lower trading cost

at simple averages. This illustrates the importance of looking at category level differences when drawing inferences.[27] In our subsequent analysis we will maintain this approach when documenting and exploring differences between market centers.

4. 2 Comparisons of Market Centers

We compare each market center with the NYSE in a series of tables that look at various Dash5 measures of execution quality. We begin by looking at spreads and spread components (realized spread and information component). We then examine price improvement, prevailing quoted spreads, and time to execution.

Spreads and Spread Components

The Dash5 statistics require reporting of effective spread and realized spread only for market and marketable limit orders. As discussed above, the effective spread is the cost to the trader, the realized spread is the gross revenue to liquidity providers (not necessarily the market maker or specialist). The difference is created by price movements subsequent to order arrival and reflects order difficulty, possibly due to the information implicit in the order (for this reason it is referred to as the information component of the spread).

Table 4 presents the analysis of spread components for very small orders. This table illustrates the analysis performed for each category. To conserve space, we will thereafter present summary tables covering all categories. We chose to present the details

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than two of the other market centers and, in general, there is less difference across market centers. This shows that, on average, there is more aggregate volume in the smaller order sizes.

[27] Bessembinder (2003) makes a similar point by showing that there is a self-selection problem in comparing market centers. Bessembinder controls for the self-selection implicit in the information content differences across market centers and points out that remaining differences are much smaller than suggested by averages.

for the smallest orders since these are most likely to be retail orders and much of the discussion and concern about order routing relates to the treatment of retail orders. Furthermore, the results for very small orders are typical of many of the results we find.

In table 4, for each market center and order type, we provide the median of the indicated measure and, more importantly, we provide the median paired difference between the NYSE and the given market center. We use medians rather than means for our comparisons since outliers affect both the mean and variation in our results.[28] For simplicity, we present the median for the NYSE but not the median NYSE value for each market center comparison.[29] We include the number of pairs (in this case equal to the number of stocks since we are examining a single order size and type) used in the comparison so the reader can be aware of the extent to which the sample might differ in each comparison. For each paired test we not only list the median paired difference, but we indicate the proportion of pairs for which the NYSE value is greater (the proportion of strictly positive differences).

Associated with each paired difference is a test of statistical significance. These are based on non-parametric Wilcoxon signed rank tests. The first two columns indicate the number of pairs and the median number of shares executed in that category on the indicated market center. Consistent with our earlier results, the NYSE is far more active than any other market center and is active in at least as many of the stocks as any other

[28] The results for means, when significant, differ from the conclusions of medians in only one case. More often, but not frequently, the results for means are statistically insignificant while median tests are significant.

[29] The NYSE median for each market center comparison could be calculated only for those pairs of observations (stock and order category) for which the NYSE and the market center both have valid observations. In most cases, however, the NYSE median for each comparison is very close to the NYSE overall median.

market center. Note that the NYSE has far more marketable limit orders than all the other market centers.[30]

The next set of columns describes the comparison of effective spreads. For market orders, the NYSE effective spread is reliably larger than Madoff and Boston (though quite small in magnitude for Boston), and reliably smaller than two of the other market centers. For marketable limit orders, the NYSE has reliably lower effective spreads than *every* market center. The most notable differences in terms of magnitude are the results for Achipelago (over a penny worse than the NYSE) and Madoff (over a half-penny better than the NYSE). In terms of percentages of category pairs, Madoff has a lower effective spread 91% of the time, whereas Knight and Archipelago are lower only 22% and 24% of the time.

The third set of columns describes the realized spread. Here the evidence is fairly uniform. The NYSE is found to have reliably lower realized spreads than every other market center for market orders and lower than all but one market center (for which there is no reliable difference) for marketable limit orders. The final set of columns describes the information component of the effective spreads. These results shed light on important differences in the nature of order flow across market centers. In the case of market orders, the NYSE has more difficult order flow than every other market center except, once again, Archipelago. Marketable limit orders are similar.

In general, the information component results are the mirror image of the realized spread results. In other words, the NYSE has effective spreads generally in line with

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[30] The raises an interesting question about order types. The choice between a regular market order and a marketable limit order may depend on the type of market center to which one is routing an order. It should

other market centers, but the difficulty of the execution for NYSE order flow dramatically reduces liquidity provider gross trading revenues. In this context, it is worth noting that the magnitude of the realized spread differences and information component differences (both generally over a penny), are often much greater than for the effective spread differences.

Table 5 summarizes the paired differences for market and marketable limit orders for all order sizes. For simplicity, we omit the other information from Table 4. There are few distinctive patterns in these results that we have not observed in the very small orders. In general, however, we observe fewer significant differences in the large order size category. While not reported, it should be noted that the number of observations decreases dramatically as we move to larger order sizes, consistent with the evidence in Table 2 that competing market centers provide services predominantly to smaller orders. Taken together, the Table 5 results suggest that Madoff and, to a much lesser extent, Boston, have consistently lower effective spreads while Archipelago has higher effective spreads.

