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Quantifying market order execution quality at the New York stock exchange☆

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Abstract

This paper provides a detailed description of how to quantify best execution on market orders. We address two important issues: how to measure best execution on market orders and the need for cross-market standardization to facilitate comparisons. We propose six measures for quantifying best execution on eligible system market orders and present NYSE estimates for August 1999. These measures include percent executions inside the quote, percent executions outside the quote, percent discount relative to the quoted price, percent executions receiving depth improvement, percent single price executions, and turnaround time. We also show that best-execution statistics are sensitive to the calculation methodology. For valid cross-market comparisons, therefore, we must standardize methodologies and control for other factors that may affect best execution performance.

JEL classificaion: G10

Keywords: Best execution; Execution quality; Price improvement; Depth improvement

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1. Introduction

In trading equity, investors typically choose a broker and then the broker chooses the market venue to which the order is routed for execution.[1] For NYSE stocks a broker may route an order to the NYSE, route the order to one of the five regional exchanges, "internalize" the order, route the order to another third-market dealer, route the order to an alternative trading system and may even route the order overseas.[2] In choosing among these alternatives, brokers must fulfil their fiduciary responsibilities to their investor clients: they must route orders to the market that delivers best execution.

The Securities and Exchange Commission has been encouraging market centers to provide brokers, directly or indirectly, with the statistics necessary to make informed decisions on which venue to direct orders so as to fulfil their best execution obligations. In November 2000, the U.S. SEC issued Rule 11Ac1-5 requiring market centers to broadly distribute execution quality statistics in electronic format. This paper provides a detailed description of some statistics that should be useful in quantifying best execution for market orders. We address two important issues: how to measure best execution on market orders and the need for cross-market standardization to facilitate comparisons.

Several academic studies examine the issue of best execution. Bessembinder and Kaufman (1997), Blume and Goldstein (1992) and Lee (1993) assess whether significant differences in trading costs exist between the NYSE and the regional exchanges/third market in the trading of NYSE-listed securities. These studies find that trading costs on the NYSE are lower than in other markets. These studies use trade and quote data as opposed to order level data. Peterson and Sirri (1999) show that the use of trade and quote data results in biased estimates of trading costs. To obtain more accurate estimates Petersen and Fialkowski (1994), and Lightfoot et al. (1999) use order level data to assess best execution.[3] These studies also find that trading costs are lowest on the NYSE. Ross et al. (1996) also use order data to estimate price improvement on the NYSE.

All these studies focus on quoted and effective spreads as a measure of best execution. Harris (1995) and Macey and O'Hara (1997) argue that there are additional dimensions of execution quality that also need to be incorporated. Macey and O'Hara also provide a useful discussion of the legal aspects of the brokers' best execution obligations and the difficulties of quantifying best execution. Currently, there is no legal definition of best execution. Macey and O'Hara argue that given the

[1] Investors may access some market venues directly and may request their broker to direct their orders to a particular market venue. This two-step process is also changing in another way: the proliferation of direct-access systems allows investors to route their orders directly to an execution venue (e.g. Instinet).

[2] Prior to May 2000, NYSE members were subject to certain restrictions in NYSE Rule 390 stocks. At the end of October 1999, 23 percent of NYSE issues accounting for 46 percent of the volume were subject to Rule 390.

[3] Almost all studies of execution quality assess the costs incurred by market order traders. Battalio et al. (2002), Harris and Hasbrouck (1996), and Lightfoot et al. (1999) investigate the execution quality of limit order traders as well.

diversity across market participants, a single definition will likely be over-restrictive to some, and under-restrictive to others. Conceptually, the most important obstacle is that best execution should be defined relative to investor intentions and expectations, which are hard to observe and quantify. A "patient" investor, for example, may want to wait to get a better price while an "impatient" investor may want immediate execution and may be willing to forego the possibility of a better price. So should the broker send all orders to the faster market? In this paper we sidestep this fundamental problem and propose six measures for quantifying best execution on eligible system market orders:

(a) Percent executions inside the quote. At the NYSE in August 1999, 35.5 percent of eligible execution reports executed inside the quoted price.[4]
(b) Percent executions outside the quote. 6.9 percent of eligible execution reports executed outside the quoted price. The main reason for executions outside the quoted price is multiple orders hitting the quote at the same time.
(c) Percent discount/premium relative to the quote. The average NYSE percent quoted spread on eligible execution reports was 35.5 basis points and the average effective spread 22.1 basis points. On a $50 stock, investors save on average 7 cents per round-trip share relative to the quoted price.
(d) Percent executions receiving depth improvement (an order exceeding the quoted size executes inside or at the quoted price). Of the eligible orders in our sample exceeding the quoted size, 61.6 percent executed either inside or at the quoted price receiving depth improvement.
(e) Percent single price executions. 99 percent of eligible system market orders received single price executions and 98 percent received single report (print) executions.
(f) Exposure-to-execution time. Excluding guaranteed (stopped) orders, the average time from order exposure to execution was 16.5 seconds. Including guaranteed orders the average time from exposure to execution was 22.5 seconds.

In the paper we highlight the sensitivity of best-execution statistics to the calculation methodology. On the same order flow, for example, effective spreads can range from 22.1 to 79.5 basis points and the frequency of executions outside the quote can range from 1.9 to 7.0 percent depending on the averaging method. Another important factor is order size. The effective spread is 17.7 basis points on 100-share orders and 53.5 basis points on block-size orders, and 40.4 percent of 100-share orders receive executions inside the quote compared with 25.6 percent for block-size orders. For valid cross-market comparisons, therefore, we must standardize methodologies and control for other factors that may affect best execution performance. Without these common standards, cross-market comparisons are meaningless.

The remainder of this paper is organized as follows. Section 2 develops the best execution measures we will be using. Section 3 describes the sample and data, and

[4]Order size less than or equal to the reference NBBO size. The same for (b), (c), (e) and (f).

Section 4 presents best execution statistics for eligible market orders. We conclude in Section 5 with a discussion of our findings.

2. Measures of best execution

In this section, we discuss best execution statistics for "regular" market orders ("I want to buy 500 shares at the quoted price") that reach the NYSE specialist post through the NYSE's electronic order transmission system, SuperDot. Typically order routing is done in two steps: (a) the investor routes the order to her broker, and (b) the broker routes the order to the execution venue. The investor chooses a broker, and a broker chooses the execution venue. We focus on the second step: providing information to brokers to assess the quality of executions they receive when they route their orders to the NYSE.

Suppose an investor wants to buy 500 shares of XYZ at the market. The NYSE quote is \$50 bid for 5,000 shares, 10,000 shares offered at \$50.20; the Other Exchange quote is \$50 bid for 1,000 shares, 1,000 shares offered at \$50.25. By comparing these quotes, the broker should route the order to the NYSE, which has the lowest offer. The presence of the Intermarket Trading System (ITS), however, makes the comparison of quoted spreads (across ITS-participating venues) irrelevant. ITS is an electronic network that links the participating exchanges and the over-the-counter market, and facilitates the execution of orders in eligible securities at the best ITS quote.[5] Typically an order, therefore, will do no worse than the best quoted price across all ITS venues irrespective of where the broker sends the order. In our example, if the broker routes the order to the Other Exchange, then according to ITS rules the Other Exchange, to avoid a "trade-through" complaint, can either match the better NYSE quote and execute locally or route a "commitment to trade" to the NYSE and try to execute the order there. Either way the order will typically execute at \$50.20.

The quoted spread is irrelevant for another reason: market orders frequently execute inside the quote. Suppose the broker routes the 500-share buy market order to the NYSE. The order may then execute not at the quoted offer of \$50.20 but inside the quote at, for example, \$50.15. In this example, the investor receives "price improvement", saving 5 cents per share relative to the quoted offer. This potential saving is not available through ITS: if the broker routes the order to the Other Exchange and the Other Exchange routes the order to the NYSE through ITS, the order is not eligible for price improvement and will execute at \$50.20. Price improvement, therefore, is a relevant best execution attribute: all else equal, brokers should route market orders to the market providing the most price improvement.

