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Implications of a Reduction in Tick Size on Short-Sell Order Execution[1]

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The U.S. Securities and Exchange Commission is committed to having exchanges fully implement decimal pricing by April 9, 2001, and is also considering revising the Uptick Rule. We consider the likely impact of the pending smaller tick size associated with decimalization on the efficacy of this rule by examining the execution quality of NYSE short-sell orders immediately before and after the tick size was reduced from 1/8th to 1/16th in 1997. We conclude that, in general, short market orders will receive better execution after decimalization, but at-the-quote limit orders will receive worse execution, and suggest revisions to the Rule. *Journal of Economic Literature* Classification Numbers: G18, K22. © 2002 Elsevier Science (USA)

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In designing a stock exchange, decisions have to be made with regard to the size of the minimum price variation, known as the tick, and the extent to which short-selling should be regulated. In January 1994, the U.S. Securities and Exchange

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Commission (SEC) released its Market 2000 report that recommended a reduction in the tick size of \$1/8 that was widely used in the pricing of common stocks.[2] The stated reason behind this recommendation was that the use of \$1/8 pricing "... can cause artificially wide spreads and hinder quote competition" (p. 18). Subsequently, the Common Cents Pricing Act was introduced by Representatives Michael Oxley and Edward Markey in the U.S. Congress in March 1997 with the intent of legislating a reduction in the tick size. Shortly thereafter, NASDAQ, the New York Stock Exchange (NYSE), and the other organized exchanges switched to \$1/16 pricing (teenies) for most common stocks. This switch reduced the tick size and hence represented a move toward a decimal pricing system like the one adopted by the Toronto Stock Exchange in 1996.[3] Studies such as Bollen and Whaley (1998) and Goldstein and Kavajecz (2000) found that the switch to teenies had an immediate impact on quoted spreads and depths, as predicted by Harris (1994), causing both of them to, in general, decrease.[4]

On January 28, 2000, the SEC issued an order that directed U.S. exchanges and the National Association of Security Dealers (NASD) to implement decimal pricing by July 3, 2000.[5] The SEC subsequently issued an order on June 8, 2000 that gave the exchanges and NASD until April 9, 2001 to finish phasing in the use of decimal pricing.[6]

Under Rule 10a-1, commonly known as the Uptick Rule, short-sell orders placed on organized exchanges cannot be executed on either downticks or zero-minus ticks.[7] This means that a short-sell order can only be executed at a price higher than the price of the previously executed order (i.e., an uptick) or at the same price if that price is higher than the most recently executed order involving a different price (i.e., a zero-plus tick). Basically, the objective of the Uptick Rule is to prevent short-selling into declining markets while not restricting short-selling into advancing markets. The SEC is considering revising the Uptick Rule; one of the alternatives under consideration involves complete elimination of the Rule.[8]

[2] See U.S. Securities and Exchange Commission (1994, pp. 18–19). A minimum tick size of \$1/8 was applicable to stocks selling above \$1 on the NYSE, \$5 on the Amex, and \$10 on NASDAQ.

[3] Toronto lowered the tick from \$1/8 to \$.05 for stocks selling at or above \$5, and from \$.05 to \$.01 for stocks selling between \$3 and \$4.99. This tick-size change is examined by Bacidore (1997) and Porter and Weaver (1998).

[4] Interestingly, similar results were found by Bacidore (1997) when the Toronto Stock Exchange switched to decimal pricing, suggesting these results are robust across transitions to smaller ticks of different sizes and on different exchanges. The net effect is to make liquidity demanders trading small orders better off while making those trading large orders worse off; see Goldstein and Kavajecz (2000). For a discussion on the economic relevance of the minimum tick size, see, for example, Angel (1997a), Anshuman and Kalay (1998), Chordia and Subrahmanyam (1995), Harris (1991, 1994, 1996), and Hausman *et al*. (1992).

[5] See U.S. Securities and Exchange Commission (2000a). It should be noted that the SEC did not define the minimum tick size in its order for decimalization, preferring to leave this issue to the exchanges.

[6] See U.S. Securities and Exchange Commission (2000b).

[7] For more on the Uptick Rule and its impact on price discovery, see Macey *et al*. (1989).

[8] See U.S. Securities and Exchange Commission (1999).

In this paper we raise the following questions: How will a move to decimal pricing impact the efficacy of the Uptick Rule? Will it make it easier or more difficult to have a short-sell order executed? We examine a sample of NYSE short-sell orders immediately before and after the move to teenies in 1997 in seeking answers to these questions. In doing so we consider two measures of execution quality—the probability of execution and the time to execution—that seem most likely to gauge how much the Rule is hindering the execution of short-sell orders. To isolate the effects of the tick size change on the execution quality of short-sell orders we use a matching routine to control for stock characteristics, market conditions, and any potential change in order submission strategy, e.g., the choice of using a market vs a limit order. In doing so, two samples are analyzed.

With the first sample, orders involving stocks whose spread at the time of submission are equal to one tick both before and after teenies are examined, suggesting the tick was binding in the pre-period. That is, orders placed in \$1/8-spread markets before teenies are compared with similar orders placed in \$1/16-spread markets afterward. Consider a short market order in this sample that is placed in the pre-period and cannot be executed immediately because of the Uptick Rule. Since there may be smaller depth at the ask after the introduction of teenies, the matching post-period order would seem to have an increased opportunity to be executed. This is primarily because it would, in general, be treated as a limit order at the ask, allowing it to benefit from an improved position in the order queue due to the reduced depth at the ask with teenies. Thus, such orders should have a higher probability of being executed and execution should take less time with teenies. Similarly, short at-the-quote limit orders (i.e., a limit order with a limit price equal to the ask) should also benefit from the move to teenies.

The second sample involves orders where the spread is one tick before the introduction of teenies but afterward it is two ticks, suggesting the tick was not binding in the pre-period.[9] That is, orders placed in \$1/8-spread markets before teenies are compared with similar orders placed in \$1/8-spread markets afterward. When the Uptick Rule prevents the immediate execution of a short-sell market order at the bid in both periods, the reduced tick size allows such an order to "step ahead of the book," or "quote jump," other sell orders at the ask (Harris, 1996) in the post-period.[10] Consequently, the execution of these orders should improve after the move to teenies since they will become, in essence, limit orders at their minimum shortable price (MSP). This price, defined as the lowest price that a stock can be sold short under the Uptick Rule, will at certain times be below the ask after the move to teenies.

[9] Some of the orders in this sample might have had a spread of \$3/32 if 32nds, for example, were allowed. Hence, by "not binding" we mean "not binding with respect to the tick size." See Ronen and Weaver (1999).

[10] This is especially an issue in our study since Alexander and Peterson (1999) and Angel (1997b) report that less than 10% of short-sell orders can execute at the bid at order submission time.

In contrast, a short at-the-quote limit order might suffer from quote-jumping by other sell orders when the spread remains the same size after the introduction of teenies. This can happen because there will be more intervening prices below the ask but above the bid at which other sell orders could receive execution ahead of the short at-the-quote limit order.

In summary, an analysis of short-sell orders around the time that teenies were introduced can lead to insights on the likely impact of a move to decimal pricing on the efficacy of the Uptick Rule. In answer to the previously posed questions, we find that the move to teenies led, in general, to better execution of short market orders, but worse execution for short at-the-quote limit orders. These observations conflict with the objectives of the Uptick Rule, since they mean that: (1) most market orders were easier to execute in declining markets, and (2) most at-the- quote limit orders were more difficult to execute in advancing markets. This suggests that the Uptick Rule will need to be revised upon the advent of decimalization, if not sooner.