These results identify a number of important characteristics of competition among markets. First of all, consistent with differences in size and type of orders, other characteristics of order flow are not the same across market centers. The substantial variation in the information component makes this point clear. Second, competition has minimized realized spreads on the NYSE. One interpretation of the realized spread is the equilibrium cost of executing an order conditioning on all order characteristics, including

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be clear from the evidence we will present, that combining market and marketable order results will improve the relative performance of the NYSE.

informativeness and difficulty. Under this interpretation, then the NYSE is clearly the lowest cost market center.

Price Improvement, Quoted Spreads, and Time to Execution

There are two other dimensions of order execution that are emphasized in the Dash5 statistics. These are price improvement and time to execution. We begin with an analysis of price improvement. Recall that price improvement measures the price relative to the quoted spread. If the quoted spread represents a public benchmark price (like a suggested manufacturer's price), then price improvement is the discount from that benchmark. An interesting characteristic of the data, mentioned earlier, is that the combination of effective spread and price improvement (specifically the effective spread plus twice the improvement) must be equal to the prevailing quoted spread at the time of order arrival.

Examining quoted spreads provides information on the market conditions associated with the time of order arrival. In particular, variations in quoted spreads will reflect variations in liquidity due to market conditions or recent order flow. Thus, we can compare the average quoted spread at order arrival time across market centers to obtain another view (in addition to the information component) of the difficulty of executing order flow that is directed to various market centers.

The analysis of price improvement and quoted spreads is shown in Tables 6 in a format similar to Table 5. Specifically, the table lists the median difference between the NYSE and the indicated market center. For market orders, the NYSE provides more price improvement than most market centers (no worse than any market center) for very small orders. As order size increases, competing market centers tend to provide better

improvement to the point where, for large orders, all market centers provide better price improvement. As with most of the measures, for marketable limit orders, there is evidence the NYSE does better than every market center.

The quoted spread analysis provides interesting results, particularly in light of the price improvement results. For very smaller orders, prevailing spreads are typically narrower, on average, at the time of NYSE order arrivals than at the time of competing market center order arrivals. As with price improvement, this reverses as we mover to larger order sizes. For the large orders, spreads are substantially smaller on the NYSE at the time of NYSE arrivals than at the competing market centers at the time of competing market center arrivals. In fact, the magnitude of the improvement typically parallels the magnitude of the quote difference. Thus, though there is clearly selection in the timing of orders being routed to various market centers, price improvements offset most of the differences.

Most notably, the two market centers that typically provide lower effective spreads than the NYSE (Madoff and Boston) are the two market centers that capture order flow at times when prevailing quoted spreads are smaller. This suggests these market centers are executing orders when market conditions are more favorable. Put another way, the results suggest market centers are filling small niches in the provision of execution services and these niches may not be just customer niches, but market condition niches.

Our analysis of the time to execution is presented in Table 7. The time to execution results vary by market center comparison, as might be expected given the differences in market center design (see Boehmer (2003)). We find that only the broker-

dealers Madoff and Knight provide execution times that are reliably shorter than the NYSE for market orders. This is surprising in the case of Archipelago, Chicago and Cincinati since these are all electronic order driven markets. For marketable limit orders, the variation in execution time differences is much greater. In this case, Archipelago and Madoff are both faster. In general, the NYSE is faster than all the other exchanges, Archipelago is slower on market orders but faster for marketable limit orders, and the broker-dealer Madoff is reliably fast in every case.

Dispersion in Execution Quality Within Market Centers

In addition to the level of differences, it is important to assess the predictability of the difference. In other words, one might save a half a penny, on average, at a given market center, but that saving might be highly variable with extreme costs and extreme savings. We address this question by looking at the dispersion of reported results within each category. We concentrate on effective spreads, but results for other measures of execution quality provide similar inferences.

Table 9 presents measures of dispersion of the effective spread observations for each market center in a format similar to Tables 5 and 6. This analysis excludes all categories with less than 10 orders so that outliers do not drive the results. The table presents the standard deviation, minimum, and maximum effective spreads for four order sizes and for market and marketable limit orders. These statistics are measures of the dispersion across stocks and months. Consider, for example, very small market orders at the NYSE. The standard deviation in effective spreads is about 0.7 pennies. In every case but market orders at Madoff, the variation (whether in standard deviation or range) is lower at the NYSE. In some cases the variation is much greater – notably at

Archipelago. This basic result holds true in for all the order sizes, except that Madoff variation becomes larger than the NYSE for larger order sizes. In general, the results suggest that order execution at the NYSE is more predictable than at other market centers with the exception of Madoff. The order driven ECN Archipelago provides executions with extremely high variability.

These results suggests that predictability of execution costs may be a factor that should be considered when choosing execution venues. It is not a statistic that is generated for each stock. However, the variation across stocks, when market centers trade similar stocks, gives some idea of the predictability of execution. The caveat is that the variation may be generated by variation across stocks, rather than within stocks. However, since the NYSE trades every stock traded on other market centers, and the range will reflect the range across all stocks, we have evidence of greater consistency in NYSE results.

4. 3 Execution Quality in the Cross-Section

In the prior sections, we examined differences in average Dash5 statistics between the NYSE and competing market centers. Our results suggest that in many cases market centers are competing with the NYSE by targeting segments of the market. This process may involve innovation, but it would appear that success is related more to selectivity than to any specific market design innovation. If this is the case, then one might expect the ability to target segments of the market to vary depending on the stock being traded. For example, if Madoff is able to cream skim less informed order flow by purchasing orders, they may be better able to screen orders in this fashion for less active stocks. We

explore this possibility in this section by examining the cross-section of differences in effective spreads.