Occasionally, orders may execute outside the quote. In our example, suppose the 500-share buy market order reaches the specialist Display Book a split second after a 10,000-share buy market order. The 10,000-share buy order takes the 10,000 shares offered at \$50.20 and the 500-share order executes "up the book" at \$50.25. The

[5] For a discussion of ITS see Hasbrouck et al. (1993).

500-share order now executes outside the quote that prevailed when the order reached the Display Book. The likelihood of executing outside the quote is also a relevant best execution attribute: all else equal, a broker should route orders to the market with the least likelihood of executing outside the quote (or most *net* likelihood of executing inside the quote).

We also quantify best execution by measuring the discount/premium defined as the quoted minus the effective spread. The effective spread on a buy order is twice the trade price minus the midquote; on a sell order it is twice the midquote minus the trade price. In our example, the NYSE midquote is $50.10, the order executes at $50.15, so the effective (roundtrip) spread is 10 cents. The quoted spread is 20 cents, so the discount—the roundtrip cost saving relative to the quoted spread—is 10 cents per share.

The discount/premium measure has two advantages over simply reporting percent executions inside and outside the quote. The first advantage is that the discount/premium nets the impact of executions inside and outside the quote. Executions inside the quote lower the effective spread and increase the discount; executions outside the quote raise the effective spread and lower the discount (or may create a premium). The second advantage of the discount/premium measure is that it puts a value on executions inside and outside the quote. A two-tick price improvement, for example, has a bigger value than a one-tick price improvement and the discount measure captures this.

To facilitate comparison across different-priced stocks and across market venues with a different mix of stocks, we report quoted spreads, effective spreads and discounts as a percent of the midquote in basis points (bp). In our example, the quoted spread is 40 bp, the effective spread is 20 bp, and the discount 20 bp: on a $100-stock, investors save on average 20 cents per *round-trip* share relative to the posted quote.

In evaluating execution quality, it is important to consider the size of the order relative to the quoted depth. Suppose an investor submits a 15,000 share order when the quoted depth is only 10,000 shares. Suppose 12,000 shares execute at the quote and the remaining 3,000 shares "walk-up the book". In our calculations the 3,000 shares will show up as executions outside the quote and raise the effective spread. But should the market venue be penalized when an investor knowingly sends an order exceeding the quote? Comparing the execution price to the posted (inside) quote, does not give the correct best execution metric for orders that exceed the quoted size. Bacidore, Battalio and Jennings (2002) (BBJ) develop a methodology for handling these orders. For market orders exceeding the quoted depth, they propose that the volume-weighted execution price should be compared with the volume-weighted slope of the book including any depth in the book away from the quote. The BBJ methodology takes on even greater importance now that U.S. equity markets have reduced their minimum tick size to one cent.

In this paper we split market orders into (a) orders whose size does not exceed the quoted size, and (b) orders whose size exceeds the quoted size. We examine the two types of orders separately. For orders not exceeding quoted depth, our methodology of benchmarking off the quoted best bid and ask is valid. We use the same

methodology to present preliminary best-execution statistics for orders exceeding the quoted depth. However, the interpretation is different since such large orders may receive "depth improvement", i.e., additional shares at the quoted price (or better) in excess of the number of shares quoted. When an order exceeds the quoted depth, execution inside the quote means depth improvement and price improvement, while execution at the quote means depth improvement but no price improvement. This preliminary approach exaggerates the true number of executions outside the quoted BBJ price.

Another possible best-execution attribute is the time it takes for a market order to execute. Suppose one venue advertises a turnaround time of 6 seconds while another venue advertises a turnaround time of 22 seconds. Should the broker route the orders to the faster market? Why is the speed of execution important? One possible reason is that slower executions increase the likelihood of executing outside the prevailing quote. But this cost of slower execution is already included in the price improvement and effective spread statistics: the market with slower executions will have more executions outside the quote. Another possibility is that a trader may be trying to take advantage of a short-term mispricing in the market. In such a scenario, the trader may not be concerned with the *average* price improvement and disimprovement rates, effective spread, etc. Rather, she may believe that, in these instances, statistics related to speed of execution are most relevant since the probability of missing the price is exceptionally high. Nevertheless, there exist a class of trader who places a premium on fast execution, as evidenced by the existence of online brokers who promise instantaneous executions.

Another execution characteristic is the number of execution reports: orders occasionally execute over multiple execution reports at the same price or at multiple prices. All else equal, brokers prefer single print executions to multiple print executions because it simplifies processing. The percentage of single print executions is another attribute of best execution we will be examining.

Our approach is a "partial equilibrium" approach. Occasionally, for example, when a market order receives price improvement, a counter-side limit order may take longer to execute or not execute at all. To provide the full picture we also need to calculate best execution statistics for limit orders. Also, one component of execution costs is hard to quantify on a per share basis: the trading fees brokers pay to the NYSE specialists and to the Exchange. Member firm payments are capped, so that for at least the bigger firms the marginal fee paid to the Exchange is zero. Furthermore, during our sample, the Exchange did not allow specialists to charge fees on post-opening market orders of less than 2,100 shares (96.1 percent of the eligible system market orders in our sample),[6] and some specialists do not charge trading fees on any market orders. The marginal fee cost to brokers for NYSE-executed system market orders is very small and is hard to quantify; we ignore these costs.

[6] The Exchange has since extended this prohibition to cover *all* system orders that execute within 5 minutes, effectively preventing specialists from charging fees on any system order.

To summarize, we examine the following best-execution attributes of market orders:

(a) Percent executions inside the quote.
(b) Percent executions outside the quote.
(c) Percent quoted spread, percent effective spread, and the discount/premium relative to the posted quote.
(d) Depth improvement.
(e) Exposure-to-execution time.
(f) Single price executions.

3. Description of sample

Orders on the NYSE arrive at the specialist's post either via floor broker (''floor orders'') or via SuperDot (''system orders''). Five percent of executed orders are floor orders: a floor broker walks the order to the specialist. Another 33 percent are system limit orders, 16 percent are system marketable limits and 46 percent are system market orders. In terms of executed *share volume*, floor orders account for 42 percent of executed share volume, system limits 25 percent, system marketable limits 15 percent, and system market orders 18 percent. In this paper we focus on system market orders.

Our sample period consists of the 22 trading days in August 1999. We include all NYSE-listed issues (common, preferred, warrants) except 110 ''unusual'' stocks: 2 stocks priced above $1,000; 20 stocks trading in variations of less than 1/16th; and 88 stocks trading in round lots of less than 100 shares. Our sample consists of 3,665 issues. Our data come from the SIAC-created daily SOD and SODQ files. SOD contains detailed information on the entry and processing of all orders that reach the specialist posts electronically through SuperDot (''system'' orders). Each file has at least one record for every system order for which something was done (e.g. order entry, execution, cancellation, etc.). SODQ contains the NYSE and best off-NYSE quotes at various times for every record of the companion SOD file. All quote data in SODQ are derived from the NYSE's Consolidated Quote (CQ) file.[7]

We begin with all NYSE system market order execution reports and discard all execution reports associated with non-market orders (marketable limit orders, limit orders, etc.). We now have 7.4 million execution reports associated with market orders. We next exclude ''special'' market orders: odd-lot orders, opening orders, market-on-close orders, crossing session orders, and tick sensitive orders. Such orders are handled differently than ''regular'' market orders. Odd-lot orders execute automatically against the specialist inventory at the prevailing quote. Opening orders and market-on-close orders are batched at a single price at the start and end of trading respectively, while crossing session orders are executed after-hours. Tick sensitive orders execute conditional on the previous (non-zero) price change, which

[7] The CQ file is publicly available as part of NYSE's TAQ database.

may result in a delay in execution relative to regular market orders. In addition, we discard any orders which arrive when no valid quote exists (e.g., quoted prices are zero). Finally, "write-in" orders, which require a broker to enter the approximate time of the order, are excluded since the execution time for such order is not reliable. After discarding ineligible market orders (odd lot orders, market-on-close orders, etc.), our final sample represents 30 percent of the orders executed on the NYSE accounting for 11 percent of NYSE volume.

Most of the time an order executes in one execution report, so there is a one-to-one association between orders and execution reports. Occasionally, however, orders may execute over two or more execution reports and an order will be associated with multiple execution reports.[8] Since 95 (97) percent of orders execute with a single report (price), our use of reports as opposed to orders is not critical to much of the analysis, except where noted.