We have organized the rest of this paper as follows. Section 1 describes the data and sampling procedure. Section 2 elaborates on the expected effect of the introduction of teenies on the quality of order execution. Section 3 presents the results from testing these expectations, and Section 4 is the conclusion.

1. DATA

1.1. Order Matching Routine

We use matched pairs of short-sell orders placed on the NYSE during June and July of 1997 to compare the execution quality of short-sell orders for different tick sizes. The order matching routine controls for many factors simultaneously that may otherwise distort the interpretation of results. We match every short-sell order placed during the two weeks of June 9 through June 20, 1997 (the pre-period) where possible with another short-sell order placed during the two weeks of June 30 through July 11, 1997 (the post-period). These 2-week periods bracket the date of the changeover to teenies on Tuesday, June 24, but do not include the trading day before the changeover and the first four trading days of teenies due to possible unusual trading associated with the changeover.[11]

The orders are matched first by stock and second by type of short-sell order. The four types of orders considered are: (1) market orders, (2) marketable limit orders (i.e., orders with a limit price equal to or lower than the bid price), (3) quote-improving limit orders (i.e., orders with a limit price above the bid, but lower than the ask), and (4) at-the-quote limit orders. Third, orders are matched by order size, where three size categories are utilized: 100 to 500 shares, 501 to 5000 shares, and over 5000 shares. Fourth, orders are matched by the time the order is submitted,

[11] Goldstein and Kavajecz (2000) found no discernible differences in their data between the June 30–July 25 and the August 25–September 19 periods in 1997, suggesting our use of the June 30–July 11 period is appropriate.

where three time categories are utilized: 9:30–10:30, 10:30–3:00, and 3:00–4:00. Finally, orders are matched by tick status at the time of order submission, where the tick status can be either an uptick or a downtick.[12] In the multivariate analysis that follows, we also control for other possible effects that were not considered in the matching routine. The results presented focus on market and at-the-quote limit orders, since the results for marketable limit orders were virtually the same as those for market orders.

To build the transaction-level database, we exclude all short-sell orders that arrive when a valid quote is not available (e.g., orders entered prior to the opening) or short-sell orders exempt from the Uptick Rule (e.g., short-selling associated with certain arbitrage strategies). Limit orders above the ask and orders that are not regular market or limit orders are also excluded so as to eliminate many of the potential confounding effects arising from unusual order characteristics.[13] Any order without a time limit is assumed to expire at the end of the day. Last, a record is kept of orders subsequently canceled and the time of cancellation.

1.2. Market Conditions during Pre- and Post-Periods

Market conditions in the pre- and post-periods are comparable. In the pre-period the average daily trading volume on the NYSE was 530 million shares, while in the post-period it was 521 million shares. The average value of the NYSE Composite Index was 461 in the pre-period, with a minimum, average, and maximum daily change of −2.2, 2.0, and 7.1, respectively. Similarly, the average value of the index was 473.3 in the post-period, with a minimum, average, and maximum daily change of −5.5, 1.6, and 6.0, respectively.

1.3. Data Sources

The data consist of trades and quotes from the Securities Industry Automation Corporation (SIAC) files and order submission data from the NYSE's System Order Database (SOD) file. The SIAC trade and quote data include all quotes and executions for all NASDAQ and exchange-listed stocks. This file is used for two purposes. First, the national best bid and offer (NBBO) is re-created for each of the stocks at the time of each order submission during the pre- and post-periods (from here on, we simply refer to the NBBO as the bid and ask). Second, trades occurring on the NYSE are ordered in time sequence and the tick status is calculated for each point in time. Note that the NYSE uses the last trade on the NYSE as the reference price in determining the tick status. These data allow for the calculation of the minimum shortable price for each stock at each moment during the pre- and post-period.

[12] Hereafter, we include zero-plus ticks in referring to upticks, and zero-minus ticks in referring to downticks.

[13] Stop, stop limit, market on close, market or better, market if touched, cabinet, market with or without a round-lot sale, limit or better, limit with or without a round-lot sale, limit basis price, crossing session I, and limit on close orders are excluded.

The SOD data include all relevant order information (e.g., order submission time, order type, order size) but only for orders submitted through the NYSE's SuperDOT system.[14] Ross *et al*. (1996) have reported that over 80% of the NYSE orders, accounting for 30–40% of the volume, are executed through SuperDOT. This database has commonly been used when information on orders is needed; see, for example, Alexander and Peterson (1999), Angel (1997b), and Goldstein and Kavajecz (2000).

1.4. Sample Characterized by Spread

In the pre-period, 351,942 short-sell orders were submitted when the spread at the time of submission was either \$1/8 (244,818 orders) or \$1/4 (107,124 orders). Similarly, in the post-period, 384,531 short-sell orders were submitted when the spread at the time of submission was either \$1/16 (147,904 orders), \$1/8 (127,720 orders), \$3/16 (61,835 orders), or \$1/4 (47,072 orders). The matched pair sample prepared from these orders is summarized in Table I. In total, 230,134 pairs of short-sell orders are identified on the basis of stock, order type, order size, order time, and tick status. Thus, 65% of the pre-period orders and 60% of the post-period orders are included in the pairing routine. The table shows that short-sellers make use of at-the-quote limit orders far more than any other type of order, as they constitute nearly 62% of all short-sell orders. Next largest, making up about 19% of the total, are market orders.[15]

A second observation is that the spread in the post-period can be quite different from that observed in the pre-period. More pre-period orders that were placed when the spread was \$1/8 tended to be paired with post-period orders that had a spread of \$1/16 than any other size spread. Nevertheless, roughly 50% of the pre-period orders with spread equal to \$1/8 are paired with post-period orders that had spreads of \$1/8 or larger. This suggests that for roughly half of the orders, the spread in the pre-period was larger than that dictated by competitive market forces.[16]

We focus on two sets of paired orders. The first set consists of the 77,786 pairs that have a spread of \$1/8 in the pre-period and \$1/16 in the post-period (the 1/8th–1/16th sample). Analysis of this set allows us to examine the impact of teenies on short-sell orders in minimum tick markets. There is reason to believe that the tick size was sufficiently binding in the pre-period to lead to a reduction in the spread in the post-period. The second set consists of the 49,339 pairs that have a spread of \$1/8 in both the pre- and the post-period (the 1/8th–1/8th sample).

[14] See Hasbrouck (1992) for a description of the SOD database.

[15] Both of these observations reflect short-sell orders in both the pre- and post-periods after pairing took place. Nevertheless, Alexander and Peterson (1999) report similar percentages for short-sell orders placed in May 1996.

[16] It is possible that more than 50% of these pre-\$1/8 orders would have been paired with orders having smaller spreads in the post-period if, for example, 32nds were allowed, suggesting the spread in the pre-period might very well have been binding for more than half of the orders. See Ronen and Weaver (1999).