Persistence of Market Center Differences

We begin by establishing that differences in effective spreads between market centers for a given stock is persistent over time. Specifically, we establish that the cross-sectional variation in differences persists over time.[31] This justifies our later tests that look for association between stock characteristics and the differences in spreads. Since we will be looking at variation across stocks, we normalize all spread differences by the average price of the stock during the month the data were generated. Thus, we perform our analysis on basis point differences.

To assess whether some market centers are consistently more or less costly venues for some stocks than others, we proceed as follows.[32] We take the effective spreads calculated for the first month of our sample (July 2001) and divide the stocks into quintiles based on the *difference* in effective spreads for each market center and the NYSE.[33] The first quintile is where the NYSE provides the highest effective spread relative to a given market center, and the fifth is where the NYSE provides the lowest effective spread relative to the given market center. We then calculate the difference for each of the subsequent 11 months based on the quintiles formed from the last month. We test whether the difference in the two extreme quintiles is significant using the time series over the 11 months.

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[31] Incidentally, we also validate that our earlier conclusions about spread differences are not an artifact of the sample by showing that the results hold monthly.

[32] Note that we are looking for patterns across stocks in this analysis. Another possibility is that at certain *times* one market center might provide better execution services than another. However, we do not have the information needed to consider this possibility.

Before we consider the statistical tests, Figure 1 presents the graph of all five quintiles for Madoff. For the stocks in quintile 5, the difference between NYSE effective spreads and Madoff were the most positive in July – and the difference for these stocks remains the most positive in every other month. For the stocks in quintile 1, the difference was least positive in July (actually negative). These stocks remained the least positive in every month. In fact, the ordering remains remarkably consistent over time. This illustrates the concept we are examining in this section – whether there are patterns across stocks in how much better or worse execution is for one market center relative to another. After documenting the differences, we explore factors that might give rise to these differences.

Table 9 presents the tests of persistence for effective spreads for the whole sample, by market center and order size. There were no reliable cross-sectional differences for Archipelago, possibly a function of the large variation in Archipelago results noted in Table 8, and it has been omitted from this table. This may also reflect the possibility that this ECN does not screen order flow and, therefore, no variation would be expected. More likely, ECNs compete by attracting orders under certain market conditions, rather than from certain stocks.

The differences in Table 9, like our earlier table, are all relative to the NYSE. Consider the results for the smallest orders in Knight. The NYSE effective spreads are, on average, lower in each quintile since the difference is negative. More importantly, the difference for the quintile of stocks with the most positive difference is reliably more positive than for the quintile with the least positive difference. Put another way, for one

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[33] One could assign quintiles based on any month and results would be similar.

set of stocks, the differences between Knight and the NYSE are reliably larger in magnitude than for another set of stocks. A few results are notable. First, there are there a number of cases where patterns are persistent. For example, regardless of order size, there are persistent differences between NYSE and Madoff. For Knight, Boston, and Chicago, at least half the order sizes exhibit persistent differences.

These results suggest that there are patterns in the cross-section of execution quality differences. It would seem that not all market centers provide comparable execution quality for all stocks.

Regression Analysis

In this section, we examine execution differences to see if they are related to characteristics of the stocks being traded. Specifically, we explore the relation between differences in effective spreads and firm characteristics in the cross section of firms. This analysis focuses on differences across stocks, so we use averages over our study period to prevent distortions related to pooling cross-sections and time-series.[34]

The dependent variable is the difference in relative effective spread calculated from the Dash5 data. The independent variables we examine are the following for each firm:

Quoted Spread	The trade-weighted average quoted relative spread, expressed in percent.
Price Improvement	The difference between relative quoted spreads and relative effective spreads, expressed as a percentage.

[34] Results are similar if we use monthly observations.

Turnover	The volume in the stock divided by the number of shares outstanding.
Log(Market Value)	The average of the daily log of market value.
Volatility	The standard deviation of the daily trade-weighted prices.
PIN	The probability of informed trading calculated using the methodology of Easley, Kiefer, O'Hara and Paperman (1996).
Size Indicators	Indicator variables for small, medium, and large orders (we omit an indicator for the very small orders).

These variables capture a number of possible determinants of effective competition. The quoted spread captures the opportunity for market centers to improve on spreads. Price improvement reflects the degree to which quotes are indicative of executions results – greater price improvement suggests that competition may be less driven by quote behavior and more related to preferencing and other arrangements (see Easley, Keifer, and O'Hara (1996) and Battalio (1997), Chordia and Subrahmanyam (1995) and Battalio, Greene and Jennings (1997), and Bloomfield and O'Hara (1998), among others). This may provide greater opportunities for competition. Size and volume (turnover) reflect trading information and trading interest, respectively. Larger firms have more analysts and more investors who follow or are aware of a firm. Larger firms also have greater trading activity (see Arbel and Strebel (1982), Merton (1987) Admati and Pfleiderer (1988), and Irvine (2003), among others). All else equal, market centers may choose to compete in the most active securities or, instead, target their efforts to the less visible and less active securities. Volatility imposes a cost on market making by increasing the risks associated with holding inventory (Demsetz (1968), Benston and

Hagerman (1974), and Stoll (1978)). This can affect competition market centers differed on their ability to absorb inventory risk.