In constructing the NBBO, we identify the lower of the NYSE and off-NYSE offers, and the higher of the NYSE and off-NYSE bids.[9] In case of ties, we choose the quote with the biggest depth. Our final sample consists of 4.8 million eligible execution reports.

We divide our sample of eligible execution reports into two categories:

1. Execution reports associated with sell (buy) orders whose size is less than or equal to the reference NBB(O) size. Of the 4.8 million eligible execution reports in our sample, 4.1 million reports (85 percent), accounting for 68 percent of eligible share volume, are associated with orders of size less than or equal to the reference NBBO size.
2. Execution reports associated with sell (buy) orders whose size is greater than the reference NBB(O) size. Only 713 thousand reports (15 percent) are associated with orders exceeding the reference NBBO size, but they account for 32 percent of the eligible volume.

4. Measures of execution quality

4.1. Execution price

We classify eligible execution reports into three groups: inside the reference NBBO, at the reference NBBO and outside the reference NBBO. For a buy order execution report, for example, we compare the execution price with the reference NBBO offer price. If the execution price is lower than the reference offer price then we classify the report as "execution inside the reference NBBO," if the execution price is above the reference price we classify it as an "execution outside the reference NBBO." For each execution report we also calculate the quoted spread, the effective

[8] An order may be made up of multiple execution reports; a trade is made up of multiple (at least two) orders, and a Tape print (what's available in the TAQ database) may be made up of several trades bunched together.

[9] Our sample includes orders arriving when the NBBO is locked or crossed.

spread, and the time from order exposure to execution. We then average these figures across all execution reports across all stocks in our sample. In this section, we present results for orders that do not exceed the quoted size. We focus on orders that exceed the quoted size in Section 4.2.

Best execution statistics are sensitive to the choice of the benchmark "reference" quote to which we compare the execution price. There are two issues in choosing the reference quote: (i) which quote definition, and (ii) the quote prevailing at which time?

(i) Which quote definition?

The NYSE quote is the quoted bid and offer on the NYSE. The pure NBBO is the best quoted bid and best quoted offer across all ITS-participating markets: the regional exchanges and the over-the-counter NASD market. Should we be using the NYSE quote or the intermarket NBBO?

Suppose the NYSE offer is 10,000 shares at \$50.20 and the NBBO is 500 shares at \$50.15 with Boston having the best offer. An order to buy 200 shares arrives on the NYSE. According to the ITS rules, the NYSE specialist can either match the Boston quote and execute on the NYSE at \$50.15 or send a message to Boston through ITS giving Boston the opportunity to fill the order at its better quote. According to ITS rules, the order will typically execute at \$50.15. In calculating best execution statistics, if we use the NYSE quote as a reference quote, then the NYSE would get price improvement credit while in fact this is the result of having a worse quote than Boston and being forced by ITS to execute at the Boston quote. Using the NBBO as the reference quote is more appropriate.

One complication: not all NBBO quotes are ITS-eligible. For example ITS participants are allowed to "trade through" 100-share quotes.[10] In our example, suppose the NYSE offer is still 10,000 shares at \$50.20 and the NBBO is 100 shares at \$50.15 with Boston having the best offer. An order to buy 200 shares arrives on the NYSE. The NYSE specialist can go ahead and executes the order at \$50.20. Using the NBBO as the reference quote we will classify this execution as outside the quote. The ITS-eligible NBBO excludes 100-share quotes. In addition, because our sample period occurs prior to the repeal of NYSE Rule 390, NASD dealer (third market) quotes in Rule 390 stocks were also not ITS-eligible. Again, use of the pure NBBO may lead to misclassification of executions.

In practice, whether we use the NYSE quote or the NBBO does not make much difference. In our August sample, only 7 percent of system market orders executed when the quote at the relevant side of the market (offer for buy orders, bid for sell orders) was set off-NYSE.

[10] The history of the 100-share ITS trade-through exemption is the following. The regional exchanges autoquote because of the large number of stocks each specialist is responsible for and to comply with the two-sided quotation obligation in the ITS Plan. When ITS participants tried to trade with these autoquotes, they were autoquoted away—resulting in ITS cancellations. During the negotiations on the ITS trade-through rule, the ITS participants agreed to limit autoquoting to 100 shares and that these 100-share autoquotes should be exempt from the trade-through rules.

(ii) The NBBO at which time?

The time of the reference quote is important because the greater the slippage between reference quote time and execution time the more executions will occur outside the reference quote. The smaller the time slippage the less likely the order will execute outside the reference quote.[11] In the limit, if we choose the quote at execution time to be the reference quote then by definition there will be no outside-the-quote executions.

Suppose when the investor decides to submit a buy market order the quoted offer is \$50 and the order eventually executes at \$51. From the point of view of the investor, the \$1 difference is a trading cost. But who is responsible? The investor herself is responsible for the time lag between when she saw the quote and when she attempted to reach her broker. The broker is responsible for the time it took the investor to reach her, and, once reached, the broker is responsible for the time it takes for her to process and submit the order to the Exchange or some other executing venue. The Exchange's responsibility begins from the time the order touches the CMS system and ends when the order executes. The NYSE specialist's responsibility begins from the time the order reaches the Display Book.

Which reference quote to use, therefore, depends on whom we are evaluating. If we are evaluating the broker, we should compare the execution price with the quote prevailing when the investor first attempted to reach the broker (so if the broker is hard to reach on the phone, for example, she gets penalized). If we are evaluating the specialist, we should compare the execution price with the quote prevailing when the order reaches the Display Book. In this paper, we are evaluating the Exchange, however, so we should compare the execution price with the quote prevailing when the order first reaches CMS. Unfortunately the SODQ file does not include the quote at CMS arrival time so we will be using the next available quote: the quote at Display Book arrival.

Table 1 compares best execution statistics using the three available reference quotes: the NBBO at the time the order arrives at the Display Book (otime), the time the order is displayed (dbtime), and the time the order executed (rtime). As expected, executions outside the quote increase when we use the earlier quotes. Given the small time difference between otime and dbtime (0.3 seconds) the otime and dbtime statistics are close. For all size orders, executions outside the quote are 6.9 percent using dbtime and 6.3 percent using dbtime. Using rtime (the execution time) reduces the executions outside the quote to almost zero (the 0.7 percent executions outside the quote in this case reflect our use of the pure NBBO).

Executions inside the quote actually decrease when we use the earlier quotes: (35.5 percent using the otime quote, 35.8 percent using the dbtime quote and 41.5 percent using the rtime quote). The effective spread is 22.1 bp using the otime quote, 22.0 bp using the dbtime quote and 20.8 bp using the rtime quote. Table 1 highlights the importance of standardizing the choice of reference quote when making inter-market

[11] Also, the less the time slippage the less likely the order will execute inside the quote because of the quote moving (''accidental'' price improvement). Ignoring intentional price improvement, the less the time slippage the more likely that the execution price and the reference quote will coincide.

Table 1
Reference quote at different times.[a,b] Effect on best execution statistics (order size less than or equal to reference quote[c] size)

	% inside reference quote			% at reference quote			% outside reference quote			% effective spread (percent basis points)		
	otime	dbtime	rtime[d]	otime	dbtime	rtime[d]	otime	dbtime	rtime[d]	otime	dbtime	rtime[d]
100	40.4	40.6	46.6	51.9	52.3	52.7	7.7	7.1	0.7	17.7	17.5	16.1
101–499	37.3	37.5	42.5	57.1	57.3	56.8	5.6	5.2	0.7	20.3	20.2	19.4
500–2,099	31.6	32.0	38.7	60.1	60.5	60.4	8.3	7.5	0.9	25.4	25.2	23.6
2,100–4,999	26.9	27.2	34.9	65.9	66.4	64.6	7.2	6.4	0.5	30.3	30.1	27.9
5,000–9,999	26.8	27.1	36.9	65.6	66.3	62.7	7.6	6.6	0.4	35.4	35.3	32.4
10,000 plus	25.6	25.5	37.5	67.0	68.1	62.3	7.4	6.4	0.3	53.5	53.7	45.9
All sizes	35.5	35.8	41.5	57.6	57.9	57.7	6.9	6.3	0.7	22.1	22.0	20.8

[a] August 1999, SuperDot market orders, except odd lot orders, orders for which no valid NYSE reference quote was available, opening, MOC, tick-sensitive, and crossing session orders.

