The Effect of Tick Size on Volatility, Trader Behavior, and Market Quality[⁋]

by

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Abstract

We use the American Stock Exchange's May 1997 market-wide adoption of $1/16 ticks to examine several hypothesis relating to tick size reduction. Specifically, we consider volatility, other aspects of market quality, trader behavior, and specialist profits. The hypothesis that volatility is directly related to tick size is supported by significant decreases in both daily and transitory volatility. Consistent with the hypothesis that market quality improves after the switch, we also find that while bid-ask spreads decline, depths do not. While we find no significant changes in overall specialist profits, we develop a direct test of changes in professional traders' activity in 'stepping ahead of the book', and find an increase in this behavior, suggesting benefits to market orders through price improvement. Finally, we develop and test a model that shows that stocks with spreads greater than one tick may exhibit significant narrowing of spreads following a tick size reduction. Our results are consistent with the predictions of our model.

Key words: Market microstructure; Tick size, Volatility, Trader Behavior

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I. Introduction

A recent policy issue for security exchanges has been the adoption of decreased tick size for traded equity issues. For example, the Toronto Stock Exchange (TSE), American Stock Exchange (Amex), New York Stock Exchange (NYSE), and Nasdaq have all recently adopted market-wide tick size reductions. While previous studies have studied the impact of tick size reductions on spreads and depths, the equally important impacts on volatility and trader behavior have remained virtually unaddressed. A proper understanding of the impacts on these latter measures is necessary in order to draw appropriate and conclusive inferences regarding the overall effect on market quality. In addition, while the extant theoretical literature addressing the issue of tick reduction assumes a price/time priority system, previous empirical tests have focused on markets without price/time priority systems or alternatively, only on low-priced stocks within a price/time priority system. Of the markets mentioned, only the Amex has price/time priority for all stocks.[1]

On May 7, 1997 the Amex became the first U.S. exchange to adopt $1/16 ticks for all stocks.[2] We use the Amex's market-wide adoption of $1/16 ticks to examine several previously untested hypotheses regarding the tick size reduction. In particular, we test the hypothesis that observed volatility is directly related to tick size. The confidential database provided to us by the Amex allows us to provide the first empirical analysis of tick size impacts on professional trader behavior, such as the practice of 'stepping ahead of the book', as well as test hypotheses concerning changes in specialists' profits. In addition, the Amex's price/time priority allows us to directly test theoretical predictions, most of which assume these priority rules. For example, Harris (1994) predicts that a reduction in the tick size will cause spreads to narrow and depths to decline in a price/time priority market center. Additionally, while the Amex and one former trading system of the TSE have similar priority rules, they differ in the amount of information available to traders

[1] The NYSE maintains price/parity priority, Nasdaq has no priority rules, and the TSE currently uses price/sharing priority rules for all of its stocks. One trading system of the TSE used price/time priority rules for its stocks at the time of a tick reduction. However, the stocks in that system were generally less liquid than stocks in the other TSE system. Therefore, results for the TSE cannot be generalized across all stocks.

[2] The Amex has been gradually decreasing its tick size since 1992. In August 1992, the tick size was reduced from $1/8 to $1/16 for all stocks priced below $5, and subsequently for all stocks below $10 in February 1995

about existing order flow (known as pre-trade transparency). As Harris (1997) points out, to the extent that tick size affects quotation sizes, the impact of tick size reduction on market quality may vary with the amount of pre-trade transparency. While the TSE reveals size for prices away from the inside market, the Amex (and all other US equity markets) reveals size for the inside bid and ask only.

Thus, the impact of this study is threefold: 1) we test the theoretical prediction that volatility is directly related to tick size, 2) our data base allows testing of hypotheses regarding changes in trader behavior and specialist profits, and 3) the price/time priority rules specific to the AMEX afford the opportunity to directly test extant theoretical predictions. The tests we conduct provide evidence in support of the hypothesis that market quality is not hampered by the tick reduction: while dollar spreads decline, depths do not decrease. Additionally, significant volatility decreases are observed, and are attributed to the tick size reduction.

This paper's contributions to the growing literature on tick size and its impact on market quality and trading behavior are immediate. For example Harris (1996) examines the impact of tick size on order exposure; Cordella and Foucault (1996), Angel and Weaver (1998), and Panchapagesan (1998) examine the impact of tick size and priority rules on order submission strategies. Anshuman and Kalay (1994), Bernhardt and Hughson (1993), Chordia and Subrahmanyam (1995) and Kandel and Marx (1997) show that non-trivial ticks can lead to uncompetitive spreads. Chordia and Subrahmanyam (1995) further show that non-trivial ticks can lead to uncompetitive practices such as preferencing of order flow. Finally, Angel (1997) points out that firms can keep their relative tick constant by splitting their shares as tick sizes are reduced, such that firms, and not exchanges will determine the lower bound on relative ticks. This paper can thus be seen as having important policy implications for exchanges (who use trading rules, including tick size, to attract order flow) and is of interest to both academics and regulators (who must measure the social cost of different trading rules).

Prior research on tick changes includes Ahn, Cao, and Choe (1996), and Crack (1995) who examine the 1992 tick reduction on the Amex for stocks trading under $5. Both studies find reduced spreads of about 10 percent.[3] Several other studies examine recent decreases in tick changes on the TSE. They include Ahn, Cao, and Choe (1997), Bacidore (1997), Huson, Kim and Mehrota (1997), and Porter and Weaver (1997). While these studies differ in sample and methods, they generally conclude that market quality improved following the TSE's tick size reduction.[4] The impact of tick size reduction on institutional trading costs is analyzed in Jones and Lipson (1998). Finally, Goldstein and Kavajecz (1998) examine limit order book depth away from the inside market following the NYSE's tick size reduction. They find depth reductions throughout the entire limit order book. While all of the existing studies on tick size changes examine changes in depth at or away from the inside market, we also test competing hypotheses on expected changes to depth for stocks that had binding spread widths prior to (and that did not exhibit a narrowing of spread after) the tick reduction. Harris (1994) predicts that depths for those stocks will decline since liquidity providers face an increased risk of price improvement. In contrast, Chordia and Subrahmanyam (1995) suggest that depths will not decline since liquidity providers are competing to capture excess rents. Our findings support the Harris (1994) model.