Letting *c* represent a market center other than the NYSE, *n* represent the NYSE, *s* represent a stock, and *o* represent an order size, we first calculate the difference between the Dash5 NYSE effective spread and the Dash5 effective spread for a given market center *c* (in basis points relative to the monthly average price), order size category *o*, and stock *s*, after having calculated shares weighted averages over the twelve months.[35] This can be written as follows:

$$Difference_{c,o,s} = Effective\ Spread_{n,o,s} - Effective\ Spread_{c,o,s}$$

To prevent or results from being driven by a few outliers, we include only those observations with at least 10 orders placed during a given month.

We then run the following regression for selected market centers:

$$Difference_{c,o,s} = \alpha + \beta_1 Quoted\ Spread_s + \beta_2 Price\ Improvement_s + \beta_3 Turnover_s + \beta_4 Log(MarketValue)_s + \beta_5 Volatility_s + \beta_6 PIN_s + IND(Small)_o + IND(Medium)_o + IND(L\arg e)_o + \varepsilon$$

The results are given in Table 10. We provide the number of observations for each regression as well as adjusted *R*-squares. Given that we are looking at averages across the year, the most observations we would expect to see would be 350 stocks × 4 order sizes = 1,400 observations. Adjusted R squares vary from 0.036 (Knight) to 0.345 (Madoff). Perhaps not surprisingly, Madoff is the market center that provides the greatest improvement upon NYSE quoted spreads and statistically significant in the most number of cases. Furthermore, it is interesting to note that Madoff and Boston are the

two market centers that improve upon the NYSE and have the two highest adjusted R squares – suggesting it is easier to explain better performance than worse.

Looking at the coefficients of the regressions we note the following. Market centers compete more effectively for lower turnover stocks (true in every case), for the smallest orders (true in every case), and where volatility is greater (true for two market centers). Results also show that Madoff does better for smaller stocks and Boston does better when quotes are wide. Results for price improvement are mixed, for Knight, Boston and Chicago, market centers compete less effectively when price improvement is high whereas Madoff does better when price improvement is high. In the case of Madoff this is consistent with greater opportunities to purchase order flow, while the result for the other three centers is hard to explain. It may be that the two exchanges do better when quotes are set more competitively and, one might expect, that aggressive quoting draws order flow. Note that the price improvement conditions on the quote size, so it is not inconsistent that Boston does better when quotes are higher and also when quotes are set competitively to draw order flow.

Of course, one should be cautious when interpreting these results. For example, our results would not imply that each market center should execute the smallest orders they can attract. What we are observing is that, given the characteristics of a market center and the orders that market center has chosen to attract, the market centers provide more favorable executions for smaller orders. Also, we emphasize again that this does not imply that the executions are favorable in absolute terms relative to the NYSE, but

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[35] We conducted similar analyses for the components of the spread. In general, the results for realized spreads were similar to those for effective spreads and there were few reliable relations for the information component of the spread.

that they are *more* favorable in certain circumstances. Put another way, effective spreads for Knight are typically larger than for the NYSE, but not so much larger for the smaller orders. The central point of this analysis is that the effectiveness of the strategies employed by various market centers (which are not limited to structural innovation) differs across stocks, suggesting that business plans of competing market centers often include selective competition.

5. Conclusions

We examine competition among market centers using order level execution statistics. Our evidence suggests that competition may be best described as market centers developing strategies that allow them to profitably provide execution services to select segments of the market. Our evidence includes the fact that order flows are not similar across market centers, that effective spread differences exist but are related to characteristics of order flow, and that the ability to compete with the NYSE depends on characteristics not related to market center design. Thus, the market for NYSE-listed execution services is one where competition is not perfect and effective spreads are not driven to identical levels.

Interestingly, the differences in effective spreads for market orders are much smaller in magnitude than the differences in realized spread. This result can be interpreted in two ways. First, since the realized spread conditions on the price changes induced by an order, it implicitly controls for order difficulty. Under this interpretation, differences in effective spreads are not an appropriate basis for comparing execution results. Another interpretation (the two are not mutually exclusive) is that competition may limit potential differences in effective spreads, and that this competition, combined

with more difficult order flow being routed to the NYSE, attenuates the profitability of liquidity provision on the NYSE.

Because of differences in order flow characteristics, and the lack of consistency in results (they depend on the order type, size, and stocks examined), drawing broad conclusions about the success of various market architectures is difficult. In fact, we find no evidence that any particular market architecture is uniformly more successful at providing execution services. For example, one broker-dealer, Madoff, does quite well, whereas another, Knight, does poorly. More importantly, competition among market centers appears to lead to specialization and fragmentation, not a convergence to a single, dominant, lowest cost architecture.