[b] All NYSE issues except (a) stocks priced above $1,000, (b) stocks trading in variations less than 1/16th and (c) stocks trading in round lots less than 100 shares.

[c] Reference quote: NBBO at otime for otime columns, NBBO at dbtime for dbtime columns and NYSE quote at rtime for rtime columns.

[d] The rtime quote is the NYSE quote.

comparisons: if, for example, one market is using the execution time quote while another market uses the quote at order arrival time, comparisons will be meaningless. For the remainder of our analysis, we use the quote at Display Book arrival time (otime) as our reference quote.

Table 2 shows that best execution statistics are sensitive to the averaging methodology. We calculate report-weighted averages (first panel): (a) each execution report has equal weight irrespective of share size, and (b) if stock A has twice as many execution reports as stock B, stock A will have twice as much weight in the overall average as stock B. The report-weighted average proportion of executions inside the reference NBBO is 35.5 percent and outside the reference NBBO 6.9 percent.

An alternative methodology is to calculate volume-weighted averages: each execution report is weighted by its share size. Reports with more shares get more weight; stocks with more share volume get more weight. The volume-weighted average proportion of executions inside the reference NBBO is 28.8 percent and 7.0 percent outside the reference NBBO (Table 2, panel 2). Because larger orders are less likely to execute inside the quote, the volume-weighted average price improvement rate is lower than the report-weighted average.

Another alternative is to first calculate averages per stock and then average across stocks giving each stock equal weight in the overall average. Table 2 shows two examples of this average-of-average approach: (a) calculate report-weighted averages per stock and then average across stocks (panel 3), and (b) calculate volume-weighted averages per stock and then average across stocks (panel 4). In both cases, this approach dramatically reduces the proportion of executions outside the quote down to 1.9 percent. The reason for this is that executions outside the quote occur mostly when multiple orders hit the quote at the same time, which mostly happens in heavily traded stocks. These heavily traded stocks get a much bigger weight in the report-weighted and volume-weighted approaches (panels 1 and 2) than in the average-of-averages approaches (panels 3 and 4). Table 2 also shows that the best execution statistics within each order size bucket are much less sensitive to the averaging methodology.

There is no right or wrong averaging methodology. The differences shown in Table 2, however, suggest large cross-sectional variation in best execution statistics. To make meaningful cross-market comparisons we must be careful about how the averages are calculated. Differences in the stocks included and their relative trading activity across markets, for example, can lead to misleading conclusions when comparing best execution averages.

Because of the sensitivity of best execution statistics to order size, we present statistics for six order-size buckets. We classify execution reports into size buckets according to the size of the originating order. Suppose a 4,000-share buy order executes with one 3,000-share and one 1,000-share execution report; we classify both reports in the 2,100–4,999 share bucket. Table 3 shows the distribution of reports and volume by order-size bucket.

To standardize spreads across stocks with different prices, we report quoted and effective spreads as a percent of price. Table 3 summarizes the best execution

Table 2
Best execution statistics for eligible system market orders.[a] Order size less than or equal to reference NBBO size. Different averaging methodologies

Order size (shares)	Percentages			Percent basis points		
	Inside NBBO quoted price	At NBBO quoted price	Outside NBBO quoted price	(1) Quoted spread	(2) Effect spread	(1)–(2) Discount (premium)
Report-weighted[b]						
100	40.4	51.9	7.7	32.0	17.7	14.3
101–499	37.3	57.1	5.6	35.2	20.3	14.9
500–2,099	31.6	60.1	8.3	36.9	25.4	11.5
2,100–4,999	26.9	65.9	7.2	39.9	30.3	9.6
5,000–9,999	26.8	65.6	7.6	46.6	35.4	11.2
10,000 plus	25.6	67.0	7.4	62.0	53.5	8.5
All sizes	35.5	57.6	6.9	35.5	22.1	13.4
Volume-weighted[c]						
100	40.4	51.9	7.7	32.0	17.7	14.3
101–499	36.5	57.9	5.6	35.5	20.9	14.6
500–2,099	29.3	62.8	7.9	38.2	27.3	10.9
2,100–4,999	22.7	70.9	6.4	41.6	33.3	8.3
5,000–9,999	20.5	73.1	6.4	50.0	41.3	8.7
10,000 plus	16.6	77.4	6.1	73.2	68.0	5.2
All sizes	28.8	64.2	7.0	40.5	29.6	10.9
Average of report-weighted stock averages[d]						
100	42.7	55.3	2.0	111.7	60.5	51.2
101–499	39.8	58.6	1.7	119.8	69.2	50.6
500–2,099	28.9	68.8	2.3	106.9	78.0	28.9
2,100–4,999	18.9	78.6	2.6	91.8	76.8	15.0
5,000–9,999	17.1	80.0	2.8	81.5	68.2	13.3
10,000 plus	15.3	80.4	4.2	81.8	75.9	5.9
All sizes	36.8	61.2	1.9	120.6	73.0	47.6
Average of volume-weighted stock averages[e]						
100	42.7	55.3	2.0	111.7	60.5	51.2
101–499	38.9	59.5	1.7	119.6	70.3	49.3
500–2,099	27.0	70.9	2.1	105.9	79.0	26.9
2,100–4,999	17.0	80.8	2.2	91.5	77.5	14.0
5,000–9,999	15.0	82.7	2.4	81.4	69.7	11.7
10,000 plus	12.3	83.8	3.9	80.9	77.3	3.6
All sizes	30.6	67.5	1.9	118.4	79.5	38.9

[a] August 1999, all NYSE issues, except: (a) stocks priced above $1,000, (b) stocks trading in variations less than 1/16th and (c) stocks trading in round lots less than 100 shares.

[b] Each execution report (“trade”) has equal weight irrespective of size; stocks with more execution reports get greater weight.

[c] Each execution report is weighted by its share size; reports with more shares get greater weight; stocks with more reports/volume get greater weight.

[d] Within each stock, each execution report gets equal weight irrespective of size; calculate averages per stock and then average across stocks; all stocks get equal weight.

[e] Within each stock, each execution report is weighted by its share size; calculate volume-weighted averages per stock and then average across stocks; all stocks get equal weight.

Table 3
Best execution statistics for eligible system market orders.[a] Order size less than or equal to reference NBBO size

Order size (shares)	Eligible execution reports	Percentages			Percent basis points		
		Inside NBBO quoted price	At NBBO quoted price	Outside NBBO quoted price	(1) Quoted spread	(2) Effective spread	(1) – (2) Discount (premium)
All spreads							
100	679,558	40.4	51.9	7.7	32.0	17.7	14.3
101–499	1,864,747	37.3	57.1	5.6	35.2	20.3	14.9
500–2,099	1,335,340	31.6	60.1	8.3	36.9	24.5	11.5
2,100–4,999	125,602	26.9	65.9	7.2	39.9	30.3	9.5
5,000–9,999	41,230	26.8	65.6	7.6	46.6	35.4	11.2
10,000 plus	9,322	25.6	67.0	7.4	62.0	53.5	8.5
All sizes	4,055,799	35.5	57.6	6.9	35.5	22.1	13.4
NYSE spread 1/16th							
100	237,657	11.6	82.7	5.6	20.7	18.4	2.3
101–499	727,806	10.0	85.2	4.8	23.6	20.9	2.6
500–2,099	545,505	9.6	83.0	7.3	28.4	26.4	2.0
2,100–4,999	62,829	9.3	83.5	7.2	35.5	33.9	1.6
5,000–9,999	21,321	9.8	83.2	7.0	47.4	44.5	2.9
10,000 plus	5,348	10.6	82.9	6.5	69.8	69.5	0.3
All sizes	1,600,466	10.1	84.0	5.9	25.7	23.4	2.3
NYSE spread greater than 1/16th							
100	441,901	55.8	35.4	8.8	38.1	17.3	20.7
101–499	1,136,941	54.9	39.1	6.1	42.7	20.0	22.7
500–2,099	789,835	46.8	44.2	9.0	42.8	24.8	18.0
2,100–4,999	62,773	44.6	48.3	7.1	44.2	26.8	17.4
5,000–9,999	19,909	45.1	46.6	8.2	45.6	25.6	20.0
10,000 plus	3,974	45.7	45.6	8.7	51.5	32.1	19.5
All sizes	2,455,333	52.1	40.4	7.6	41.9	21.3	20.7

[a] August 1999, all NYSE issues, except: (a) stocks priced above $1,000, (b) stocks trading in variations less than 1/16th and (c) stocks trading in round lots less than 100 shares.

statistics for the 4.1 million market orders in our sample that do not exceed the reference NBBO size. Overall, 35.5 percent of these orders execute within, 57.6 percent at and 6.9 percent outside the reference NBBO price. The average quoted spread is 36 bp and the average effective spread is 22 bp. The average discount therefore is 14 bp: on an average-priced $50 stock investors save 7 cents per round-trip share relative to the NBBO price.