In addition, while none of the existing studies provide direct evidence on the impact of tick reductions on volatility, this paper tests Harris' (1990) conjecture that volatility is related to the tick size. Our finding of a significant reduction in volatility (conditioned on potentially confounding variables) provides support for Harris (1990) and shows that tick size reductions can improve market quality on dimensions not previously considered.

We develop a model which illustrates that the probability of spread narrowing following a tick size reduction is directly related to the amount of tick-induced rounding prior to the reduction and that this can occur in stocks without tick-induced lower bounds on observed spreads. Our results are consistent with the predictions of our model. We also examine the impact of a tick size reduction on trader behavior. In particular we provide the first empirical test of Harris' (1996) theory

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[3] Ahn, Cao and Choe (1996) examine the impact of the September 3, 1992 Amex switch to 'teenies' for stocks with prices under $5. The authors do find reductions in spreads, but no significant changes in depths or volume. That paper is subject to some testing difficulties, however, as the control groups are drawn from the NYSE. Further, no formal significance tests are conducted. Other data limitations also prevent the authors from directly testing for changes in market maker profits. Finally, only low-price stocks are considered, which weakens the generality of their results.

[4] See Harris (1997) for a comprehensive review of these papers.

that a reduction in tick size will increase the occurrence of traders providing price improvement to incoming market orders. We find that price improvement increases following tick size reduction. This benefits market orders to the detriment of limit orders. Finally, while Porter and Weaver (1997) provide direct evidence on changes in market maker profits following the TSE switch to decimalization, no previous evidence exists for U.S. markets. Our specialist participation data indicates no change in market maker profits directly due to the AMEX tick size reduction.

The paper is organized as follows. Section II provides a data description. Section III discusses the issues, states our hypotheses, and discusses our results. Section IV provides concluding remarks.

II. Data

Our data set consists of all American Stock Exchange stocks that underwent a regime change in tick size on Wednesday, May 7, 1997. The data span the period April 1, 1997 through June 30, 1997. To prevent biases that may affect the analysis, we omit one full trading week before and one full trading week after the change. Thus, we define the pre-change period as the four-week period from Wednesday, April 2 through Tuesday, April 29, and the post-change period as the four-week period from Thursday, May 15 through Thursday June 12. Each sample consists of 20 trading days.

Certain inclusion constraints are enforced. We consider all common stocks that traded above $10 during the pre-period, which did not split or undergo a price change of more than 50% over the entire period, and for which there are at least 50 quote revisions in each period (pre and post). These constraints result in a sample size of 324 firms.

Our data include all trade and quote records for the period surrounding our study. Each quote record details the time-stamped bid and ask as well as respective sizes and exchange origin. Each transaction record is time-stamped and includes the price and quantity. Additionally, each transaction record breaks down each Amex originated trade into its components. Thus, we are able to determine the exact nature of each side of the trade. For example, large orders are often filled by multiple contra orders. If a market order to buy 10,000 shares is filled by several limit orders at the inside with the remainder filled from the specialists inventory, our data set identifies the large buy order, the individual sell orders filling it and the specialist participation (buy or sell) in each trade.

III. The Issues

In this section, we develop the arguments regarding the potential impacts of a reduction in tick size on market quality. Specifically, we consider execution costs, other forms of liquidity, and volatility. We then consider the effects on trader behavior. Finally, we discuss potential market maker profits that may change as a result of the switch to ‘teenies’. Our results are consistent with the hypothesis that market quality is not reduced by the tick reduction: While spreads decline, we observe no significant changes in depth and significant decreases in volatility.

Spreads

Typically, measures of execution costs are based on the bid-ask spread. Several factors could cause changes in spread width as a result of the switch to $1/16 ticks. Specifically, spreads are expected to narrow with the tick reduction. This could be due in part to either price competition or price discreteness. Under the price competition argument, as the tick size decreases, the propensity of traders to improve on price will increase, resulting in narrower spreads. The price discreteness argument states that discrete prices causes traders to round desired spreads to the next highest tick. When tick sizes decline, observed spreads can move closer to desired spreads, hence observed spreads will decrease. In this section, we directly test these hypotheses, using alternate spread measures.

As there is no one measure of spread that is relevant for all traders, we consider several. For example, some traders think of spread in dollar terms while others prefer to think of them in (price) relative terms. Also, while some traders are satisfied with executing at currently available quotes, others routinely seek price improvement. Finally, large-order traders may be forced to either make price concessions in order to execute trades, or to break up execution of the order over time to avoid adversely impacting execution prices. Accordingly, to address relevant costs for these different types of traders, researchers typically measure spreads in several different ways. The most common way to measure execution costs is the quoted dollar spread (defined as $A_{i,t}$ -$B_{i,t}$), where $A_{i,t}$ and $B_{i,t}$ are the inside ask and bid quotes for firm *i* at time *t* . Alternatively, quoted percentage spread (defined as 2($A_{i,t}$ -$B_{i,t}$)/($A_{i,t}$ -$B_{i,t}$)) expresses the quoted spread as a percentage of price. Effective dollar spreads (defined as 2*| $P_{i,t}$-$M_{i,t}$ |) where $P_{i,t}$ is the price of stock *i* at time *t,* and $M_{i,t}$ is the midpoint of the spread for firm *i* at time *t,* takes into account the transaction price. Finally, effective percentage spreads (defined as [2*| $P_{i,t}$-$M_{i,t}$ |]/ $M_{i,t}$) expresses the effective spread as a percentage of price

Although consensus opinion maintains that execution costs will generally decline following a reduction in tick size, several studies have suggested that the impact may not be uniform across the various measures used, and may vary across trade sizes and stock price levels. Harris (1996) argues that in systems that give priority to price-improving orders, the level of competition among traders will be inversely related to the tick size since it measures the minimum cost of obtaining priority. Therefore, a reduction in tick size should lead to increased price competition, which results in narrower quoted dollar spreads. To the extent that traders consider the cost of price-improvement (the tick size) as a percentage of price, we would expect higher priced stocks to exhibit the greatest reductions in dollar quoted spread following a reduction in tick size (since on a percentage basis price improvement is smallest for these stocks).

Harris (1994) argues that the economic importance of tick size is most evident when percentage spreads are examined. While a $1/4 spread is only 0.50% of the price of a $50 stock, a $1/8 spread is 6.25% of a $2 stock. He argues therefore, that ticks can create lower bound constraints on relative spreads for low -priced stocks. That is, tick-induced discreteness prevents spreads from narrowing below $1/8. The empirical findings of Chung, Kryanowski, and Zhang (1997) support this notion. They examine the impact of tick size reduction on the Toronto Stock Exchange and find that in their sample of stocks, those with binding ticks prior to the change experience the largest spread reduction following the change.