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Table 1: Sample Summary Statistics

This table contains summary statistics for the sample firms. The sample is composed of the 100 NYSE-listed stocks with the highest June 2002 executed share volume (most active stocks) and a random sample of 250 additional stocks (less active stocks). The less active sample is composed of five sets of 50 stocks chosen at random from June 2002 executed share volume quintiles. Stocks are all NYSE listed common equity (REITs, ADRs and funds excluded) with a share-weighted average June, 2001 price of at least $5.00. The Dash-5 activity levels are average of the daily totals across the 9 market centers studied.

	Most Active Stocks	**Less Active Stocks**
Firm Characteristics		
Price (Trade-Weighted June 2001)	41.82	30.69
Shares Outstanding (thousands, End-of-June 2001)	1,438,407	100,581
Market Value (thousands, End-of-June 2001)	64,447,948	3,457,944
Average Daily Trading Activity		
Daily Consolidated Volume (June 2001)	5,313,613	419,435
NYSE Market Share (June 2001)	85.67%	87.41%
Daily Dash 5 Orders Placed		
Market Orders	2,511	227
Marketable Limits	1,392	226
Daily Dash 5 Shares Placed		
Market Orders	1,710,188	109,909
Marketable Limits	1,352,277	151,617
Daily Shares Executed		
Market Orders	1,694,070	108,340
Marketable Limits	1,068,635	119,568

Table 2: Activity by Market Center

This table presents the Dash5 trading activity for each market center. Shares executed and consolidated volume in executed stocks are the totals over the 12-month sample period from July, 2001 through June, 2002. The number of categories is the number of categories with non-zero orders placed for execution. Stocks traded is the number of stocks with at least one observation over the 12-month sample period.

	Shares Executed (millions)	Number of Categories With Observations	Number of Stocks With Observations	Volume in Stocks Traded (millions)	Average Trade Size
NYSE	65,434	32,608	350	8,914	2,360
Broker-Dealers					
Knight	3,402	26,870	350	8,914	1,873
Madoff	2,143	14,427	184	8,182	1,944
ECN					
Archipelago	820	18,201	348	8,689	1,705
Stock Exchanges					
Boston	2,990	17,527	284	8,778	2,003
Chicago	2,566	25,646	343	8,907	1,896
Cincinnati	1,439	9,996	191	7,672	2,056

Table 3: Overview of Differences in Effective Spreads for Market Orders

This table presents and overview of differences in effective spreads (in pennies) for market orders using alternative methods. Each method includes a column "NYSE vs Other", which describes the inferred difference between the NYSE and the given market center based on the approach chosen. Statistical tests in the first case are *t*-tests or the difference in means between the NYSE and competing market center. In the second two cases, we use a *t*-test to determine whether the distribution of differences is different from zero.

	Simple Average		**Paired Stocks Differences**			**Paired Category Differences**		
	Spread	**NYSE vs Other**	**Num**	**NYSE Spread**	**NYSE vs Other**	**Num**	**NYSE Spread**	**NYSE vs Other**
NYSE	11.50							
Knight	8.40	+3.10***	350	8.66	-0.04	13,752	8.18	-0.19***
Madoff	3.81	+7.70***	184	5.19	+1.99***	7,497	5.38	+1.58***
Archipelago	6.17	+5.33***	343	8.53	-0.22	7,094	5.32	-0.86***
Boston	5.85	+5.65***	283	6.72	+0.47	9,401	5.99	+0.14*
Chicago	8.14	+3.35***	343	8.41	-0.21**	12,778	7.52	-0.62***
Cincinnati	4.81	+6.70***	149	4.68	+0.25**	5,111	4.79	-0.02

*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 4: Spread Component Comparisons for Very Small Orders

This table presents our analysis of the difference in execution quality based on spread components. Values are medians across pairs and tests of significance are Wilcoxon signed rank tests on the distribution of paired differences. Also presented are the percentage of NYSE stocks whose observations greater than the given market center.

	Activity		Effective Spread			Realized Spread			Information Component		
	Num.	1,000 Shares Per Stock	Avg.	Paired Difference	NYSE Greater	Avg.	Paired Difference	NYSE Greater	Avg.	Paired Difference	NYSE Greater
Market Orders											
NYSE	350	6,241	3.62			0.41			3.00		
Knight	350	276	4.16	-0.45***	22%	2.81	-2.17***	4%	1.15	+1.60***	94%
Madoff	185	1,658	2.11	+0.55***	91%	1.62	-1.31***	3%	0.41	+1.94***	98%
Archipelago	337	7	4.51	-1.07***	24%	1.47	-0.91***	31%	2.75	-0.18	47%
Boston	277	193	3.13	+0.01*	50%	2.29	-1.97***	5%	0.44	+2.02***	93%
Chicago	345	317	3.58	-0.11***	40%	2.33	-1.98***	4%	0.88	+1.81***	94%
Cincinnati	144	966	2.60	-0.01	49%	2.01	-1.87***	6%	0.39	+1.79***	93%
Marketable Limit Orders											
NYSE	350	5,694	2.37			-0.35			2.63		
Knight	350	29	3.87	-1.33***	2%	2.24	-2.42***	9%	1.21	1.06***	79%
Madoff	173	61	1.80	-0.17***	31%	1.36	-1.69***	9%	0.35	1.47***	90%
Archipelago	347	47	3.64	-1.23***	14%	-0.31	0.07	51%	4.06	-1.37***	26%
Boston	251	26	2.39	-0.54***	20%	1.93	-2.25***	15%	0.20	1.55***	83%
Chicago	335	49	4.01	-1.54***	6%	1.08	-1.32***	31%	2.70	-0.32***	44%
Cincinnati	185	33	1.82	-0.22***	31%	1.55	-2.03***	18%	0.00	1.82***	84%

*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 5: Paired Differences for Spread Components

This table summarizes the differences in spread components for market orders between the NYSE and other market centers, for each size category, and for each sample. Values are medians across pairs and tests of significance are Wilcoxon signed rank tests on the distribution of paired differences.