TABLE I
Number of Pairs of Short-Sell Orders by Spread

Pre-period spreads	Post-period Spreads				
	\$1/16	\$1/8	\$3/16	\$1/4	All
			A. All orders		
\$1/8	77,786	49,339	18,498	11,663	157,306
\$1/4	18,356	26,184	15,562	12,726	72,828
All	96,142	75,543	34,060	24,389	230,134
			B. Market orders		
\$1/8	15,405	10,886	3,983	2,348	32,622
\$1/4	3,979	3,501	1,580	1,131	10,191
All	19,384	14,387	5,563	3,479	42,813
			C. Marketable limit orders		
\$1/8	14,589	5,713	1,017	580	21,899
\$1/4	1,021	525	110	84	1,740
All	15,610	6,238	1,127	664	23,639
			D. Quote-improving limit orders		
\$1/4	0	9,416	6,566	5,604	21,586
			E. At-the-quote limit orders		
\$1/8	47,792	32,760	13,498	8,735	102,785
\$1/4	13,356	12,742	7,306	5,907	39,311
All	61,148	45,502	20,804	14,642	142,096

Note. This table reports the number of NYSE SuperDOT matched-pair short-sell orders for NYSE-listed stocks. Orders submitted between 6/9/97 and 6/20/97 (pre-period) were matched with orders submitted between 6/30/97 and 7/11/97 (post-period). Orders were matched by stock, order type, order size, order time, and whether the previous trade was an uptick or downtick. The reference quotes are derived from the NBBO at time of order submission. Marketable limit orders have limit prices equal to or lower than the bid. Quote-improving limit orders have limit prices greater than the bid and lower than the ask. At-the-quote limit orders have limit prices equal to the ask. Only regular market orders and regular limit orders are considered, e.g., stop orders are excluded. Short-sell orders exempted from the Uptick Rule are excluded. A small number of orders submitted when the bid-ask spread is greater than \$1/4 or when the bid-ask spread is on odd-16ths in the pre-period or odd-32nds in the post-period are excluded (this amounted to 16,765 of an initial 230,134 pairs, or approximately 7%).

Analysis of this set allows us to examine the impact of teenies on short-sell orders where there is reason to believe that the tick size was not sufficiently binding in the pre-period to lead to a reduction in the spread in the post-period. Furthermore, this set permits an examination of the impact of teenies on short-sell order execution when trading at first was not allowed to take place inside the spread, but was allowed afterward. These two sets of paired orders make up, respectively, 34 and 21% of all the pairs in the sample, or 55% of the total shown in Table I.[17]

[17] While focusing on the results from these two samples, we also analyzed a third sample consisting of the 12,726 pairs where both pre- and post-period spreads were \$1/4th (the "1/4th–1/4th sample"). The results in general support those associated with the 1/8th–1/8th sample.

The data reported in Table I indicate that in the pre-period, a majority of orders were placed in minimum tick spread markets (157,306 out of 230,134, or 68%); a similar observation was also noted by Alexander and Peterson (1999) for both regular sell and short-sell orders. However, in the post-period, most orders were placed on markets where the spread was greater than one tick (230,134−96,142 = 133,992 out of 230,134, or 58%). Similarly, Goldstein and Kavajecz (2000) show that the average quoted spread before teenies was $.21, which is 1.7 times the minimum tick size at the time, but $.18 after teenies, which is 2.9 times the minimum tick size. This means that the results reported here for the 1/8th–1/8th sample are likely to describe the impact of decimalization on most short-sell orders.[18]

2. EXPECTED EFFECT OF THE INTRODUCTION OF TEENIES ON ORDER EXECUTION

We first consider the quality of order execution when the spread is bound by the minimum tick size in both periods (i.e., the 1/8th–1/16th sample). Next, we examine the case when the spread is bound by the tick in the pre-period but not in the post-period (i.e., the 1/8th–1/8th sample). The location of the minimum shortable price (MSP) is crucial in developing our hypotheses.

2.1. Market Orders

When MSP is greater than the bid, short market orders take the form of a limit order where the limit price is set equal to the lowest price at which the order can legally be executed, i.e., MSP. Hence, these orders go to the end of the order queue behind any public orders with the same limit price, but ahead of the specialist's own quotes since the specialist maintains price and time priority.

For this reason the quality of order execution for short market orders in the 1/8th–1/16th sample should improve after the move to teenies when MSP is greater than the bid. Since these orders cannot be immediately executed at the bid upon submission, they will in general be entered as limit orders at the ask and thus should benefit from the thinner depth that is present under teenies.

Short market orders in the 1/8th–1/8th sample should also receive improved execution after the move to teenies when MSP is greater than the bid. Consider orders placed when MSP is not only greater than the bid but also less than the ask. These orders would now have the opportunity to be executed at the midpoint like a quote-improving limit order. Such orders are similar to quote-jumping orders that circumvent price-time priority rules as described by Harris (1996). Since they cannot be executed immediately, they typically become limit sell orders at the

[18] While this observation must be interpreted with caution since the Table I percentages do not reflect all orders, we believe that it is supported by the results of Alexander and Peterson (1999) and Goldstein and Kavajecz (2000).

midpoint, thus stepping ahead of the queue of limit sell orders at the ask. Consider next orders placed when MSP is equal to or greater than the ask. These orders benefit from thinner depth throughout the limit order book at and above the ask after the move to teenies as documented by Goldstein and Kavajecz (2000).

Short market orders can be filled up to the depth at the bid when MSP is less than or equal to the bid. Given smaller depth after the move to teenies, it is possible that such orders will receive poorer execution. Thus, teenies should adversely impact the execution quality of these orders.

2.2. At-the-Quote Limit Orders

For short at-the-quote limit orders that are placed when MSP is less than or equal to the ask, the impact of teenies on execution quality is likely to be beneficial in the 1/8th–1/16th sample. Such orders will be placed behind any previously submitted limit sell orders at the ask but ahead of the specialist's quotes and thus should benefit from the reduced depth present after the advent of teenies. However, if MSP is greater than the ask, then the order will be treated as a limit order with a limit price above the ask. In this case the impact of teenies will depend on the depth of the limit orders placed above the ask but at or below the short-sell order's MSP. Since, as mentioned earlier, depth declined throughout the limit order book after teenies, such orders should also receive better execution after teenies.

Short at-the-quote limit orders in the 1/8th–1/8th sample that are submitted when MSP is less than or equal to the ask will be treated as regular limit sell orders at the ask. These orders are likely to receive poorer execution after teenies because other sell orders may be executed inside the spread first. That is, the execution quality of these short-sell orders should suffer from other sell orders stepping ahead of them in the order queue. However, if MSP is greater than the ask, then the order will be treated as a limit order with a limit price above the ask where it should receive better execution because of the reduced depth throughout the limit order book after teenies.

2.3. Location of MSP

Table II shows the percentage of orders in the sample and the population that were placed when MSP was less than or equal to the bid in the case of market orders and less than or equal to the ask in the case of at-the-quote limit orders. The samples closely represent the population, with small differences between the pre- and post-period for the 1/8th–1/16th sample and larger differences in the 1/8th–1/8th sample for market orders. The differences between the pre- and post-periods are significant in all cases except for market orders in the 1/8th–1/16th sample. Last, the table shows that roughly 85–90% of market orders are entered when MSP is greater than the bid, while over 90% of the at-the-quote limit orders were entered when MSP was at or less than the ask. These percentages are consistent with those found by Alexander and Peterson (1999).

TABLE II
Location of Minimum Shortable Price

Period	Market orders		At-the-quote limit orders	
	Population	Sample	Population	Sample
A. Spread = \$1/8 in pre-period and \$1/16 in the post-period				
Pre-period	15.3%	14.9%	92.3%	92.3%
Post-period	13.9%	14.5%	90.7%	91.1%
Difference	−1.4%***	−0.4%	−1.6%***	−1.2%***
B. Spread = \$1/8 in pre-period and \$1/8 in the post-period				
Pre-period	15.3%	15.6%	92.3%	91.7%
Post-period	9.2%	8.8%	92.7%	93.7%
Difference	−6.1%***	−6.8%***	0.4%***	2.0%***

Note. This table reports the percentage of short-sell orders where the location of the MSP was less than or equal to the bid for market orders, and less than or equal to the ask for at-the-quote limit orders. Percentages are shown for both the population and sample of short-sell orders that were placed during the sample periods described in Table I. Pearson's chi-square test was used to test if pre-period and post-period proportions were significantly different. */**/*** indicates the estimate is significantly different from zero at the 10%/5%/1% level, respectively.