Although this “discreteness effect” prevents spreads from narrowing below $1/8 it can also prevent spreads greater than $1/8 from reaching their equilibrium level. Therefore, the “discreteness effect” potentially exists for both dollar and percentage spreads for *all* stocks, as shown by the following model.

Let the "true" spread, S^*, be defined as the spread necessary for market makers to earn an economic profit. Further, let S be the quoted spread and τ be the exchange-imposed non-zero tick size.[5] It can then be shown that

$$S = Int\left(\frac{S^*}{\tau}\right)\tau + \gamma\tau \tag{1}$$

where *Int(•)* yields the integer portion of a function and γ is an indictor variable equal to 1 if $Int\left(\frac{S^*}{\tau}\right) ? \frac{S^*}{\tau}$, otherwise 0. It can then be seen that $S = S^*$ only if S^* is a multiple of τ, otherwise $S > S^*$.[6] That is, the quoted spread equals the true spread only if the tick size approaches zero, or if the true spread is a multiple of the tick size. Otherwise, the quoted spread will be rounded up to the next largest tick (if the quoted spread were less than "true" spread, market makers would not earn an economic profit and would exit the market). Therefore, discreteness may cause quoted spreads to be wider than "true" spreads.

Further examination of the model allows us to determine the conditions under which quoted spreads will narrow following a reduction in tick size. Let τ' be the new tick such that $\tau' < \tau$ and let S' be the observed quote following the reduction in tick. It can be shown that $S' < S$ only if $S - S^* > \tau'$, otherwise $S' = S$. In the case of the Amex, this is consistent with spreads narrowing (after the switch to 1/16th's) only if the difference between the old quoted spread and the old 'true spread' is greater than 1/16th. Thus, we show that the spread reduction can occur due to discreteness even if equilibrium spreads are greater than $1/8. In other words, while a binding spread condition may increase the probability that spreads will reduce following a tick size reduction, reductions will occur in stocks without binding spread conditions as well.

Since the hypotheses predict different spread impacts on stocks according to price level and whether a binding tick condition exists, we form both price and 'binding' quartiles where

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[5] A similar model can be developed for relative spreads by dividing *S* and ☺ by price.

[6] Our model is similar in spirit to Harris (1994), Kandel and Marx (1997,) and Rhodes-Kropf (1998.) Kandel and Marx examine competing market makers under a random priority rule. The lack of time priority allows for multiple Nash equilibria, with market makers preferring a spread one tick wider than the smaller equilibrium spread. Cordella and Foucault (1996) show that time priority (which is descriptive of the Amex) will lead to a smaller spread than under random priority. Rhodes-Kropf (1998) develops a model of competing market makers in a single auction setting.

‘binding’ is proxied by the percentage of $1/8 quotes prior to the tick reduction. Table 1 contains descriptive statistics for our sample. Although price is found to be inversely related to the percentage of observed $1/8 quotes for each stock, an examination of quartiles 1 and 4 reveals that price is not a consistent proxy for the existence of a binding condition. Therefore, we examine our execution cost measures separately by price and binding quartile.

The first execution cost we examine is quoted spread. Table 2 contains the results for dollar quoted spreads (Panel A) and percentage quoted spreads (panel B). In both cases the spreads are time-weighted. Overall dollar spreads declined by about $.02 and percentage spreads declined by 0.2 percentage points. The results for price quartiles (A.1 and B.1) are generally consistent with the predictions of Harris (1994). The highest price quartile has the smallest reductions and the next to the lowest priced quartile had the largest reduction. However, examining the results grouped by binding quartile reveals that even those stocks with least binding spreads experienced spread reduction. This is consistent with the predictions of our model and shows that a binding spread is not a necessary condition for spreads to narrow following a tick size reduction.

While our results indicate that spreads decline after the tick reduction, a relevant concern is that the reduction in quoted spread may not be directly attributable to the switch to ‘teenies’. That is, confounding effects may be driving the level changes. Stoll (1985) shows that relative spread is inversely related to price and trading activity, and directly related to volatility. Accordingly we perform a regression analysis to attempt to determine the cause of the observed reduction in quoted spread. We use the average spread (dollar or percentage) for each firm, $\overline{M}_{i,t}$, for the pre- and post- periods as our dependent variable. Our price measure, $Price_{I,t}$ is defined as the average closing price for firm *i* during period *t (pre or post),* $Volume_{I,t}$ is the average daily share volume for firm *i* during period *t*; and used as a proxy for trading activity. Volatility is measured as the average standard deviation of daily return for firm *i* during period *t,* and to test for changes due to the tick size reduction we use a dummy variable, $TickDummy_{I,t}$, which is assigned the value 1 if the spread measure is for the pre tick reduction period and 0 otherwise. Since the amount of spread narrowing appears to be related to whether the $1/8 tick imposed had a binding condition on a stock's spread, we also include a dummy variable, $BindDummy_{I,t}$, assigned the value of 1 if the proportion of quoted $1/8 quoted spreads was greater than 50%, otherwise zero.

If tick size reduction affects changes in quoted spreads, we would expect the parameter estimate for *TickDummy* to be significantly different from zero. The regression equations can be generally written as:[7]

$$\overline{M_{i,t}} = \beta_0 + \beta_1 \overline{Price_{i,t}} + \beta_2 \overline{Volume_{i,t}} + \beta_3 \sigma_{i,t} + \beta_4 TickDummy_{i,t} + \beta_5 BindDummy_{i,t} \quad (2)$$

If tick size reduction affects changes in market quality, we would expect β_4 to be significantly different from zero. Panel C of Table 2 documents results for the above conditioned regressions, and indicates that our quoted spread results are robust to these specifications, and therefore not merely artifacts of confounding factors. In particular, we find that a binding condition contributed to the observed decline in quoted spreads, as evidenced by the statistically significant negative parameter estimate for *BindDummy*. Examining the parameter estimate for *TickDummy* reveals that it is negative and statistically significant for both spread measures. Thus, we conclude that even after controlling for a binding condition, the tick reduction still contributes to the observed reduction in spread. This further confirms the predictions of our model for quoted spreads.