	Very Small			Small			Medium			Large		
	Effective	Realized	Info	Effective	Realized	Info	Effective	Realized	Info	Effective	Realized	Info
Market Orders												
NYSE Median	3.62	0.41	3.00	5.89	0.63	4.97	9.99	1.84	7.47	16.07	3.51	11.22
Median Difference Between Market Center and NYSE												
Knight	-0.45***	-2.17***	+1.60***	+0.13*	-1.58***	+1.62***	-0.25	-1.31***	+1.25***	-0.07	-1.33***	+1.11**
Madoff	+0.55***	-1.31***	+1.94***	+1.32***	-0.73***	+1.97***	+1.88***	+0.38***	+1.41***	+1.80***	+0.59***	+1.28***
Archipelago	-1.07***	-0.91***	-0.18	-0.43*	-0.03	-0.39	-0.14	-0.06	-0.14	+0.66**	-0.28	+0.55
Boston	+0.01*	-1.97***	+2.02***	+0.21***	-1.92***	+2.09***	+0.16***	-1.13***	+1.47***	+0.92***	-0.70**	+1.38***
Chicago	-0.11***	-1.98***	+1.81***	-0.36***	-2.44***	+1.83***	-0.79***	-2.17***	+1.36***	-0.32	-1.38***	+1.13***
Cincinnati	-0.01	-1.87***	+1.79***	+0.04	-1.58***	+1.66***	-0.34***	-1.20***	+1.10***	-0.02	-1.60***	+1.63***
Marketable Limit Orders												
NYSE Median	2.37	-0.35	2.63	2.80	-0.60	3.68	3.63	0.12	3.33	4.71	0.23	4.45
Median Difference Between Market Center and NYSE												
Knight	-1.33***	-2.42***	+1.06***	-0.73***	-1.38***	+0.61***	-0.50***	-0.89***	+0.35***	-0.39***	-1.29***	+0.85***
Madoff	-0.17***	-1.69***	+1.47***	-0.20***	-0.92***	+0.83***	-0.22***	-0.41	+0.08	-0.32***	-0.86***	+0.36
Archipelago	-1.23***	+0.07	-1.37***	-1.06***	+0.17	-1.05***	-0.47***	+0.72***	-1.07***	+0.32***	+0.98***	-0.75***
Boston	-0.54***	-2.25***	+1.55***	-0.59***	-2.26*	+1.57***	-0.73***	-1.80***	+1.08***	-0.60***	-2.14***	+1.17***
Chicago	-1.54***	-1.32***	-0.32***	-1.47***	-1.04***	-0.48***	-1.55***	-0.53***	-0.92***	-0.95***	-0.14	-0.73***
Cincinnati	-0.22***	-2.03***	+1.82***	-0.35***	-2.05***	+1.54***	-0.61***	-1.46***	+1.27***	-0.66***	-0.99	+0.46

*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 6: Improvement and Quote

This table summarizes the differences in price improvement and prevailing quoted spreads between the NYSE and other market centers, for each size category, and for each sample. Values are medians across pairs and tests of significance are Wilcoxon signed rank tests on the distribution of paired differences.

	Very Small		Small		Medium		Large	
	Improvement	Quote	Improvement	Quote	Improvement	Quote	Improvement	Quote
Market Orders								
NYSE Median	0.74	5.24	-0.20	5.52	-2.06	5.45	-3.18	5.87
Median Difference Between Market Center and NYSE								
Knight	+0.28***	+0.12***	-0.01	+0.07***	-0.37***	-0.37***	-1.20***	-1.09***
Madoff	-0.09	+0.22***	-0.46***	+0.22***	-0.71***	+0.33***	-1.35***	-0.28***
Archipelago	+0.80***	+0.06**	+0.06	-0.08	-0.76***	-0.45***	-1.63***	-1.25***
Boston	+0.28***	+0.18***	-0.10***	+0.08***	-0.45***	-0.07***	-0.96***	-0.54***
Cincinnati	+0.01	-0.04	-0.01*	-0.03	-0.02	-0.20***	-0.72***	-0.99***
Chicago	+0.20***	+0.12***	+0.17***	+0.02	-0.04***	-0.53***	-1.68***	-2.29***
Marketable Limit Orders								
NYSE Median	0.50	3.41	0.28	3.50	0.04	3.95	-0.20	4.08
Median Difference Between Market Center and NYSE								
Knight	+0.42***	-0.34***	+0.19***	-0.25***	+0.12***	-0.03*	-0.01	-0.06**
Madoff	+0.30***	+0.33***	+0.18***	+0.08**	+0.18***	+0.10**	+0.10***	+0.02
Archipelago	+0.46***	-0.42***	+0.22***	-0.53***	+0.06***	+0.00	-0.15***	+0.25***
Chicago	+0.58***	-0.44***	+0.44***	-0.41***	+0.21***	-0.53***	-0.00	-0.52***
Boston	+0.38***	+0.01	+0.23	-0.19***	+0.19***	-0.09***	+0.07	-0.11***
Cincinnati	+0.35***	+0.18***	+0.28***	-0.10	+0.30***	-0.08	+0.18***	-0.19***