Short market orders are the easiest type of short-sell order to execute because they have the fewest conditions attached to them. It is therefore surprising that so few of them could be executed immediately at the bid in either the pre- or the post-period. A likely explanation for the significant 6.8% decrease in the percentage of market orders that can be executed immediately in the 1/8th–1/8th sample is that in many cases an uptick represents a bid–ask bounce. As a result of the introduction of teenies, however, upticks in a \$1/8-spread market can now arise from not only the bid–ask bounce, but also from orders being sequentially executed at the bid and then the midpoint or at the midpoint and then the ask. In either case, a short market order cannot be immediately executed at the bid, since that would involve execution on a downtick.

2.4. Measures of Execution Quality and Hypotheses

In estimating execution quality, two different measures that seem most likely to gauge how much the Rule is hindering the execution of short-sell orders will be used. These measures are the probability of execution and the time from order submission to execution. In both samples, it is expected that short market orders will have a higher probability of execution and less time to execution after the move to teenies when MSP is greater than the bid. This can be attributed to the reduced depth at the ask and, in the case of the 1/8th–1/8th sample, the ability of many of these orders to step ahead of the ask by being treated as limit orders with slightly lower limit prices. Execution quality is expected to worsen for such orders when MSP is less than or equal to the bid for either sample since the percentage of orders that will exhaust the depth at the bid will likely be larger after the advent of teenies.

TABLE III
Hypothesized Impact of Teenies on the Probability of Execution and Time to Execution of Short-Sell Market and At-the-Quote Limit Orders

	Market orders ($\theta \equiv$ Bid)	At-the-quote limit orders ($\theta \equiv$ Ask)
	A. 1/8th–1/16th sample	
MSP $\leq \theta$	Worse execution quality (less depth at the bid)	Better execution quality (less depth at the ask)
MSP $> \theta$	Better execution quality (less depth at the ask)	Better execution quality (less depth in limit order book)
Overall	Better execution quality (typically MSP > bid)	Better execution quality (typically MSP $\leq$ ask)
	B. 1/8th–1/8th Sample	
MSP $\leq \theta$	Worse execution quality (less depth at the bid)	Worse execution quality (other sell orders step ahead of them)
MSP $> \theta$	Better execution quality (step ahead of limit sell orders)	Better execution quality (less depth in limit order book)
Overall	Better execution quality (typically MSP > bid)	Worse execution quality (typically MSP $\leq$ ask)

Note. This impact is based on the spread and the location of the MSP relative to the bid in the case of market orders and the ask in the case of at-the-quote limit orders.

Short at-the-quote limit orders should have a higher probability of execution and a shorter time to execution after teenies when MSP is less than or equal to the ask for the 1/8th–1/16th sample, as they should benefit from smaller depth at the ask. In contrast, such orders in the 1/8th–1/8th sample should be worse off after teenies, as other sell orders are now able to step ahead of them in the order queue by quoting a slightly better limit price. When MSP is greater than the ask, short at-the-quote limit orders for both samples should benefit from the thinner depth throughout the limit order book after teenies.

Table III summarizes the hypothesized impact of teenies on the probability of execution and time to execution of short-sell orders. Note that the expected impact of teenies is dependent on the type of order, spread, and location of MSP. The overall results are based on the observation from Table II that most market orders are made when MSP is greater than the bid and that most at-the-quote limit orders are made when MSP is less than or equal to the ask. In comparing the orders, market orders should receive better execution than at-the-quote limit orders in both pre- and post-periods.

3. EXECUTION QUALITY RESULTS

Our matching routine eliminates any biases in execution quality measurement that may be due to a change in the choice of order type, i.e., market or limit. However, Harris (1996) suggests traders will allow their orders to stand for a shorter period of time and will cancel their orders more often when the tick size is

small relative to the price.[19] Consequently, a smaller tick size may hurt exposed orders by making quote-jumping strategies more profitable and lead traders to respond by canceling their orders more frequently and more quickly. Thus, it is possible that the probabilities of cancellation and execution are jointly related. Ignoring the probability of cancellation in estimating the probability of execution could introduce a selection bias.

3.1. Methodology for Analyzing the Probability of Execution

One well-known method for handling selection bias is the Heckman (1979) two-step procedure (see Greene, 1993, pp. 711–713). In our case the selection equation models the probability of an order *not* being cancelled by using a probit regression. In the usual implementation of Heckman's procedure the second step involves estimation of the conditional mean of a continuous variable. However, in our application we wish to model the probability of execution, a qualitative binary dependent variable. Van de Ven and Van Praag (1981) show that the bivariate probit model is equivalent to the Heckman two-step.

The probit models used for the probabilities of cancellation and execution take the following respective forms:

$$\begin{aligned}\Pr\{\text{Cancellation}_i\} = \Phi(&\beta_0 + \beta_1\text{PRE}_i + \beta_2\text{PRE}_i \times \text{MSP}_i + \beta_3\text{MSP}_i \\ &+ \beta_4\text{ENTRY}_i + \beta_5\text{PRICE}_i + \beta_6\text{OSIZE}_i + \beta_7\text{TICK}_i \\ &+ \beta_8\text{INDIV}_i + \beta_9\text{RETURN}_i + \beta_{10}\text{VOLUME}_i \\ &+ \beta_{11}\text{ASIZE}_i + \varepsilon_i) \qquad (1)\end{aligned}$$

$$\begin{aligned}\Pr\{\text{Execution}_i\} = \Phi(&\delta_0 + \delta_1\text{PRE}_i + \delta_2\text{PRE}_i \times \text{MSP}_i + \delta_3\text{MSP}_i + \delta_4\text{ENTRY}_i \\ &+ \delta_5\text{PRICE}_i + \delta_6\text{OSIZE}_i + \delta_7\text{TICK}_i + \delta_8\text{INDIV}_i \\ &+ \delta_9\text{RETURN}_i + \delta_{10}\text{VOLUME}_i + \delta_{11}\text{ASIZE}_i + \nu_i), \qquad (2)\end{aligned}$$

where Φ is the standard normal CDF, $\text{PRE}_i = 1$ if order i is placed in the pre-period, or 0 otherwise; $\text{MSP}_i = 1$ if order i is a market order that is placed when the minimum shortable price is above the bid, or if it is an at-the-quote limit order that is placed when the minimum shortable price is above the ask, or 0 otherwise; ENTRY_i is the time difference, in seconds, from when order i was submitted and 9:30 AM; PRICE_i is the midpoint of the stock's spread when order i is submitted; OSIZE_i is the size of order i, in number of shares; $\text{TICK}_i = 1$ if order i is placed on an uptick, or 0 otherwise; $\text{INDIV}_i = 1$ if order i is placed by an individual, or 0 otherwise; RETURN_i is the return on the stock in the 15 min prior to submission of order i, but if submitted within the first 15 min of trading, it is the return from the opening; VOLUME_i is the natural log of trading volume on stock i from

[19] Goldstein and Kavajecz (2000) observed an increase in the rate of order cancellation for limit orders after the introduction of teenies.