While quoted spreads may be an adequate measure of execution costs for small traders, Hasbrouck (1991) argues that large-order traders must often make price concessions to execute. In addition, Lee and Ready (1991) find that about 30% of the trades in their sample of NYSE stocks execute inside the quoted spread. Therefore, effective spreads (which takes into account the relationship between execution price and quoted spread) are often a more appropriate measure for these traders. The findings of Benston, Irvine, and Kandel (1997) as well as Jones and Lipson (1998) suggest that trade size is an additional important factor for effective spreads. Specifically,

[7] It could be argued that the relationship between spread and the independent variables changes between the pre and post period, therefore interactive variables should be used. However, Harris (1990) argues that tick size reduction will cause a reduction in observed volatility, Harris (1994) argues that tick size reduction will increase volume, while Angel (1997) argues that a smaller tick will cause a reduction in price. Therefore, it may be impossible to disentangle tick size induced changes from structural induced changes in the relationships between independent and dependent variables. Thus we do not report results of egressions including interaction variables. However, we find that when we include interaction variables, *TickDummy* is still of the correct sign but is statistically significant only for percentage quoted and percentage effective spreads.

both studies show that tick size reductions have a differential effect on trades of different sizes.[8] Accordingly, we also test whether the spread reductions observed may be a function of trade size. As in Jones and Lipson (1998), we examine effective spreads for portfolios formed of all trades; trades of less than 1,000 shares; trades between 1,000 and 9,999 shares; trades between 10,000 and 99,999 shares, and trades of 100,000 shares or more. The volume-weighted results are reported in Table 3. The results for price and binding quartiles suggest that effective spreads are reduced, but no clear pattern emerges. However, consistent with Jones and Lipson, we find that the largest reductions in dollar effective spreads occur for medium size trades between 1,000 and 9,999 shares. These findings may indicate that small traders benefit most as a result of the tick size reduction.[9]

One again, the results for effective spreads may be mere artifacts of confounding factors. Accordingly, we test for this directly by performing the regressions indicated by Equation (2) for effective dollar and percentage spread. The results are contained in Panel C of Table 3, and indicate that the majority of the reduction in effective spreads was confined to stocks with binding tick condition prior to the switch. Overall, our results support the notion that the observed narrowing documented in panels A and B of table 3 is not merely an artifact of confounding factors.

In summary, the reduction in tick size is accompanied by a reduction in both quoted and effective spreads. The degree to which quoted spreads narrow is inversely related to price and directly related to the percentage of $1/8 spreads (a proxy for a binding condition). The fact that spread reductions are observed in all binding quartiles supports the predictions of our model. This suggests that a binding tick condition is not a necessary condition for spread narrowing. Finally, the evidence regarding effective spread changes suggests that small traders benefit most from tick

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[8] Benston, Irvine, and Kandel (1997) develop a measure of effective spread which is independent of a transaction occurring and incorporates a notion of price impact. They assume that incoming orders will execute exclusively against the book at subsequent price levels. They argue that changes in depth away from the inside market will impact order execution quality. They employ order data to reconstruct a dynamic limit order book. We do not have order data therefore, we are unable to construct their measure. Jones and Lipson (1998) use the Plexus database, and as such are able to calculate transaction cost measures based on the standing quotes *at the time the order was placed*. Standard effective spread measures assume the order was placed at the time of execution, and therefore may impart a bias for large orders that may take a while to be "worked."

[9] Ahn, Choe, and Cao (1997), Porter and Weaver (1997), and Goldstein and Kavajecz (1998) suggest that trading activity is an important predictor of tick size effects. In a previous version of this paper we ranked stocks according to high/low price and volume and formed two dimensional quadrants. The results from partitioning by price and volume are consistent with the findings reported here for both quoted and effective spreads.

reduction. In the next two sections we examine the impact of tick size reduction on other measures of liquidity.

Depths

Another component of liquidity examined in this paper is depth. Recent studies indicate that spreads should not be examined in isolation when considering liquidity provision. See for example, Lee, Mucklow, and Ready (1993) who find that volume shocks impact liquidity by simultaneously widening spreads and reducing depths. Goldstein and Kavacjez (1997) examine the impact on the depth of the NYSE limit order book subsequent to that exchange's tick reduction. Finally, Rhodes-Kropf (1998) provides theoretical justification for spread narrowing to be accompanied by depth reductions following tick reductions.[10] Accordingly, we also examine the effect of the tick reduction on depths. The theoretical predictions support a decline in depths following the tick reduction. See for example, Harris (1994), who argues that large minimum ticks (and time precedence) protect traders from 'quote matchers' who improve on price following the exposure of a large (informed) trade. A smaller tick reduces the cost of stepping in front of exposed orders, therefore traders are more reluctant to expose their orders if the tick size declines. These lead to a lowering of the quoted depth.

Recent empirical evidence also supports this hypothesis. Bacidore (1997) and Porter and Weaver (1997) both report significant reductions in depths for their sample of Toronto Stock Exchange stocks subsequent to tick price changes. Goldstein and Kavajecz (1998) examine the impact of the NYSE tick reduction and find that quoted depths decline throughout the entire limit order book. We test the hypothesis that depth, measured as the sum of the NBBO ask and bid depths is equal across periods (before and after tick reduction). Changes in time-weighted depths across periods are tested with paired *t*-tests. Table 4 indicates that while overall there are no significant changes in depth following the tick reduction, stocks in the most binding quartile do exhibit a statistically significant decline in depth.[11]

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[10] His model is derived under the assumption of competitive market makers in an auction setting.

[11] As reported earlier, in a previous version of this paper we partitioned by both price and volume. Those results are consistent with the results reported here.

The statistically significant decline in depth for binding quartile 1 supports the Harris (1994) conjecture that traders will withhold revealing their orders since 'price improvers' can now step in front of them at minimal cost, whereas this was not possible at the former one-tick spread.[12] An alternative explanation for the reduction in depth can be found in Chordia and Subrahmanyam (1995). In Chordia and Subrahmanyam's model, finite tick sizes can cause quoted prices to be greater than specialist and off-floor market-maker reservation prices. They use this fact to show that off-floor market-makers can pay a small amount for order flow and still earn rents in excess of their reservation prices. The same logic can be applied to traders who might pile-on liquidity if they can earn excess rents. When the tick size is then reduced, spreads should narrow towards reservation prices and excess rents should decrease, causing a reduction in quoted depth. Thus, while both Harris (1994) and Chordia and Subrahmanyam (1995) predict a decline in depth following a reduction in tick size, these two theories imply different predictions for stocks that do not experience spread declines following the tick reduction. Accordingly, we conduct a test to distinguish the two theories from each other.