*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 7: Time to Execution

This table presents our analysis of the time to execution partitioned by sample and order type. The column labeled "paired vs. NYSE" presents the difference for each pair of stocks for which reports were available. The number of stock pairs is given. Values are medians across pairs and tests of significance are Wilcoxon signed rank tests on the distribution of paired differences.

	Execution Time			**Distribution of Execution Time (%)**			
	Median Time	Num Pairs	Median Paired Difference	By 10 Seconds	11 to 30 Seconds	31 to 60 Seconds	Over 60 Seconds
Market Orders							
NYSE	23.45			32	44	16	9
Knight	21.07	350	+01.83***	54	18	15	12
Madoff	4.13	184	+16.09***	89	4	4	2
Archipelago	29.07	343	-06.06***	19	48	21	12
Boston	30.20	283	-08.26***	44	19	18	19
Chicago	39.46	343	-16.67***	41	17	14	29
Cincinnati	21.90	148	-01.03***	55	19	17	9
Marketable Limit Orders							
NYSE	48.47			41	36	12	11
Knight	74.16	349	-20.44***	44	18	17	21
Madoff	19.84	173	+13.16***	77	7	9	7
Archipelago	24.82	348	+16.37***	54	31	8	7
Boston	68.35	274	-27.55***	30	18	23	28
Cincinnati	42.36	191	-14.01***	50	19	17	14
Chicago	66.86	336	-12.16***	28	40	12	20

*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 8: Variation in Effective Spreads

This table presents measures of dispersion for effective spreads. The standard deviation and range of values is given for the NYSE. We then present the difference between the given market center and the NYSE. These results exclude any category with less than 10 orders and for which there were observations for less than 10 months. The statistics are calculated across stocks and months. Values are medians and tests of significance are Wilcoxon signed rank tests on the distribution of paired differences

	Very Small		**Small**		**Medium**		**Large**	
	Std. Deviation	Range	Std. Deviation	Range	Std. Deviation	Range	Std. Deviation	Range
Market Orders								
NYSE Median	0.69	2.17	1.11	3.65	1.90	6.13	2.05	6.61
Median Difference Between Market Center and NYSE								
Knight	-0.40***	-1.31***	-0.35***	-1.04***	-0.69***	-2.57***	-0.49***	-1.74***
Madoff	0.06***	0.16***	0.12***	0.38***	-0.02***	-0.13***	-0.26	-1.08
Archipelago	-1.19***	-4.26***	-1.06***	-3.57***	-1.34***	-4.10***	-2.62***	-11.02***
Boston	-0.21***	-0.82***	-0.18***	-0.68***	-0.50***	-1.51***	-0.40***	-1.15***
Chicago	-0.27***	-0.96***	-0.53***	-1.84***	-0.75***	-2.88***	-0.75***	-2.36***
Cincinnati	-0.08***	-0.23***	-0.23***	-0.85***	-0.73***	-2.39***	-0.92***	-2.44***
Marketable Limit Orders								
NYSE Median	0.37	1.19	0.49	1.57	0.73	2.35	0.90	3.10
Median Difference Between Market Center and NYSE								
Knight	-0.42***	-1.41***	-0.43***	-1.54***	-0.40***	-1.36***	-0.42***	-1.22***
Madoff	-0.26***	-0.94***	-0.28***	-0.98***	-0.24	-0.58	-0.42*	-1.17
Archipelago	-0.91***	-3.17***	-0.88***	-3.01***	-0.73***	-2.42***	-	-
Boston	-0.39***	-1.40***	-0.46***	-1.60***	-0.54***	-1.78***	-0.30***	-0.87***
Cincinnati	-0.50***	-1.82***	-0.96***	-3.18***	-0.43***	-1.50***	-0.49***	-1.61***
Chicago	-0.82***	-2.74***	-1.10***	-3.50***	-1.27***	-4.04***	-1.20**	-4.25***

*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 9: Persistence of Spread Performance Relative to the NYSE

This Table presents tests of whether differences in effective spreads between the NYSE and other market centers for subsets of stocks are persistent. Stocks were placed in quintiles based on their July, 2001 differences in effective spreads between the NYSE and the indicated market center (NYSE – market center). This table shows the median difference for the remaining 11 months for the fifth and first quintiles and a Wilcoxon test comparing the difference between the fifth and first quintiles.