(a) Order size effect. Table 3 also shows that price improvement decreases with order size. Inside the quote executions are 40.4 percent for 100-share orders and the

percentage drops monotonically to 25.6 percent for block-size orders. The percentage of executions outside the quote remains roughly constant irrespective of order size. Both the quoted and the effective spread also rise with order size: the quoted spread increases from 32 bp for 100-share orders to 62 bp for block orders; the effective increases from 18 to 54 bp. The discount actually drops from 14 bp for 100-share orders to 8 bp for block orders.

Part of the increase in the percent quoted and effective spreads reflects the fall in average stock price with order size: the average price of 100-share orders is $55 compared with $39 for block orders. As order size increases, therefore, the percent minimum tick size also increases, raising the quoted and effective spreads. The sensitivity of best execution statistics to order size indicates the importance of standardizing by order size when doing inter-market comparisons.

(b) Spread effect. Panels 2 and 3 in Table 3 show that the rate of price improvement also increases with the size of the quoted spread. Panel 2 focuses on the 1.6 million executions in minimum variation markets. In minimum variation markets there is less room for executing inside the quote: price improvement can occur only when a buy order executes at the bid or a sell order at the ask.[12] Even in minimum variation markets 10 percent of order executions receive price improvement.

The percent quoted spread increases from 21 bp for 100-share orders to 70 bp for block orders. Since by construction the spread is 1/16th for this subset of orders, the increase in the percent quoted spread reflects the price effect: the average price drops from $48 on 100-share orders to $32 on block orders.

For spreads greater than 1/16th (Panel 3), 52 percent of market orders execute inside the spread and 7.6 percent outside the spread. Reflecting the larger quoted spread the average discount is now 20.7 bp: on an average-priced $50 stock investors save 10 cents per round-trip share relative to the NBBO.

(c) By stock trading activity. Another important factor influencing best execution statistics is how actively a stock is traded. For very active stocks, multiple orders hit the quote at the same time relatively frequently, increasing the likelihood of executions outside the reference NBBO. Table 4 shows that this is indeed the case. The percent of executions outside the quote is 10 percent for the 100 most active stocks in our sample but only 0.6 percent for the 1,000 least active stocks. Because we report trade-weighted averages, the more active stocks get a greater weight, increasing the average of executions outside the quote in the full sample.

Table 4 also shows that spreads are dramatically different between active and inactive stocks. The average quoted spread is 20.2 bp on the top 100 stocks and 118.9 bp on the 1,000 least active; the corresponding effective spreads are 12.1 and 75.2 bp. On an inactive stock, the average discount relative to the reference NBBO is 22 cents on a $50 stock; on an active stock the average discount is 4 cents.

(d) Reasons for execution outside the quote. Table 4 suggests an important reason for executions outside the reference NBBO is multiple orders hitting the quote at the same time. In this section we report the results of a detailed analysis of the 11,982

[12] Also NYSE Rule 116.30 imposes restrictions on the ability of the specialist to "stop" stock in minimum variation markets.

Table 4
Best execution statistics for eligible system market orders.[a] Order size less than or equal to reference NBBO size. Active and inactive stocks

Order size (shares)	Eligible execution reports	Percentages			Percent basis points		
		Inside NBBO quoted price	At NBBO quoted price	Outside NBBO quoted price	(1) Quoted spread	(2) Effective spread	(1) – (2) Discount (premium)
All stocks							
100	679,558	40.4	51.9	7.7	32.0	17.7	14.3
101–499	1,864,747	37.3	57.1	5.6	35.2	20.3	14.9
500–2,099	1,335,340	31.6	60.1	8.3	36.9	25.4	11.5
2,100–4,999	125,602	26.9	65.9	7.2	39.9	30.3	9.5
5,000–9,999	41,230	26.8	65.6	7.6	46.6	35.4	11.2
10,000 plus	9,322	25.6	67.0	7.4	62.0	53.5	8.5
All sizes	4,055,799	35.5	57.6	6.9	35.5	22.1	13.4
100 most active stocks[b]							
100	294,521	39.0	49.9	11.2	18.3	10.4	7.9
101–499	690,357	36.7	55.2	8.1	20.7	11.4	9.3
500–2,099	606,580	33.7	54.8	11.5	20.2	13.2	7.0
2,100–4,999	61,020	30.6	59.1	10.3	21.5	14.7	6.7
5,000–9,999	22,034	32.0	57.7	10.3	23.2	15.7	7.5
10,000 plus	5,430	31.2	59.4	9.4	24.1	16.7	7.4
All sizes	1,679,942	35.7	54.3	10.0	20.2	12.1	8.1
1,000 least active stocks[c]							
100	5,169	50.5	48.5	1.1	125.4	62.6	62.8
101–499	19,047	44.5	55.0	0.5	118.1	71.1	47.0
500–2,099	10,506	29.6	69.9	0.6	115.3	86.8	28.5
2,100–4,999	337	13.9	85.5	0.6	170.5	137.6	32.9
5,000–9,999	60	8.3	91.7	0.0	90.9	31.9	59.1
10,000 plus	15	6.7	73.3	20.0	302.5	278.7	23.7
All sizes	35,134	40.5	58.9	0.6	118.9	75.2	43.7

[a] August 1999, all NYSE issues, except: (a) stocks priced above $1,000, (b) stocks trading in variations less than 1/16th and (c) stocks trading in round lots less than 100 shares.

[b] We rank all stocks in our sample by their NYSE volume for September 1999 and choose the 100 most active stocks.

[c] We rank all stocks in our sample by their NYSE volume for September 1999 and choose the 1,000 least active stocks (we exclude 43 stocks that had no trades in September).

execution reports outside the reference NBBO, on February 11, 1999. Table 5 summarizes the various causes we identified and presents estimates of their relative frequency.

1. Multiple orders hitting the quote at the same time. Market orders arrive almost simultaneously and the reference NBBO is exhausted before all are executed. To quantify the importance of this potential explanation, we calculated the time

between the arrival of orders executing outside the NBBO. We find that 43 percent of execution reports outside the NBBO occurred within 2 seconds of the previous order, 62 percent within 5 seconds, 76 percent within 10 seconds and 87 within 20 seconds. Most executions outside the reference NBBO, therefore, occur in fast markets.