TABLE IV
Interpretation of Coefficients for the Bivariate Probit Models of the Probabilities of Cancellation and Execution

	$PRE_i = 1$ (pre-period) (1)	$PRE_i = 0$ (post-period) (2)	Test statistic (3) = (1) − (2)	Reported variable for test statistic
A. $MSP_i = 0$ (Rule is not binding)	$\beta_0 + \beta_1$	β_0	β_1	PRE: MSP $\leq \Theta$
B. $MSP_i = 1$ (Rule is binding)	$\beta_0 + \beta_1 + \beta_2 + \beta_3$	$\beta_0 + \beta_3$	$\beta_1 + \beta_2$	PRE: MSP $> \Theta$
C. Test statistic = B − A	$\beta_2 + \beta_3$	β_3		
Reported variable for test statistic	10A1: PRE	10A1: POST		

Note. This table indicates how to interpret the coefficients β_0, β_1, β_2, and β_3 from the bivariate probit models of the probabilities of cancellation and execution:

$$\begin{aligned}\Pr\{\text{Cancellation}_i\} = \Phi(&\beta_0 + \beta_1 \text{PRE}_i + \beta_2 \text{PRE}_i \times \text{MSP}_i + \beta_3 \text{MSP}_i + \beta_4 \text{ENTRY}_i + \beta_5 \text{PRICE}_i \\ &+ \beta_6 \text{OSIZE}_i + \beta_7 \text{TICK}_i + \beta_8 \text{INDIV}_i + \beta_9 \text{RETURN}_i \\ &+ \beta_{10} \text{VOLUME}_i + \beta_{11} \text{ASIZE}_i + \varepsilon_i)\end{aligned}$$

$$\begin{aligned}\Pr\{\text{Execution}_i\} = \Phi(&\delta_0 + \delta_1 \text{PRE}_i + \delta_2 \text{PRE}_i \times \text{MSP}_i + \delta_3 \text{MSP}_i + \delta_4 \text{ENTRY}_i \\ &+ \delta_5 \text{PRICE}_i + \delta_6 \text{OSIZE}_i + \delta_7 \text{TICK}_i + \delta_8 \text{INDIV}_i \\ &+ \delta_9 \text{RETURN}_i + \delta_{10} \text{VOLUME}_i + \delta_{11} \text{ASIZE}_i + \nu_i)\end{aligned}$$

where Φ is the standard normal CDF; $\text{PRE}_i = 1$ if order i is placed in the pre-period, 0 otherwise; $\text{MSP}_i = 1$ if order i is a market order that is placed when the minimum shortable price is above the bid, or if it is an at-the-quote limit order that is placed when the minimum shortable price is above the ask, 0 otherwise; ENTRY_i is the time difference, in seconds, from when order i was submitted and 9:30 AM; PRICE_i is the midpoint of the stock's spread when order i is submitted; OSIZE_i = size of order i, in number of shares; $\text{TICK}_i = 1$ if order i is placed on an uptick, 0 otherwise; $\text{INDIV}_i = 1$ if order i is placed by an individual, 0 otherwise; RETURN_i is the return on the stock in the 15 min prior to submission of order i, but if submitted within the first 15 min of trading, it is the return from the opening; VOLUME_i is the natural log of trading volume on stock i from January 1 to May 31, 1997; ASIZE_i is the depth at the ask when order i is submitted, except it is 0 if it is a market order that is submitted when MSP equals or is below the bid.

January 1 to May 31, 1997; ASIZE_i is the depth at the ask when order i is submitted, except it is 0 if it is a market order that is submitted when MSP equals or is below the bid.

The test design of the PRE_i and MSP_i variables in Eqs. (1) and (2) is summarized in Table IV. Consider Eq. (1) first. Note that $\text{PRE}_i \times \text{MSP}_i$ is an interaction term between the dummy variables PRE_i and MSP_i that is necessitated by the hypotheses that were presented earlier. The presence of this term means that the coefficient β_1 denotes the impact of teenies on the probability of cancellation when MSP is less than or equal to the bid for market orders and less than or equal to the ask for at-the-quote limit orders; it will be reported in the tables as PRE: MSP $\leq \theta$.

Similarly, the reported coefficient PRE: MSP $> \theta$ corresponds to the sum of the coefficients $\beta_1 + \beta_2$ and represents the impact of teenies on the probability of cancellation when MSP is greater than the bid for market orders and the ask for at-the-quote limit orders.

Also of interest is the coefficient β_3, which denotes the effect of the location of MSP on the probability of cancellation during the post-period; it will be reported as 10A1: POST. Similarly, the sum of the coefficients $\beta_2 + \beta_3$ denotes the effect of the location of MSP on the probability of cancellation during the pre-period and will be reported as 10A1: PRE.

It is straightforward to conduct tests of significance for PRE: MSP $\leq \theta$ and 10A1: POST since the tests correspond to a single coefficient (β_1 and β_3, respectively) in Eq. (1). However, we would also like to conduct tests of significance for PRE: MSP $> \theta$ and 10A1: PRE. These tests cannot be cleanly done with the current definitions of the PRE and MSP dummy variables since the test statistics involve the sum of two coefficients ($\beta_1 + \beta_2$ and $\beta_2 + \beta_3$, respectively). However, a clean test for PRE: MSP $> \theta$ can be obtained by simply reversing the earlier definition of the MSP_i term. That is, we redefine MSP_i to be 1 if order i is a market order that is placed when MSP is at or below the bid or if it is an at-the-quote limit order that is placed when MSP is at or below the ask, and 0 otherwise. After doing so, the coefficient β_1 will denote the impact of the introduction of teenies on the probability of cancellation when MSP is greater than the bid for market orders and greater than the ask for at-the-quote limit orders. By re-estimating Eq. (1), the estimated value of β_1 can be tested for significance in order to see if it is significantly different from zero; it is reported as PRE: MSP $> \theta$ in subsequent tables.

Last, consider using the original definition of MSP_i but now redefine PRE_i to be 1 if order i is placed during the post-period, and 0 otherwise. After doing so, the coefficient β_3 will denote the effect of the location of MSP on the probability of cancellation during the pre-period. By once again re-estimating Eq. (1), the estimated value of β_3 can be tested for significance in order to see if it is significantly different from zero; it is reported as 10A1: PRE in subsequent tables.

Since the same alterations can be made to the definitions of MSP_i and PRE_i when estimating Eq. (2), their impact on the probability of execution will be similarly evaluated.

3.2. Bivariate Probit Model Test Results

Table V reveals the bivariate probit model test results and is based on the assumption that the error terms ε_i and ν_i in Eqs. (1) and (2), respectively, are correlated.[20]

[20] We also ran bivariate probits on subsamples formed from each of the four samples shown in Table V. As an example, consider the 1/8th–1/16th sample of market orders. Similar to Goldstein and Kavajecz (2000), we split this sample in half, based on trading volume in the pre-period. Then we split each of the two subsamples in half based on average price level in the pre-period, resulting in a set of four subsamples—high volume and high price, high volume and low price, low volume and high price, low volume and low price. The results for each subsample were not substantively different from what is reported here.