	Very Small	**Small**	**Medium**	**Large**
Knight				
Quintile 5 (largest)	-7.95	-1.25	-2.17	-6.94
Quintile 1 (smallest)	-0.68	1.42	0.64	-6.07
Difference	-7.27***	-2.67***	-2.80**	-0.87
Madoff				
Quintile 5 (largest)	0.72	2.27	3.89	4.92
Quintile 1 (smallest)	3.94	9.04	8.37	8.99
Difference	-3.22***	-6.77***	-4.48***	-4.07
Boston				
Quintile 5 (largest)	-2.44	-1.45	-2.45	0.14
Quintile 1 (smallest)	0.89	1.84	-1.05	2.52
Difference	-3.33***	-3.28***	-1.40	-2.38
Chicago				
Quintile 5 (largest)	-4.48	-4.27	-12.29	-11.15
Quintile 1 (smallest)	0.01	-0.80	-2.90	-5.33
Difference	-4.49***	-3.47**	-9.39***	-5.82*
Cincinnati				
Quintile 5 (largest)	-0.37	0.17	-1.31	2.02
Quintile 1 (smallest)	1.48	0.48	-1.47	-1.73
Difference	-1.85**	-0.31	0.17	3.76

*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 10: Regression Analysis

Regression of differences in effective spread on stock characteristics. The dependent variable is the difference between the NYSE effective spread and the effective spread for the indicated market center/order size. The sample in each regression is all monthly observations with both NYSE and market center effective spreads. The explanatory variables are characteristics of stock trading activity during June, 2001 (out of sample). They include the NYSE quoted spread, total executed volume, turnover (volume divided by shares outstanding, and volatility (the standard deviation of June, 2001 daily trade-weighted transaction prices). Standard errors are reported in parentheses and the sample size is given for each regression. We report the adjusted *R*-squared from the OLS regression.

	Knight	**Madoff**	**Boston**	**Chicago**	**Cincinnati**
Intercept	-7.845***	33.605***	-11.670***	-8.480***	10.255***
	(6.834)	(4.575)	(6.053)	(10.418)	(6.535)
Quoted Spread	0.046	0.065	0.207***	0.131	0.046
	(0.057)	(0.080)	(0.064)	(0.092)	(0.086)
Price Improvement	-0.075***	0.058**	-0.104***	-0.144***	0.008
	(0.025)	(0.024)	(0.022)	(0.036)	(0.021)
Turnover	-0.613***	-1.172***	-2.415***	-3.085***	-2.647***
	(0.705)	(0.518)	(0.718)	(1.087)	(0.750)
Log (Market Value)	0.395	-1.927***	0.358	0.551	-0.505
	(0.303)	(0.228)	(0.271)	(0.460)	(0.322)
Volatility (%)	-1.098	1.057**	1.696***	-0.235	0.864
	(0.722)	(0.425)	(0.649)	(1.060)	(0.542)
PIN	0.117	-0.090	0.198*	0.151	-0.019
	(0.129)	(0.069)	(0.112)	(0.203)	(0.084)
Indicator Small	3.429***	2.943***	1.890***	-0.596	
	(1.000)	(0.559)	(0.714)	(1.547)	
Indicator Large	1.108	6.510***		-2.581	
	(1.162)	(0.571)		(1.764)	
Indicator Very Large				-9.577***	
				(2.371)	
Observations	885	502	453	913	141
Adjusted R-Square	0.036	0.345	0.077	0.055	0.050

*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

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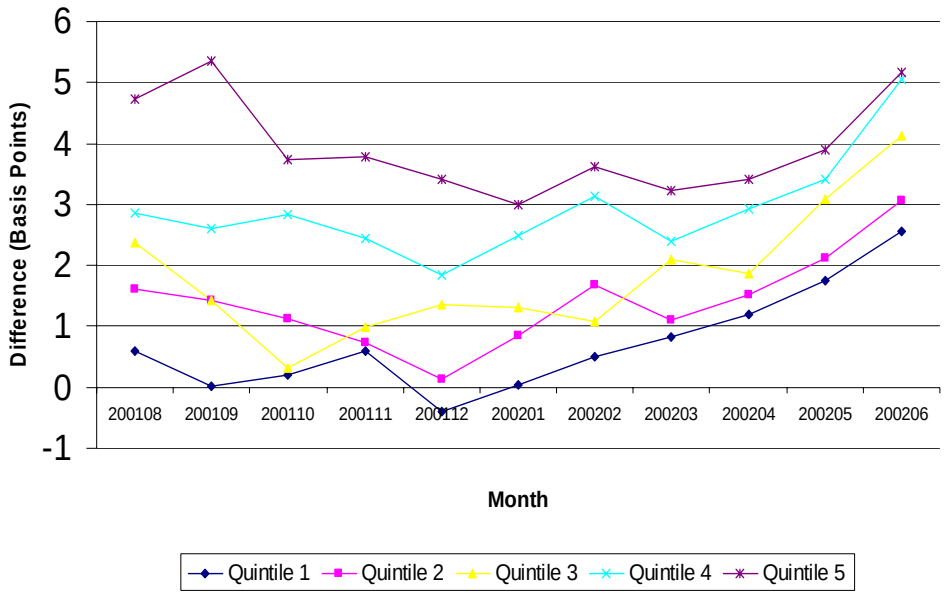

Figure 1: NYSE Effective Spreads Differences

These figures graph the difference in effective spreads (in basis points) between the NYSE and tMadoff for quintiles based on that difference in June 1001, over twelve months (July 2001 to June 2002). Stocks were assigned to quintiles based on their June 2002 differences.