We identify the 58 stocks from binding quartile 1 that had a $1/8 spread at least 50% of the time, and further reduce our sample by excluding stocks that had an average quoted dollar spread of less than $1/8 following the tick size reduction. The resulting sample is comprised of 44 stocks that had binding ticks prior to, and did not experience a decline in spread following, the tick size reduction. Empirical support for Harris (1994) implies empirically observed declines in depth for this sample, since traders can now step in front of existing orders at little cost. Alternatively, if we observe no depth declines, the Chordia and Subrahmanyam (1995) hypothesis is supported in that excess rents (spreads did not narrow) may still exist, inducing traders to provide liquidity. We find that depth declined by a statistically significant average of 2,600 shares, a finding that lends support to Harris (1994).

Although we find that depths decline for some stocks, the fact that the majority of the stocks in our sample experienced no change in depth is surprising, especially in light of recent evidence from other exchanges reporting significant depth declines. A specialist convention of quoting

[12] Harris (1994) actually refers to them as 'quote matchers.' We think the term 'price improvers' is a better descriptor since they aren't matching the quote, they are improving on price.

minimum depths may explain the fact that we find no statistically significant overall change in depth. Conversations with exchange officials revealed that many specialists feel obligated to quote minimum depths of 500 or 1,000 shares. The frequency distributions of quoted bid and separately ask depths indicate that the most commonly found NBBO bid or ask depths observed in both the pre and post periods are 500 and 1,000 (occurring about 12% of the time each for the pre period, and 13% of the time each in the post period). Thus, while depths are not decreasing in our sample, this may be attributable to the minimum quoted size convention, which may be masking a reduction in public liquidity on the Amex and regional exchanges.[13]

Volume

A second measure of liquidity is volume. Harris (1994), predicts increases in volume due to a smaller tick size. Since traders face lower trading costs, they are more willing to trade (increasing volume). Table 5 indicates no significant change in share volume for any price or binding quartile. These findings are consistent with recent evidence form other studies indicating reductions in volume or insignificant changes after the tick reduction. See for example, Ahn, Cao and Choe (1997), Bacidore (1997), Bessembinder (1997), Huson, Kim and Mehrotra (1997), Ricker (1997), and Porter and Weaver (1997).

These results are puzzling given the theoretical predictions of an increase in volume following a reduction in tick size, and may be attributable, at least in part, to the partitioning method employed here. Ahn, Cao, and Cho (1997), Porter and Weaver (1997), and Goldstein and Kavajecz (1998) suggest that trading activity is an important predictor of tick size effects. To test if pre tick-reduction volume is a determinant of volume changes we rank stocks according to price and volume and form two dimensional (price and volume) quadrants. The results are presented in Panel C of Table 5. Interestingly, Panel C indicates significant increases in volume in the low price/low volume quadrant (47.5%) as well as the high price/low volume quadrant (85%). If the increase in volume is due to spread narrowing, we would expect the high price/low volume

[13] A second possible explanation for the discrepancy is that our definition of depth is capturing other effects not associated with tick size reduction. Recall that we use the NBBO depth, which is the aggregate sum of inside quote depths across exchanges. If one or more of the exchanges had an increase in depth unrelated to the tick reduction, this may mask any decrease in the depth quoted by the remaining exchanges. Prior to the beginning of our study period, the CHX undertook a program to increase trades in Amex-listed stocks, which may account for our results.

quadrant to exhibit the largest decline in spread following the tick reduction. Accordingly, we estimate the quoted dollar and effective spread based on the same price/volume partitions. We find that for both quoted dollar and percentage spread the high price low volume quadrant exhibited the lowest spread narrowing (albeit by a small amount). This is inconsistent with Harris (1994) and suggests that the observed increase in volume may be due to factors unrelated to the tick size reduction.

Volatility

A major issue addressed in this paper is the effect of a tick size reduction on market efficiency. Several studies have recently focused on efficiency by examining transitory volatility magnitudes and patterns throughout the day.[14] The theoretical predictions regarding the effect of the tick reduction upon volatility are mixed and attributable to different factors. The first argument, which predicts an increase in observed volatility is based on the premise that depths will decrease as a result of the tick reduction: If quoted depths decrease, more transactions may exhaust the inside depths, forcing subsequent volume to the next quote and resulting in greater transaction price variations. Conversely, theoretical justification exists in support of volatility decreases (following a reduction in tick size). Specifically, Harris (1990) shows that the variance of price changes can be decomposed into three components: value innovations, bid-ask bounce, and (tick size induced) rounding errors. That is, the discreteness of prices may magnify the bid ask bounce effect if traders round to the next available tick. Thus, a reduction in tick size should reduce this (discreteness-induced) volatility, indicating an improvement in market quality.

In general, these two predictions regarding the effect of tick reductions on volatility may co-exist, and have potentially confounding effects, rendering their empirical observability difficult. This is especially true in light of recent evidence from other exchanges, documenting depth reductions following tick reductions (See for example, Bacidore (1997), and Porter and Weaver, (1997)). In this paper, however, we are able to empirically distinguish among the two hypotheses (since we find that depths do not significantly decline for most stocks) and derive conclusions which

[14] See for example, Forster and George (1995), Cao and Choe (1994), George and Hwang (1995).

may be illustrative of investment welfare improvements (when interpreted in conjunction with our evidence on reduced spreads and increased volumes). Since depths do not decrease, any observed changes in volatility must be attributable to factors other than depth reductions.

Panel A of Table 6 indicates that volatility, measured as the standard deviation of the midpoint of quote revisions, generally decreases after the tick reduction. The significance levels reported are based on Wilcoxon paired tests. Overall, we observe a 7 percent significant reduction in volatility. These results comprise the first documented evidence of significant decreases in volatility following a reduction in tick size. Further, Panel A indicates that the volatility reductions are statistically significant for all price quartiles except the 'highest', and for all binding quartiles except the 'least'. This is largely consistent with the notion that market quality is improved: while spread reductions occur throughout and depth reductions are generally not observed, volatility reductions are observed. Since they persist even in those quartiles where depth reductions are not observed, we attribute the volatility reductions to improvements made through the reduced incidence of rounding induced by discreteness.[15] Basically, this can be summarized most simply as follows: in the absence of depth effects, there are two potential tick effects on volatility. First, when the tick size is wide, prices may be 'stickier' (will less likely bounce to the next 'far away' price), yet when the tick size is made narrower and possible increments are finer, then potential price changes may be smaller, thereby resulting in less variable price changes. However, at the same time, the number of revisions may increase in the 'finer' case, increasing the potential number of price changes, which may in turn increase observed volatility. Given the results of this paper, the second effect seems to be dominated by the former.