TABLE V
Bivariate Probit Model Results of Probabilities of Cancellation and Execution

Coefficient	Market orders		At-the-quote limit orders	
A. Spread = \$1/8 in the pre-period and \$1/16 in the post-period				
Probability of cancellation				
PRE: MSP $\leq \theta$	−0.185***	(0.060)	−0.133***	(0.009)
PRE: MSP $> \theta$	0.117*	(0.062)	−0.031	(0.031)
10A1: PRE	0.723***	(0.048)	0.156***	(0.023)
10A1: POST	0.605***	(0.043)	0.187***	(0.022)
ENTRY $\times 10^{-5}$	−0.566***	(0.121)	−0.033	(0.063)
PRICE $\times 10^{-2}$	0.290***	(0.032)	0.518***	(0.019)
OSIZE $\times 10^{-6}$	0.776	(1.927)	−8.346***	(1.040)
TICK	−0.181***	(0.018)	−0.338***	(0.009)
INDIV	−0.901***	(0.076)	−0.621***	(0.056)
RETURN	−9.351***	(2.207)	−11.352***	(0.984)
VOLUME	−0.088***	(0.008)	−0.171***	(0.004)
ASIZE $\times 10^{-3}$	0.718***	(0.068)	1.103***	(0.030)
Probability of execution				
PRE: MSP $\leq \theta$	0.316**	(0.140)	−0.133*	(0.069)
PRE: MSP $> \theta$	−0.533***	(0.127)	−0.150**	(0.074)
10A1: PRE	−0.859***	(0.266)	−0.164***	(0.060)
10A1: POST	−0.326	(0.238)	−0.145	(0.091)
ENTRY $\times 10^{-5}$	−8.166***	(0.917)	−5.811***	(0.721)
PRICE $\times 10^{-2}$	0.330*	(0.182)	0.374	(0.255)
OSIZE $\times 10^{-6}$	7.755	(7.224)	−16.077***	(4.774)
TICK	0.133	(0.092)	0.430***	(0.082)
INDIV	0.130	(0.346)	−0.033	(0.228)
RETURN	−6.620	(6.182)	−1.497	(5.125)
VOLUME	0.184***	(0.036)	0.225***	(0.041)
ASIZE $\times 10^{-3}$	−1.491***	(0.288)	−2.298***	(0.164)
Test statistic	$\rho = 0.135$	(1.012)	$\rho = 0.306$	(0.531)
B. Spread = \$1/8 in the pre-period and \$1/8 in the post-period				
Probability of cancellation				
PRE: MSP $\leq \theta$	−0.370***	(0.085)	−0.450***	(0.011)
PRE: MSP $> \theta$	0.450***	(0.088)	0.122***	(0.042)
10A1: PRE	0.920***	(0.062)	0.174***	(0.027)
10A1: POST	0.470***	(0.064)	0.051	(0.033)
ENTRY $\times 10^{-5}$	−0.341**	(0.143)	−0.394***	(0.074)
PRICE $\times 10^{-2}$	0.375***	(0.038)	0.429***	(0.022)
OSIZE $\times 10^{-6}$	15.209***	(4.137)	−7.872***	(1.519)
TICK	−0.253***	(0.022)	−0.291***	(0.011)
INDIV	−1.131***	(0.117)	−0.968***	(0.075)
RETURN	−7.115***	(2.509)	−19.596***	(1.253)
VOLUME	−0.072***	(0.010)	−0.160***	(0.005)
ASIZE $\times 10^{-3}$	0.687***	(0.099)	1.395***	(0.043)

TABLE V—*Continued*

Coefficient	Market orders		At-the-quote limit orders	
Probability of execution				
PRE: MSP $\leq \theta$	0.236	(0.199)	0.279	(0.185)
PRE: MSP $> \theta$	−0.547***	(0.194)	−0.148	(0.094)
10A1: PRE	−0.774*	(0.405)	−0.020	(0.104)
10A1: POST	−0.227	(0.287)	0.128	(0.092)
ENTRY $\times 10^{-5}$	−7.130***	(1.836)	−6.393***	(1.288)
PRICE $\times 10^{-2}$	0.071	(0.277)	0.325	(0.280)
OSIZE $\times 10^{-6}$	28.787	(20.255)	−17.770***	(7.234)
TICK	0.169	(0.134)	0.400***	(0.085)
INDIV	0.437	(0.483)	0.055	(0.433)
RETURN	7.501	(5.696)	−1.432	(10.412)
VOLUME	0.154***	(0.024)	0.258***	(0.040)
ASIZE $\times 10^{-3}$	−1.585***	(0.195)	−2.592***	(0.290)
Test statistic	$\rho = 0.332$	(1.039)	$\rho = 0.326$	(0.654)

This table reports the results from the bivariate probit models of the probabilities of cancellation and execution. PRE is a dummy variable set to 1 if the order is from the pre-period; 0 otherwise. For market orders, 10A1 is a dummy variable equal to 1 if the MSP is greater than the bid; 0 otherwise. For at-the-quote limit orders, 10A1 is equal to 1 if MSP is greater than the ask; 0 otherwise. ENTRY is the difference between the order time and 9:30AM in seconds. PRICE is the midpoint of the spread at order submission. OSIZE is the order size in shares. TICK is equal to one if the trade previous was an uptick; 0 otherwise. INDIV is a dummy variable equal to 1 if the order was placed by an individual; 0 otherwise. RETURN is the return in the 15 min prior to order submission, but if the order is submitted within the first 15 min of trading, it is the return from the opening. VOLUME is the natural log of the traded volume from 1/1/97 to 5/31/97. ASIZE is equal to the depth ahead of the short order. θ is the bid price for the market order regressions and the ask price for the at-the-quote limit regression. */**/*** indicates the estimate is significantly different from zero at the 10%/5%/1% level, respectively. Standard errors are in parentheses.

The test statistic, ρ, that measured this correlation was not significant at the 10% level for any of the four cases. Thus, we cannot reject the null hypothesis that the probability of cancellation and the probability of execution are not jointly determined.[21] This suggests that investors do not cancel their short-sell orders because they think they will not execute, but instead is consistent with investors canceling orders to reduce the costs of exposing their order.

Consider the probability of cancellation results shown in the top half of both panels of Table V first. As shown in Table IV, the coefficient labeled PRE: MSP $\leq \theta$ reveals the impact of teenies on the probability of cancellation when MSP is less than or equal to the bid for market orders and the ask for at-the-quote limit orders. Table V shows that it is significantly lower in the pre-period for both

[21] Because of the lack of significance of the test statistic it is not surprising that the bivariate probit model results are not substantively different from the results obtained for univariate probit and logistic models that were applied separately to the probability of cancellation and execution.

types of orders in both samples. Particularly important is the observation that the probability is significantly lower in the pre-period for the at-the-quote limit orders in both samples, since roughly 92% of these orders are placed when MSP is less than or equal to the ask.

As shown in Table IV, the coefficient labeled PRE: MSP $> \theta$ reveals the impact of teenies on the probability of cancellation when MSP is greater than the bid for market orders and the ask for at-the-quote limit orders. Table V shows that it is not significantly different from zero at the 5% level for either type of order in the 1/8th–1/16th sample. Surprisingly, however, it is significantly higher in the pre-period for both types of orders in the 1/8th–1/8th sample. A possible explanation can be found in subsequent test results from the 1/8th–1/8th sample that reveals quicker execution (see Tables VI and VII) of these orders in the post-period than in the pre-period. Since there is less opportunity for them to be cancelled in the post-period, it is no longer surprising that they had higher cancellation rates in the pre-period.

In general, orders have a greater likelihood of being cancelled if they: (1) involve stocks with higher prices (PRICE), lower trading volume (VOLUME), and lower pre-order returns (RETURN); (2) are placed earlier in the day (ENTRY), on downticks (TICK), and not by individuals (INDIV); and (3) are placed when the Uptick Rule is impeding their execution in either period (10A1: PRE and 10A1: POST). In addition, the probability of cancellation is positively related to the depth in the limit order book ahead of the short order (ASIZE).