2. The reference NBBO is set off the NYSE. In general, 93 percent of all NYSE system market order execution reports occur when the NYSE quote makes the NBBO on the relevant side of the market. For executions outside the quote, the NYSE was at the relevant side of the market only 70 percent of the time (bottom panel in Table 5). This suggests that part of the executions outside the NBBO reflect the working of ITS. We identified three ways in which ITS results in executions outside the quote.

i. Order arrives when off-NYSE quote is not ITS-eligible, either because the off-NYSE quote is for 100 shares or because the inside quote is set by the third market on a Rule 390 stock. We find that eight percent of executions outside the reference NBBO occurred when the best (off-NYSE) quote was 100-shares and three percent of executions outside the NBBO occurred when the third market was posting the best price on a Rule 390 stock.

ii. Order arrives, the NYSE specialist sends an ITS commitment, receives a partial fill and executes the remainder of the order at an inferior price. For our sample period, the ITS file contains 815 ITS commitments originating from the NYSE that were not filled entirely by the receiving market. Assuming all these commitments were filled at the NYSE outside the NBBO gives us an upper bound estimate of 7 percent of executions outside the quote are in this category. To get a more precise estimate, we tried to match commitments to executed orders. Of the 815 returned commitments, only 202 (2 percent of executions outside the NBBO) had matching order records. If we add the constraint that the response occurred prior to execution on the NYSE, this number falls to 91 ITS commitments with matching order records (0.76%). This indicates that between 1% and 2% of unfavorable executions could be associated with unfilled ITS commitments.

iii. Order arrives at the NYSE and executes at the NYSE even though the data show an ITS-eligible better quote off-NYSE (apparent "trade-through" order). Our sample contains in total 3,500 executions outside the reference NBBO when the NBBO on the relevant side of the market was made off-NYSE. Of these, 27 percent occurred while the size equaled 100 shares (accounted in (i) above), 10 percent occurred in Rule 390 stocks when Nasdaq had the best quote (accounted in (ii) above), and 6 percent were associated with partially filled ITS commitments (accounted in (iii) above). This leaves 61 percent of the 3,500 apparent trade-throughs (18 percent of the total number of executions outside the quote) unexplained. These unexplained executions may be the results of: (a) data misalignment, (b) the off-NYSE NBBO was exhausted or updated between the time the order arrived at the NYSE and the time the specialist reacted, and (c) unchallenged "trade-through" orders.

Table 5
Executions outside the quote[a]

		Executions outside the quote[b] by reason (%)
Reasons for the 11,982 executions outside the quote, February 11		
1	Multiple orders hitting the quote at the same time/arrival of system market orders within 5-seconds window	62
2	Reference NBBO set off NYSE/ITS-ineligible because size = 100 shares	8
3	Reference NBBO set by Nasdaq/ITS-ineligible because Rule 390 stock	3
4	Reference NBBO set off NYSE/ITS commitment sent, only partially filled	1–7
5	Reference NBBO set off NYSE/apparent "trade-through" orders	18
6	Floor broker stepping in front of system market orders	N/A
7	Percentage orders share in the available depth	N/A
Who makes the NBBO on the 11,982 executions outside the quote, February 11		
	NYSE was at the relevant side of the NBBO	70
	Regionals, NASD were at the relevant side of the NBBO	30

[a] February 11.
[b] Orders might be included in multiple categories (e.g., quote is ITS-ineligible because the stock is a rule 390 stock and the size of the quote is 100 shares). Therefore, these percentages may sum to more than 100%.

3. Floor orders share the quote. The arrival of a system market order may trigger a percentage order; the market order and the percentage order split the available depth.[13] If the market order is not completely filled, the remaining shares may execute outside the reference NBBO. Suppose, for example, the quote is 10,000 shares offered at $50 and the specialist is holding a 6,000-share percentage market order to buy. A 6,000-share system buy order arrives. The specialist splits the 10,000 shares at the quote between the two orders. The market order receives 5,000 shares at $50 and the remaining 1,000 shares execute outside the reference NBBO. We do not have the data to estimate how often, if ever, this scenario occurs.

4.2. Depth improvement

So far we have been examining eligible orders whose size is less than or equal to the size of the reference NBBO. In this section we focus on the 713 thousand execution reports (15 percent of eligible orders, 32 percent of eligible volume) in our sample that are associated with orders exceeding the quoted size. Table 6 provides some preliminary statistics.[14] The table shows that 13.3 percent of eligible orders

[13] For a discussion of percentage orders see Sofianos and Werner (2000).
[14] The table is preliminary for two reasons. First, orders exceeding the reference NBBO size tend to have more multiple execution reports (see below) than orders not exceeding the reference NBBO size; this leads to greater slippage because we are classifying reports and not orders. Second, we are not using the BBJ methodology to classify (see Section 2); instead we are classifying orders and measuring effective spreads relative to the reference NBBO.

Table 6
Best execution statistics for eligible system market orders.[a] Order size greater than reference NBBO size

Order size (shares)	Eligible execution reports	Percentages			Percent basis points		
		Inside NBBO price Price and depth improvement	At NBBO price Depth improvement	Outside NBBO price	(1) Quoted spread	(2) Effective spread	(1) – (2) Discount (premium)
All spreads							
100	0	—	—	—	—	—	—
101–499	93,540	16.2	40.7	43.2	27.5	48.1	(20.6)
500–2,099	395,664	14.1	49.0	36.9	36.0	53.1	(17.1)
2,100–4,999	134,689	11.2	51.9	36.9	37.5	58.4	(20.9)
5,000–9,999	68,518	10.4	48.1	41.4	36.3	65.5	(29.2)
10,000 plus	20,968	9.1	46.2	44.7	38.6	78.5	(39.8)
All sizes	713,379	13.3	48.3	38.4	35.3	55.4	(20.1)
NYSE spread 1/16th							
100	0	—	—	—	—	—	—
101–499	18,885	3.5	50.8	45.7	11.3	42.9	(31.5)
500–2,099	102,621	3.7	62.0	34.3	18.3	37.4	(19.0)
2,100–4,999	44,504	3.4	62.0	34.6	21.6	42.5	(20.9)
5,000–9,999	24,028	3.7	58.2	38.2	24.4	51.5	(27.1)
10,000 plus	8,340	2.9	56.1	41.1	31.7	68.4	(36.7)
All sizes	198,378	3.6	60.2	36.2	19.7	42.1	(22.4)
NYSE spread greater than 1/16th							
100	0	—	—	—	—	—	—
101–499	74,655	19.4	38.1	42.5	31.6	49.5	(17.9)
500–2,099	293,043	17.7	44.4	37.9	42.2	58.5	(16.4)
2,100–4,999	90,185	15.1	46.9	38.1	45.3	66.2	(20.9)
5,000–9,999	44,490	14.1	42.7	43.2	42.8	73.1	(30.3)
10,000 plus	12,628	13.1	39.7	47.1	43.2	85.1	(41.9)
All sizes	515,001	17.1	43.7	39.3	41.3	60.5	(19.2)

[a] August 1999, all NYSE issues, except: (a) stocks priced above $1,000, (b) stocks trading in variations less than 1/16th and (c) stocks trading in round lots less than 100 shares.

exceeding the reference NBBO size execute inside the quoted price: these orders therefore receive both depth improvement and price improvement. The rate of price-and-depth improvement decreases with order size: from 16.2 percent for orders less than 500 shares to 9.1 percent for block-size orders.

Another 48.3 percent of orders exceeding the quoted size execute at the quote; these orders receive depth improvement but no price improvement. The remaining 38.4 percent of orders exceeding the quoted size execute partially or wholly outside

the reference NBBO. An investor, therefore, sending an order to the NYSE that exceeds the quoted size, stands a good chance (61.6 percent) of executing the order at or inside the quote.

The quoted spread on orders exceeding the quoted size is 35.3 bp (identical to the quoted spread on orders that do not exceed the quoted size). The average effective spread, however, is 55.4 bp: on an average-priced $50 stock investors pay a premium of 10 cents per round-trip share to execute an order that exceeds the quoted size.

4.3. Single price executions

Market orders occasionally execute over multiple execution reports either because the order exceeds the quoted depth or because the quoted depth decreases between order arrival and execution. Multiple execution reports can be all at the same price or at multiple prices. Multiple reports at multiple prices, in particular, can be a nuisance to brokers and investors.

The first panel in Table 7 classifies eligible market orders into (a) single report executions, (b) multiple report, single price executions, and (c) multiple report, multiple price executions. For multiple report executions, the table also shows where the order executes relative to the reference NBBO.

Overall, the ratio of execution reports to orders is 1.06, with 97 percent of eligible orders receiving single price executions and 95 percent receiving single report executions. Of the 3 percent of orders in our sample that receive multiple report/multiple price executions, one quarter execute at or within the NBBO. Only 2 percent of eligible orders execute with multiple reports at least partially outside the NBBO (“walking up the book”).

The second and third panels in Table 7 split eligible orders into (a) order size less than or equal to the reference NBBO size, and (b) order size greater than the reference NBBO size. When order size does not exceed the quoted size (second panel) the ratio of multiple reports to orders is only 1.03, with 99 percent of orders receiving single price executions (over single or multiple prints). When order size exceeds quoted size (third panel) the ratio of multiple reports to orders increases to 1.27, with 82 percent of orders now receiving single price executions.