Table 6, Panel B indicates that daily return (defined as the return on closing quote midpoints) volatility is also reduced after the tick reduction, providing further evidence of market quality improvements. Since we are concerned that structural intertemporal volatility shifts may have transpired between the two periods examined, we test whether the standard deviation declines are attributable to the reduction in tick size. It is also true that the decrease in volatility may be related to changes in other variables, that in turn may have changed due to the tick reduction. For

[15] Indeed, although depth reductions are observed for the most binding group, the largest volatility reductions are observed in the second and third binding quartiles, for which no depth reductions are documented..

example, Jones, Kaul, and Lipson (1994) find that the number of transactions is directly related to daily return volatility (based on daily closing quote midpoints). Accordingly, we regress daily return volatility against the number of trades and a pre or post-period indicator variable. Because we find that depth reduces significantly (about 16%) for those stocks that had binding tick sizes in the pre-period, we also include a binding tick dummy variable and fit the following regression:

$$\sigma_{i,t} = \beta_0 + \beta_1 N\_Trades_{i,t} + \beta_2 TickDummy_{i,t} + \beta_3 BindDummy_{i,t} \quad (3)$$

where $\sigma_{i,t}$ is the standard deviation of return based on closing spread midpoints for firm *i* in period *t* (pre or post,) N_Trades_{It} is the number of transactions for firm *i* in period *t* (pre or post,) $TickDummy_{I,t}$ is a dummy variable assigned the value of 1 if the period is post, otherwise zero, and $BindDummy_{I,t}$ is a dummy variable assigned the value of 1 if the percentage of quoted spreads equal $1/8 in the pre period is greater than 50%, otherwise zero. Table 6, Panel C documents the results from these tests. Although the coefficient on the variable for number of trades is statistically significant and positive, consistent with Jones, Kaul and Lipson (1994), the parameter estimates for Tick Dummy and Binding Dummy are also significant and negative, implying that the volatility reduction can be attributed to the tick reduction. We thus find support for Harris' (1990) conjecture that tick size is directly related to volatility.

Of most interest, perhaps, are the patterns of transitory volatility observed throughout the trading day, both before and after the tick reduction. Several studies document transitory volatility patterns on different exchanges (See for example Cao, Choe and Hatheway (1994), Forster and George (1995), Smith (1994), and Madhavan and Panpachagesan (1998)). Accordingly, we calculate daily return volatilities based upon returns calculated using prices determined at different times of the day. Open, close, and variances based on 24 hour returns calculated at each hour (10, 11, 12,1, 2, and 3) of the trading day are reported for both the pre and post tick reduction periods. The differences in volatility in the pre and post periods are documented in Table 6 Panel C, and are significant.[16] Smith (1994) documents a U shaped pattern in 24 hour volatility throughout the day. Figure 1 graphs the pattern of daily volatility both before and after the tick reduction. Interestingly, while this pattern is clearly seen in the pre-period, the reductions in post tick reduction volatilities are apparent for each hour of the day, and the result is a flattening of this U-shaped pattern in the post period.

These results indicate that we do not find support for the conjecture that $1/16 ticks increases volatility. In fact, our results are largely consistent with significant decreases. Since depths are not found to decrease, we are able to attribute these volatility reductions to the reduced incidence of discreteness-induced rounding. Further, since return volatility is found not to increase due to the switch to 'teenies', and liquidity increases (in the form of reduced spreads), we conclude that then market quality is not diminished.

In summary, we find that market quality is not diminished following the adoption of the smaller tick size. While spreads decline, depths generally do not. Volume remains largely unchanged, while volatility is reduced. Therefore, we conclude that market quality is improved following the reduction in tick size. In the next two sections we examine two issues related to market quality – trader behavior and specialist profits.

Trader Behavior

Harris (1996) suggests that smaller tick sizes will increase price competition. In the Harris framework, price competition results when traders improve on price by submitting better priced limit orders. However, another form of price competition arises when specialists or floor brokers bid or offer better prices to incoming market orders than exist on the limit order book (see Harris (1997)). The result is an increased time to execution for limit orders on the book but price improvement for market orders. This market practice is referred to as 'stepping ahead of the book.' This paper tests directly for the incidence of 'stepping ahead of the book' behavior, both before and after the switch to 'teenies'. Our results provide support for Harris' (1997) conjecture that a smaller tick size causes an increase in the probability that a professional trader will improve on quoted prices. Specifically, we test the null that the number of trades occurring inside the spread remains constant in the pre- and post periods. Table 7 indicates increases in the number of trades occurring inside the spread

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[16] Ronen(1997) shows the importance of conducting multivariate tests on the differences of such variances to incorporate the contemporaneous and overlapping correlations in these variances. However, our sample length does not allow for tests of such rigor, as they typically require longer samples for adequate statistical power. Thus, our significance levels are subject to certain interpretive difficulties.

(accompanied by a decrease in the number of trades occurring at the spread) in all cases except for the binding quartile 4 (least binding)). The results for price quartiles do not appear to have a pattern, but the increases in stepping ahead of the book appear to be directly related to how binding the tick was prior to reduction. This is consistent with our previous conclusion that depths decline following the tick size reduction, because traders are afraid to expose their orders to potential price-improvers.

Since trades occurring without the involvement of the specialist may confound these results, we repeat the analysis for only those transactions in which the specialist is involved. Panel B indicates that the patterns observed persist when only professional trader transactions are considered, further supporting the notion that the frequency of 'stepping ahead of the book' behavior increases. The investor welfare effects of this increased activity are mixed. While this increase may yield better transactions price for market orders, the same may not be true for limit orders. The professional trader who steps ahead of the book is essentially competing with the limit order book, resulting in possibly worse execution for the limit order investor. [17]

Profits

The recent changes adopted by various exchanges regarding tick sizes have raised the question of whether market makers are better or worse off. This has important policy implications, since a sufficient decrease in profits may cause market makers to exit the market. Volume has a role in determining the degree to which market maker profits may be affected. Clearly, if volume increases (as we observe for some stocks), reductions in per share profits caused by narrower spreads may be offset by an increase in the number of trades.