The bottom half of the two panels of Table V provides the results for the probability of execution. The reported coefficient labeled PRE: MSP $\leq \theta$ indicates that this probability is of the correct sign in the pre-period for both types of orders in both samples when MSP is less than or equal to the bid for market orders and the ask for at-the-quote limit orders, and is statistically significant in two of the four cases. These results can be attributed to increased quote-jumping and a decrease in the depth of the limit order book with the advent of teenies.

The coefficient labeled PRE: MSP $> \theta$ indicates that the probability of execution was significantly lower in the pre-period for both types of orders in both samples (with the exception of at-the-quote limit orders in the 1/8th–1/8th sample, where it was lower but not significantly so) when MSP is greater than the bid for market orders and the ask for at-the-quote limit orders. Again, these results are consistent with the increased presence of quote-jumping and decreased depth in the limit order book associated with teenies.

In general, orders have a greater likelihood of being executed if they: (1) are placed earlier in the day (ENTRY) and are for a smaller number of shares (OSIZE; but only for at-the-quote limit orders), (2) involve stocks with greater trading volume (VOLUME), (3) are placed on upticks (TICK; but only for at-the-quote limit orders), and (4) are placed when the Uptick Rule is not impeding their execution in the pre-period (10A1: PRE). In addition, the probability of execution is negatively

TABLE VI
Censored Regression of Time to Execution of Short-Sell Orders

	Spread = \$1/8 in pre-period and \$1/16 in the post-period				Spread = \$1/8 in pre-period and \$1/8 in the post-period			
Coefficient	Market orders		At-the-quote limit orders		Market orders		At-the-quote limit orders	
PRE: MSP$\leq \theta$	−0.210***	(0.047)	0.208***	(0.016)	−0.323***	(0.066)	−0.392***	(0.022)
PRE: MSP $> \theta$	0.478***	(0.052)	0.164***	(0.059)	0.999***	(0.071)	0.496***	(0.084)
10A1: PRE	2.245***	(0.039)	0.783***	(0.048)	2.095***	(0.046)	0.773***	(0.055)
10A1: POST	1.767***	(0.038)	0.619***	(0.041)	1.096***	(0.063)	0.277***	(0.067)
ENTRY $\times 10^{-5}$	−0.512***	(0.134)	0.408***	(0.111)	−0.253*	(0.167)	−0.866***	(0.144)
PRICE $\times 10^{-2}$	−0.500***	(0.036)	−0.522***	(0.034)	−0.300***	(0.041)	−0.514***	(0.042)
OSIZE $\times 10^{-6}$	6.959***	(1.562)	19.100***	(2.047)	6.781	(5.371)	27.904***	(3.386)
TICK	−0.772***	(0.021)	−1.059***	(0.017)	−0.997***	(0.025)	−0.949***	(0.022)
INDIV	−0.103*	(0.058)	0.140	(0.086)	−0.163**	(0.072)	−0.090	(0.114)
VOLUME	−0.549***	(0.010)	−0.532***	(0.008)	−0.489***	(0.012)	−0.563***	(0.011)
RETURN	−9.794***	(2.386)	−32.73***	(1.855)	−14.76***	(2.686)	−38.04***	(2.447)
ASIZE $\times 10^{-3}$	3.430***	(0.008)	4.560***	(0.059)	3.720***	(0.115)	5.101***	(0.096)
Scale	1.510	(0.008)	2.013	(0.007)	1.524	(0.009)	2.092	(0.011)
Shape	−0.205	(0.017)	−0.483	(0.015)	−0.350	(0.021)	−0.475	(0.022)
Pseudo R^2	0.564		0.368		0.562		0.326	

Note. This table reports the results from a censored regression with the time to execution (first fill) as the dependent variable and several independent variables. PRE is a dummy variable set to 1 if the order is from the pre-period; 0 otherwise. For market orders, 10A1 is a dummy variable equal to 1 if the minimum shortable price (MSP) is greater than the bid; 0 otherwise. For at-the-quote limit orders, 10A1 is equal to 1 if MSP is greater than the ask; 0 otherwise. ENTRY is the difference between the order time and 9:30AM in seconds. PRICE is the midpoint of the spread at order submission. OSIZE is the order size in shares. TICK is equal to one if the trade previous was an uptick; 0 otherwise. INDIV is a dummy variable equal to 1 if the order was placed by an individual; 0 otherwise. RETURN is the return in the 15 min prior to order submission but if the order is submitted within the first 15 min of trading, it is the return from the opening. VOLUME is the log of the traded volume from 1/1/97 to 5/31/97. ASIZE is equal to the depth ahead of the short order. θ is the bid for the market order regressions and the ask for the at-the-quote limit order regression. */**/*** indicates the estimate is significantly different from zero at the 10%/5%/1% level, respectively. Standard errors are in parentheses.

TABLE VII
Time to Execution in Minutes of Short-Sell Orders

Order type	MSP $\leq \theta$	MSP $> \theta$	All
A. Spread = \$1/8 in pre-period and \$1/16 in the post-period			
Market			
Pre-period	0.3	8.5	6.7
Post-period	0.4	5.1	4.3
Difference	−0.1***	3.4***	2.4***
At-the-quote limit			
Pre-period	14.3	47.8	16.0
Post-period	8.5	28.9	9.4
Difference	5.8***	18.9***	6.6***
B. Spread = \$1/8 in the pre-period and \$1/8 in the post-period			
Market			
Pre-period	0.3	7.3	5.8
Post-period	0.5	2.6	2.3
Difference	−0.2***	4.7***	3.5***
At-the-quote limit			
Pre-period	15.9	47.9	17.8
Post-period	19.0	45.2	20.0
Difference	−3.1***	2.7***	−2.2***

Note. This table reports the median time to execution, in minutes, of short-sell orders. Times reported reflect the 50th percentile point of the estimated distribution, estimated with the model in Table VI. Pre-period refers to the sampled orders that were placed before the introduction of sixteenths. Post-period refers to the sampled orders that were placed after the introduction of sixteenths. */**/*** indicates the difference is significantly different from zero at the 10%/5%/1% level, respectively, using a Wilcoxon signed rank test.

related to the depth in the limit order book ahead of the short order (ASIZE) for both order types and spreads. This is expected, as the NYSE observes what is referred to as priority, parity, and precedence.[22]

3.3. Time to Execution

In estimating the time to execution of short-sell orders, consideration must be given to both executed orders and those not executed because they expired without being filled or were cancelled. Ignoring these censored orders most certainly biases the time to execution. We employed a survival analysis model similar to Lo *et al.* (1997) to more accurately measure the time to execution by accounting for all orders, not just the executed ones. The dependent variable is the time to execution, which is censored at the time of cancellation for cancelled orders and censored at the close for expired orders. The independent variables are the same as those used in Table V.

[22] Rule 72 of the New York Stock Exchange (1989) describes the secondary priority rules in the NYSE.

Table VI, reporting the time to execution results, indicates that orders placed on downticks (TICK) and when the Uptick Rule is blocking their execution (10A1: PRE and 10A1: POST) have a longer time to execution. As expected, for all order types and spreads, the time to execution is negatively related to the stock's trading volume (VOLUME), price (PRICE), and pre-order return (RETURN) and positively related to order size (OSIZE) and the depth ahead of the short order (ASIZE). These results are consistent with the probability of execution bivariate probit results presented in the previous table.