Table 7 also quantifies the sensitivity of the percentage of single price executions to order size in general. When order size does not exceed the reference NBBO size, the ratio of execution reports per order increases monotonically from 1.01 for 101–499 share orders to 1.26 for block-size orders. When order size exceed the reference NBBO size, the ratio of execution reports per order increases from 1.05 for 101–499 share orders to 1.81 for block-size orders.

This finding also suggests that using the number of trades may be misleading in measuring trading activity. The number of trades in a stock is not only a function of trading activity, but also hinges on how frequently orders are executed across multiple prints. In fact, all else equal, one would expect a relationship between number of trades and price changes even if trading volume were held constant:

Table 7
Single and multiple execution reports for eligible system market orders.[a] Order distribution

Order size (shares)	Eligible execution reports	Execution reports per order	Orders with one execution report		Orders with multiple execution reports							
					Single price				Multiple prices			
					At or within NBBO		Outside NBBO		At or within NBBO		At least partially outside the NBBO	
			Number	% of orders	Number	% of orders	Number	% of orders	Number	% of orders	Number	% of orders
All orders												
100	656,250	1.00	656,250	100	—	0	—	0	—	0	—	0
101–499	1,880,014	1.01	1,858,951	99	10,815	1	595	0	5,040	0	4,613	0
500–2,099	1,543,173	1.08	1,429,891	93	42,689	3	3,880	0	18,124	1	48,589	3
2,100–4,999	197,011	1.27	152,597	77	11,414	6	1,115	1	4,846	2	27,039	14
5,000–9,999	73,856	1.42	49,958	68	5,078	7	538	1	2,331	3	15,951	22
10,000 plus	18,020	1.60	10,538	58	1,484	8	196	1	619	3	5,183	29
All sizes	4,368,324	1.06	4,158,185	95	71,480	2	6,324	0	30,960	1	101,375	2
Order size less than or equal to NBBO size on order arrival												
100	656,250	1.00	656,250	100	—	0	—	0	—	0	—	0
101–499	1,786,865	1.01	1,770,792	99	9,252	1	379	0	4,758	0	1,684	0
500–2,099	1,237,399	1.05	1,185,008	96	27,455	2	1,511	0	14,488	1	8,937	1
2,100–4,999	108,956	1.12	98,674	91	5,041	5	230	0	2,948	3	2,063	2
5,000–9,999	33,891	1.18	29,679	88	2,001	6	76	0	1,291	4	844	2
10,000 plus	7,032	1.26	5,871	83	576	8	20	0	323	5	242	3
All sizes	3,830,393	1.03	3,746,274	98	44,325	1	2,216	0	23,808	1	13,770	0
Order size greater than NBBO size on order arrival												
100	—	—	—	—	—	—	—	—	—	—	—	—
101–499	93,149	1.05	88,159	95	1,563	2	216	0	282	0	2,929	3
500–2,099	305,774	1.22	244,883	80	15,234	5	2,369	1	3,636	1	39,652	13
2,100–4,999	88,055	1.46	53,923	61	6,373	7	885	1	1,898	2	24,976	28
5,000–9,999	39,965	1.63	20,279	51	3,077	8	462	1	1,040	3	15,107	38
10,000 plus	10,988	1.81	4,667	42	908	8	176	2	296	3	4,941	45
All sizes	537,931	1.27	411,911	77	27,155	5	4,108	1	7,152	1	87,605	16

[a] August 1999, all NYSE issues, except: (a) stocks priced above $1,000, (b) stocks trading in variations less than 1/16th and (c) stocks trading in round lots less than 100 shares.

orders that are broken up across multiple prices are reported across a greater number of trades.

4.4. Turnaround time

In terms of transit or "turnaround" time, a non-guaranteed system market order takes 2.9 seconds, on average, to travel from the Central Messaging Switch (CMS), the "electronic gateway of the NYSE,[15] to the specialist's Display Book and an additional 1.6 seconds to show up on the Book screen. The slight slippage between arrival and display time can be at least partially explained by the specialist "freezing" the book, i.e., halting the display of incoming orders while she processes existing orders. Once displayed, it takes an additional 16.5 seconds to execute and another 1.8 seconds for the execution report to return to CMS. The overall CMS-to-CMS round-trip averages 22.8 seconds. The electronic transit time averages 6.3 seconds. Most of the round trip time represents the interaction of the system order with the floor, i.e. the specialist exposing the order to the Trading Crowd to get a better price. The electronic transit times are roughly constant across different order sizes.[16] The screen-to-execution time, however, increases sharply with order size, as shown in Table 8.[17]

We first focus on order sizes not exceeding the reference NBBO size (Table 8). Including guaranteed orders, the average time from exposure to execution is 22.5 seconds.[18] Even though guaranteed orders are only 2.6 percent of eligible orders,[19] they take considerably longer to execute, raising the overall average time to execution: the average time from exposure to execution is 16.5 seconds for non-guaranteed orders and more than 4 minutes (251.1 seconds) for guaranteed orders.

For non-guaranteed orders, the time from exposure to execution ranges from 15.3 seconds for 100-share orders to 27.4 seconds for block-size orders. The time from

[15] CMS is a store and forward message-switching device that connects member firm and Exchange systems. For more information see Hasbrouck et al. (1993).

[16] All calculations are based on non-guaranteed, eligible system market order execution reports.

[17] These statistics may not be applicable for adjusting trade and quote data to account for reporting delays as we do not measure the amount of time that elapses between when the order is executed and the trade hits the Tape (i.e., the 1.8 seconds measures the amount of time it takes for the report to "leave" the NYSE systems on its way back *to the broker's order management system*, not to the Tape). Furthermore, since we focus only on system orders, it is unclear how this would apply to *all* trades since floor orders entered manually may suffer from greater lags.

[18] For guaranteed orders we measure time the same way as for non-guaranteed orders: from when the order shows up on the screen to execution. An alternative way of measuring time for guaranteed orders is from when the order shows up on the screen to when the specialist stops the order and guarantees a price.

[19] Over the past few years, the percentage of orders guaranteed declined sharply. In the first quarter of 1996, 20 percent of eligible system market orders were guaranteed. In May 1997, the month before the switch to teenies, this percentage was down to 15 percent. The month after teenies, July 1997, the percentage guaranteed dipped to 10 percent. See also Ready (1999) and Ross et al. (1996). Although the percent of guaranteed orders was declining prior to teenies and fell drastically after teenies, the price improvement rate on guaranteed orders remained at 56 percent with remarkable regularity. For non-guaranteed orders, on the other hand, prior to teenies, the price improvement rate was around 18 percent, following teenies, the rate increased to 30 percent.

Table 8
Average exposure-to-execution time.[a] Eligible system market orders.[b] Order size less than or equal to reference NBBO size

Order size (shares)	Eligible execution reports	Seconds			
		All eligible executions	Eligible executions Inside NBBO	Eligible executions at NBBO	Eligible executions outside NBBO
All orders					
100	679,558	19.8	23.7	16.0	25.5
101–499	1,864,747	21.2	26.2	17.1	28.4
500–2,099	1,335,340	24.6	34.3	18.9	29.1
2,100–4,999	125,602	29.9	48.0	21.8	36.4
5,000–9,999	41,230	35.7	64.5	23.2	41.8
10,000 plus	9,322	33.8	49.1	26.9	43.4
All sizes	4,055,799	22.5	29.0	17.8	28.6
Non guaranteed orders					
100	665,432	15.3	17.2	12.6	24.4
101–499	1,818,251	15.7	17.8	13.2	27.1
500–2,099	1,296,989	17.4	20.1	14.5	28.2
2,100–4,999	121,343	20.9	25.4	17.6	35.3
5,000–9,999	39,774	23.3	29.3	19.1	40.3
10,000 plus	9,086	27.4	35.5	23.0	42.1
All sizes	3,950,875	16.5	18.6	13.8	27.5
Guaranteed orders					
100	14,126	231.8	227.5	250.0	128.9
101–499	46,496	233.7	226.9	252.8	130.1
500–2,099	38,351	270.7	270.0	284.2	123.9
2,100–4,999	4,259	286.3	286.7	297.0	137.4
5,000–9,999	1,456	373.9	407.9	305.9	155.2
10,000 plus	236	277.8	234.1	411.1	140.6
All sizes	104,924	251.1	248.6	265.9	128.2

[a] Time from order arrival at Display Book screen (dbtime) to execution time (rtime).
[b] August 1999, all NYSE issues, except: (a) stocks priced above $1,000, (b) stocks trading in variations less than 1/16th and (c) stocks trading in round lots less than 100 shares.

exposure to execution also varies depending on where the order executes relative to the reference NBBO. On 100-share orders, for example, non-guaranteed executions inside the quote average 17.2 seconds, executions at the quote 12.6 seconds and executions outside the quote 24.4 seconds. We observe similar patterns for all order sizes. Even ignoring guaranteed orders, therefore, price improved orders take longer to execute. The trade-off is a slower execution.