Our approach is similar to Sofianos (1995), and Hansch, Naik, and Viswanathan (1997). Let x_{it} be the signed volume representing specialist participation in stock i for transaction *t.* The sign is determined by the direction of the specialist's cash flow (+ for sell, - for buy). p_{it} is the price of transaction *t*, while I_{it} is the specialist's inventory in stock *i* at time *t.* Sofianos (1995) shows that specialists trade inside the spread more than 40% of the time. To be conservative, we therefore measure inventory using the quote midpoint for stock *i* at time *t*, m_{it}. Total profits can be written as:

$$TP_i = \sum_{t=1}^{n} p_{it} x_{it} + m_{in} I_{it} - m_{i0} I_{i0} \tag{4}$$

where $I_{it} = \sum_{t=1}^{n} x_{it}$ and where we assume that I_{i0} = 0 (due to data limitations).

As suggested by Sofianos (1995) we decompose profits into spread (*SR)* and positioning revenue (*PR).* Spread revenue is based on the half spread:

$$SR_i = \sum_{t=1}^{n} (P_{it} - m_{it}) x_{it} \tag{5}$$

and

$$PR_i = TP_i - SR_i \tag{6}$$

As mentioned earlier specialist profits are partially volume dependent. Since we found significant changes in volume by partitioning by high/low price and volume, we use those partitions here. Table 8 indicates that overall total profit as well as spread revenue decreased, but not by a statistically significant amount. However, for the low volume quadrants (recall volume increased by a significant amount for these groups) spread revenue increased. For the quadrant that experienced an 85% increase in volume, spread revenue increased by a significant amount. This suggests that for this group of stocks the reduction in spread was more than offset by an increase in volume. If the volume increases documented in Table 5 are a result of spread narrowing, then the results in Table 8 are consistent with Harris (1994) prediction that the net effect of tick size reductions on profits should be negligible- while spreads decline, volume increases, thereby mitigating the loss from reduced spread revenue.

As an interesting aside, the nature of the data employed in this study allows us to compare spread revenues for AMEX specialists with those previously reported for NYSE specialists in

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[17] We also examine trades not involving the specialist and find a similar increase in 'stepping ahead of the book' for those trades as well. The pre and post "inside the spread" numbers are about 40% of those reported for specialists. However, since we lack order data, we cannot distinguish between public limit orders executed before they are included in the quote and those orders involving floor traders. Therefore, we cannot distinguish professional from public orders.

Sofianos (1995). We find that AMEX specialist daily spread revenues ($7,499.09/20=$375) are about 1/3 of the daily amount of NYSE revenues ($970).

V. Concluding Remarks

Recent studies have focused on the potential effects of a reduction in tick size on various aspects of market quality. Although theoretical predictions address the effects on trader behavior and volatility, the extant empirical studies focus on the impact on spreads and depths. This paper examines the Amex's May 1997 switch from a $1/8 to $1/16 tick size, and the effects of this tick reduction on volatility, , other aspects of market quality, trader behavior, and specialist profits.

We view our results as carrying important policy implications, especially in light of the fact that previous research has been limited to studying tick size changes on exchanges that do not have price/time priority rules and a level of pre-trade transparency similar to those assumed by the theoretical models (which the AMEX does). The results found in this paper are largely consistent with the theoretical predictions of Harris (1994). Specifically, we find that while bid-ask spreads decline, depths do not. We also find that specialist profits are relatively unchanged. These results are consistent with decreased transactions costs and increased liquidity. Further confirmation of improved (not impaired) market quality lies in our evidence on volatility changes. The interday and intraday return volatility decreases observed after the tick reduction are shown not to be attributable to potentially confounding factors. Further, we find that transitory volatility, based on daily returns measured at different points during the day, decreases. Examining the pattern of changes throughout the day reveals a flattening of the typical U-shaped pattern following the tick reduction.

Finally, we provide the first empirical test of Harris' (1996) conjecture that a reduction in tick size will be accompanied by an increase in the occurrence of professional traders providing price improvement to arriving market orders to the detriment of existing limit orders. The observed increase in price improving trades lends support to Harris (1996).

The results in this paper may be viewed as indicating improved market quality after the tick reduction, and are consistent with current research examining impacts on execution costs and other forms of liquidity for other market structures. Future investigation of these issues may determine if our results for volatility and trader behavior are robust across alternative market structures or particular to price/time priority rule markets.

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Table 1.
Descriptive Statistics of Portfolios for Amex Stocks that experienced a reduction in tick size

This table shows average price, average percentage of $1/8 quotes, average daily share volume (000s), and the number of stocks in our sample. Groups were formed by ranking stocks by average price and separately by average daily volume for the period April 2 to April 29, 1997. Stocks were ranked and placed into price and binding quartiles. Binding is defined as the percentage of $1/8 quotes. All numbers reported below are for the ranking period April 2 to April 29, 1997. Overall averages are also provided.

A. Price Quartiles					
	All Firms	**1 (Lowest)**	**2**	**3**	**4(Highest)**
Average Price	$21.28	$11.74	$14.29	$18.79	$40.31
Average % $1/8 Quotes	28.9%	37.9%	31.2%	27.5%	18.9%
Average Volume	22.204	8.54	10.66	23.90	45.70
N	324	81	81	81	81
B. Binding Quartiles					
		1 (Most)	**2**	**3**	**4(Least)**
Average Price		$16.51	$16.31	$21.05	$31.27
Average % $1/8 Quotes		58.3%	33.6%	18.4%	5.2%
Average Volume		65.49	15.47	5.09	2.76
N		81	81	81	81

Table 2
Change in Time-Weighted Quoted Spreads Following the Reduction in Tick Size