The PRE variable once again is a dummy variable denoting whether the order is submitted in the pre- or post-period. And as in Table V, by allowing for an interaction term with the MSP dummy variable, we must evaluate two cases. In the first case when MSP is less than or equal to the bid, the time to execution is significantly quicker in the pre-period for market orders in both samples. At-the-quote limit orders receive significantly slower execution in the pre-period when MSP is less than or equal to the ask for the 1/8th–1/16th sample, but faster execution in the pre-period for the 1/8th–1/8th sample. In the second case when MSP is greater than the bid, market orders in both samples receive slower execution in the pre-period in both samples. In addition, at-the-quote limit orders in both samples also receive slower execution in the pre-period when MSP is greater than the ask.

Table VII shows the median time to execution of short-sell orders using the censored regression model from Table VI where consideration is given to not only executed orders but also to those that were cancelled or expired. Consistent with Table VI, the model estimates a significantly quicker time to execution overall for both types of orders and for the subsamples that are conditioned on the location of MSP after the change to sixteenths pricing, with three exceptions. These exceptions are for market orders in both samples when MSP is less than or equal to the bid and for at-the-quote limit orders in the 1/8th–1/8th sample when MSP is less than or equal to the ask; in these cases, execution was significantly quicker in the pre-period.

In summary, consistent with the model of Harris (1996, 1997), the results presented in Tables V, VI, and VII show an increase in quote jumping and order cancellation associated with the advent of teenies.[23] The quality of execution of short market orders that are placed when MSP is greater than the bid (which occurs most of the time) has been improved by the introduction of teenies. This is due to the decreased depth at the ask for orders placed in markets where the spread is one tick and the increased ability of such orders to step ahead of other orders in

[23] We also examined price improvement for short market orders (all short at-the-quote limit orders that are executed, by definition, receive price improvement since they are executed above the bid). Conditioned on execution, 3.6% fewer short market orders in the 1/8th–1/16th sample received price improvement in the post-period than in the pre-period, but 12.5% more received price improvement in the 1/8th–1/8th sample; both of these differences are statistically significant at the .01 level. Thus, faster execution means a higher probability of a better price for market orders when the spread is larger than a tick.

the order queue when the spread is larger than one tick. Short at-the-quote limit orders that are placed when MSP is greater than the ask have also benefited from the introduction of teenies due to the reduced depth in the limit order book. As for short at-the-quote limit orders that are placed when MSP is at or less than the ask (which occurs most of the time), the impact of teenies when the spread is one tick is unclear. However, when the spread is larger than a tick, the quality of execution for such orders is worse after teenies as other orders now have an increased ability to step ahead of them in the order queue.

4. CONCLUSIONS

Our analysis suggests that a move to decimalization, as recommended in the SEC's Market 2000 report, would lessen the impact of the Uptick Rule when it comes to short market orders, even in declining markets. If the Rule blocks immediate execution of these orders, then such orders will find it easier to step ahead of other orders in the queue when the spread is larger than one tick. For example, consider a penny pricing system where a stock is quoted \$20.00 bid and \$20.05 asked with the last trade being at \$20.00 on a downtick. In this situation a new short market order will have limit price set to \$20.01 and the specialist will requote the market to \$20.00 bid and \$20.01 asked. Thus, the market order will have jumped the ask and narrowed the spread to one tick, making execution easier. Furthermore, execution will be easier even if the spread is already one tick due to the likely reduced depth at the ask after decimalization that the short order will be placed behind.

In contrast, short at-the-quote limit orders in markets where the spread is larger than the minimum tick size are likely to be hurt by a smaller tick size, as other sell orders will have a greater opportunity to step ahead of them. Consequently, the Uptick Rule will be more of a hindrance to the execution of such short-sell orders under decimalization. This is of concern since, as noted earlier, most short-sell orders are at-the-quote limit orders, and most spreads under teenies are larger than a tick. Thus, a move to decimalization (particularly pennies) can be expected to bring about an increase in the amount of quoting jumping taking place, benefiting certain kinds of short-sell orders but hurting others.

Hence, the Uptick Rule will need to be redesigned with the move to decimalization, as it will become a greater hindrance to the execution of most short at-the-quote limit orders that are placed on organized exchanges where the spread is greater than a tick.[24] Since this will happen even to those orders that are placed in

[24] Interestingly, the SEC has approved the NASD's amendment to their short sale rule which redesigns the Minimum Increment Rule (see NASD notice to Members 97-74 at the Web site, www.investor.nasd.com /notices/9774ntm.txt). The Minimum Increment Rule was implemented to ensure that short sales were not effected at prices so close to the inside bid during down markets that they were inconsistent with the underlying purposes of the short sale rule. Accordingly, the NASD has

advancing markets, the Uptick Rule will continue to fail to meet one of its primary objectives, namely, to allow relatively unrestricted short-selling in such markets. Thus, the SEC's recent concept release concerning the Rule (U.S. Securities and Exchange Commission, 1999) is very timely.

While there would appear to be a good case for eliminating the Rule (Alexander and Peterson, 1999), the evidence here suggests a simple revision if it must be kept in some form.[25] The Rule will continue to hinder the execution of short market orders, but to a much smaller degree, when decimalization occurs. Consequently, there is no compelling reason to revise the Rule with respect to such orders. However, since most short at-the-quote limit orders will be adversely affected by the Rule when decimalization occurs, a simple remedy is to make the Rule inapplicable for them, as these orders, by definition, do not precipitate price declines. For a similar reason, the remedy would also make the Rule inapplicable for short quote-improving orders.

Besides suggesting a need to revise the Uptick Rule, another implication of a move to decimalization is that short-sellers may use relatively more market orders, but fewer at-the-quote limit orders, and cancel their orders more frequently and more quickly. Since about 62% of all short-sell orders placed in the pre- and post-periods are at-the-quote limit orders, it is possible that the net effect will be fewer short-sell orders in aggregate.[26] If so, then it is possible that the move to decimalization will be detrimental with respect to both market liquidity (see Harris, 1996) and market efficiency (see Miller, 1977, and Diamond and Verrecchia, 1987). Whether this will actually happen upon the move to decimalization remains to be seen.

amended the Minimum Increment Rule to provide that a "legal" short sale must be effected at a price equal to or greater than the ask when the inside spread is less than 1/16th. There would be no change to the current definition for stocks with a spread of $1/16 or greater. In other words, on a down-bid when the spread is greater than or equal $1/16 the minimum shortable price is the bid plus $1/16. When the spread is less than $1/16, the minimum shortable price is the ask. Hence, this rule amendment prevents quote-jumping by improving the ask by $1/32 when the spread is $1/16. It remains to be seen how NASD will alter the Minimum Increment Rule when decimalization occurs.

[25] There are a myriad of other remedies, such as replacing the Uptick Rule with an 'Upday Rule' where short-selling is prohibited at a price less than the previous day's close (we thank the referee for suggesting this remedy). See U.S. Securities and Exchange Commission (1999) for additional remedies. It is possible that no remedy will be needed if Angel (1997a) is correct, as firms, desiring to maintain the same stock price relative to the tick size, would be expected to simply split their stock after decimalization. Since the average common stock price on the NYSE has decreased slightly from $43.47 on May 30, 1997 to $40.99 on May 30, 2000 (these figures can be obtained by going to the NYSE's Web site that contains its statistics archive, www.nyse.com/marketinfo/marketinfo.html, and clicking on Trading Data and Market Value; Common MktVal must be divided by Common Shrsout to get the appropriate average price) it appears that firms have not engaged in any notable splitting of their common stock since teenies were introduced nearly three years ago. Thus, if such an adjustment is to occur, it will only be in the long term. However, the Uptick Rule should be revised in the meantime.

[26] An interesting question which we leave for future research is whether a smaller tick size leads to an increase in the types of abusive short selling strategies that the Uptick Rule was designed to discourage.

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