The third panel in Table 8 shows the exposure-to-execution times for the 2.6 percent of execution orders in our sample that are guaranteed. Interestingly, the

price improvement rate on guaranteed orders is 62 percent (not reported), almost double the rate on non-guaranteed orders (35 percent). On a $50 stock (the average price in our sample), investors on average save 17 cents per round-trip share (relative to the NBBO) on guaranteed orders and 7 cents per round-trip share on non-guaranteed orders. Table 8 quantifies the time trade-off: investors have to wait on average 251.1 seconds to save 17 cents per round-trip share compared with 16.5 seconds to save 7 cents. In deciding if this trade-off is worthwhile, the investors should bear in mind that there is no price risk when an order is guaranteed.

Table 9 presents the exposure-to-execution times for order sizes exceeding the NBBO size. Intuitively these orders are more difficult and should take longer to execute. Table 9 shows that this is indeed the case. Non-guaranteed orders exceeding the NBBO size take on average 22.5 seconds to execute compared with 16.5 seconds for non-guaranteed orders not exceeding the NBBO size. The average exposure-to-execution time on non-guaranteed orders exceeding the NBBO size ranges from 17.9 seconds on 100–499 share orders to 31.6 seconds on block-size orders.

5. Conclusion

Best execution statistics are extremely sensitive to the way they are calculated. Best execution measures vary depending on:

1. The averaging method. Effective spreads on the same order flow, for example, can range from 22.1 to 79.5 bp depending on how the spreads on individual orders are averaged across all orders and stocks (Table 2). Similarly, the frequency of execution reports outside the reference NBBO can vary from 1.9 to 7.0 percent. Comparisons across markets are meaningless unless the same averaging methodology is used.
2. Definition of reference quote. There are several possible choices of quotes to use: the NYSE quote, the pure NBBO, the ITS-eligible NBBO. Thirty percent of NYSE executions outside the quote occur when the NYSE does not set the NBBO (Table 5). Using the NYSE quote as the reference quote, therefore, would reduce the frequency of NYSE executions outside the quote. Similarly, using the ITS-eligible NBBO would also reduce executions outside the quote. Again, there is a need for standardization across markets.
3. Time of reference quote. Executions outside the quote range from 6.9 percent when we evaluate executions using the prevailing quote when an order arrives at the Display Book to 0.7 percent when we use the prevailing quote when the order executes (Table 1). We argue that the conceptually correct quote time to use, is when a market center takes "responsibility" for an order. More important, however, is again the need to standardize across market centers.
4. Market orders included in calculation. For conceptual reasons, we use a narrow definition of market orders. We do not, for example, know how to evaluate best

Table 9
Average exposure-to-execution time.[a] Eligible system market orders.[b] Order size greater than reference NBBO size

Order size (shares)	Eligible execution reports	Seconds			
		All eligible executions	Eligible executions inside NBBO	Eligible executions at NBBO	Eligible executions outside NBBO
All orders					
100	0	—	—	—	—
101–499	93,540	20.7	27.6	17.7	21.1
500–2,099	395,664	24.7	29.5	21.5	27.2
2,100–4,999	134,689	28.4	30.6	24.6	33.2
5,000–9,999	68,518	34.2	30.0	28.0	42.3
10,000 plus	20,968	35.7	33.4	28.4	43.7
All sizes	713,379	26.1	29.5	22.5	29.5
Non guaranteed orders					
100	0	—	—	—	—
101–499	92,240	17.9	20.9	15.4	19.1
500–2,099	389,937	21.4	24.2	18.2	24.5
2,100–4,999	132,287	24.4	27.2	20.1	29.4
5,000–9,999	67,128	29.3	27.5	21.8	38.4
10,000 plus	20,536	31.6	28.4	23.3	40.8
All sizes	702,128	22.5	24.5	18.8	26.6
Guaranteed orders					
100	0	—	—	—	—
101–499	1,300	223.8	496.6	187.7	155.2
500–2,099	5,727	253.3	353.7	242.9	222.5
2,100–4,999	2,402	251.6	214.6	245.1	276.6
5,000–9,999	1,390	268.1	190.5	270.4	282.5
10,000 plus	432	229.6	319.2	224.3	218.7
All sizes	11,251	250.5	336.6	241.8	229.7

[a] Time lag from order arrival at Display Book screen (dbtime) to execution time (rtime).
[b] August 1999, all NYSE issues, except: (a) stocks priced above $1,000, (b) stocks trading in variations less than 1/16th and (c) stocks trading in round lots less than 100 shares.

execution for market-on-close orders. We, therefore, exclude them and other special orders. For valid comparisons across markets, best execution statistics must be calculated using the same definition of "eligible" orders.

5. Stocks included in calculation. The average effective spread on the 100 most active stocks in our sample is 12.1 bp; the average effective spread on the 1,000 least active stocks was 75.2 bp. For valid cross-market comparisons, the same sample of stocks must be used.

6. Spreads. Overall, 35.5 percent of executions occur within the quote. In minimum variation markets included in our calculations, only 10.1 percent of executions occur within the quote (at the other side of the quote). If we exclude minimum variation markets, executions inside the quote increase to 52.1 percent.
7. Time period. As our comparison of active and inactive stocks suggests, executions outside the quote increase with trading activity. Trading activity varies across stocks but also over time.
8. As percent of price. Stock prices in our sample range from $1 to $1,000. To compare a 6-cent spread on a $1 stock with a $10 spread on a $1,000 stock we must standardize by stock price. We report quoted and effective spreads as well as the discount/premium as a percent of the mid-quote.
9. Comparisons by order size. The effective spread is 17.7 bp on 100-share orders and 53.5 bp on block-size orders (Table 3). 40.4 percent of 100-share orders receive executions inside the quote compared with 25.6 percent for block-size orders. For valid cross-market comparisons, therefore, we must control for order size.
10. Order size greater than the reference NBBO. How should we measure best execution when an investor knowingly sends an order exceeding the quoted depth? Presumably, the investor is aware that the order will most probably execute at least partially outside the quote and is willing to pay the premium relative to the NBBO. In our sample, the average effective spread on block-size orders less than the reference NBBO size is 53.5 bp; investors save 8.5 bp per round-trip share relative to the NBBO (Table 3). The effective spread on block-size orders greater than the reference NBBO size is 78.5 bp; investors pay a premium of 39.8 bp per round-trip share relative to the NBBO (Table 6). At a minimum, we need to separate these two conceptually different types of orders and this is what we do in this paper. For orders exceeding the quoted size, the possibility of depth improvement becomes an important best execution attribute. Moreover, the distinction between orders exceeding the NBBO size and orders that do not needs to carry over in cross-market comparisons.

In the U.S. equity markets, order flow is fragmented across several market venues. The measures we develop in this paper are designed to help investors and brokers acting on their behalf determine which market venue is most likely to provide best execution. For example, an investor trying to determine which market provides the best price may compare statistics on how frequently a market provides executions inside and outside the NBBO, while an investor concerned with speed could compare turnaround times. While no single measure can be used by all investors to identify a "best market", providing investors with a menu of statistics will allow each investor to make informed order routing decisions based on her own preferences for price, speed, etc.

It is important to note, though, that our analysis takes the market as given. For example, cross-market comparisons of execution price essentially measure which market provides the best execution price *relative to the prevailing quote*, implicitly

taking the price discovery process as given. At some point, however, too much order flow fragmentation may harm the price discovery process, increasing trading costs at all market venues. Care is needed, therefore, in balancing the benefits of competition across market venues with the costs of order flow fragmentation.

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