This table shows the average time-weighted quoted spreads for AMEX stocks during the periods April 2 to April 29, 1997 (Pre-Period) and May 15 to June 12, 1997 (Post-Period). These periods surround the tick size reduction, which occurred on May 7, 1997. Also reported is the average change between the two periods. Panel A. lists the results for quoted spreads expressed in dollar terms and defined as $A_{i,t}$ -$B_{i,t}$, where $A_{i,t}$ and $B_{i,t}$ are the inside ask and bid quotes for firm *i* at time *t* . Panel B. lists the results for quoted spreads expressed as a percentage of the spread midpoint at time t. Stocks are grouped by price (A.1 and B.1) and binding (A.2 and B.2) quartile. Binding is define as the percentage of $1/8 quotes in the pre-period. In Panels A and B, tests of significance are paired *t*-tests. Panel C reports the results of the regression

$$\overline{M_{i,t}} = \beta_0 + \beta_1 \overline{Price_{i,t}} + \beta_2 \overline{Volume_{i,t}} + \beta_3 \sigma_{i,t} + \beta_4 TickDummy_{i,t} + \beta_5 BindDummy_{i,}$$

where: $\overline{M_{i,t}}$ is the average quoted (dollar or percentage) spread for firm *i* in period *t* (pre or post reduction); $\overline{Price_{i,t}}$ is the average closing price for firm *i* during period *t*; $\overline{Volume_{i,t}}$ is the average daily share volume for firm *i* during period *t*; $\sigma_{i,t}$ is the standard deviation of daily return for firm *i* during period *t*; *TickDummy* is a dummy variable assigned the value of 1 if the period is post, otherwise zero, and *BindDummy* is a dummy variable assigned the value of 1 if the proportion of quoted spreads equaled $.125 in the pre period, otherwise zero . Parameter *t* statistics are in italics.

A: Quoted Spread (in Dollars)					
A.1: Price Quartiles					
	All Firms	**1 (Lowest)**	**2**	**3**	**4(Highest)**
Before	0.296	0.219	0.255	0.266	0.445
After	0.277	0.205	0.230	0.251	0.423
Net Change	-0.019***	-0.015***	-0.024***	-0.015	-0.022
A.2: Binding Quartiles					
		1 (Most)	**2**	**3**	**4(Least)**
Before		0.177	0.225	0.278	0.050
After		0.159	0.207	0.263	0.480
Net Change		-0.018***	-0.019***	-0.015***	-0.024

B: Quoted Spread (as Percentage of Spread Midpoint)					
B.1: Price Quartiles					
	All Firms	**1 (Lowest)**	**2**	**3**	**4(Highest)**
Before	0.016	0.019	0.018	0.014	0.012
After	0.014	0.017	0.016	0.013	0.011
Net Change	-0.002***	-0.0020***	-0.0024***	-0.0015**	-0.0012***
B.2: Binding Quartiles					
		1 (Most)	**2**	**3**	**4(Least)**
Before		0.012	0.015	0.016	0.019
After		0.010	0.013	0.014	0.018
Net Change		-0.0017***	-0.0018***	-0.0019***	-0.0016**

Table 2 (Continued)

C. Regression Results							
Measure	**Intercept**	**Price**	**Volume**	**σ**	**Tick Dummy**	**Bind Dummy**	**F–Stat R^2**
Quoted Spread	0.130 *7.860****	0.007 *24.814****	-0.0004 *-4.470****	2.755 *3.306****	-0.024 *-2.034***	-0.082 *-4.846****	144.2 0.525
Percentage Quoted Spread	0.016 *22.568****	-0.00008 *-6.484****	-0.00002 *-5.131****	0.163 *4.490****	-0.001 *-2.791****	-0.003 *-5.314****	30.7 0.187

*** Denotes significant at the 0.01 level
** Denotes significant at the 0.05 level

Table 3.
Change in Volume-Weighted Effective Spread Following the Reduction in Tick Size

This table shows the average volume-weighted effective spread for AMEX stocks during the periods April 2 to April 29, 1997 (Pre-Period) and May 15 to June 12, 1997 (Post-Period). These periods surround the tick reduction, which occurred on May 7, 1997. Also reported is the average change between the two periods. Panel A lists the results for effective spread in dollar terms, effective spread is defined as 2*| $P_{i,t}$-$M_{i,t}$ |, where $P_{i,t}$ is the price of stock *i* at time *t,* and $M_{i,t}$ is the midpoint of the spread for firm *i* at time *t.* Panel B lists the results as a percentage of the spread midpoint at time t. Effective spreads are weighted by the number of shares for each transaction. Stocks are grouped by price (A.1 and B.1) and binding (A.2 and B.2) quartile as well as by trade size (A.3 and B.3).. Binding is define as the percentage of $1/8 quotes in the pre-period. In Panels A and B, tests of significance are paired *t*-tests. Panel C reports the results of the regression

$$\overline{M_{i,t}} = \beta_0 + \beta_1 \overline{Price_{i,t}} + \beta_2 \overline{Volume_{i,t}} + \beta_3 \sigma_{i,t} + \beta_4 TickDummy_{i,t} + \beta_5 BindDummy_{i,}$$

where: $\overline{M_{i,t}}$ is the average quoted or dollar spread for firm *i* in period *t* (pre or post reduction); $\overline{Price_{i,t}}$ is the average closing price for firm *i* during period *t*; $\overline{Volume_{i,t}}$ is the average daily share volume for firm *i* during period *t*; $\sigma_{i,t}$ is the standard deviation of daily return for firm *i* during period *t*; *TickDummy* is a dummy variable assigned the value of 1 if the period is post, otherwise zero, and *BindDummy* is a dummy variable assigned the value of 1 if the proportion of quoted spreads equaled $.125 in the pre period, otherwise zero . Parameter *t* statistics are in italics.

A: Effective Spread (in Dollars)					
A.1: Price Quartiles					
	All Firms	**1 (Lowest)**	**2**	**3**	**4(Highest)**
Before **After** **Net Change**	0.229 0.214 -0.016**	0.165 0.154 -0.010	0.203 0.183 -0.019	0.198 0.189 -0.008	0.354 0.328 -0.026
A.2: Binding Quartiles					
		1 (Most)	**2**	**3**	**4(Least)**
Before **After** **Net Change**		0.147 0.129 -0.018	0.158 0.155 -0.003	0.213 0.200 -0.013	0.399 0.370 -0.029
A.3: By Trade Size					
		<1,000	1,000 to 9,999	10,000 to 99,999	>99,999
Number of Firms with Trade Size		324	302	113	10
Before **After** **Net Change**		0.208 0.197 -0.011***	0.223 0.202 -0.021***	0.146 0.137 -0.009	0.279 0.121 -0.157

Table 3. (Continued)

B: Effective Spread (as Percentage of Spread Midpoint)					
B.1: Price Quartiles					
	All Firms	**1 (Lowest)**	**2**	**3**	**4(Highest)**
Before **After** **Net Change**	0.012 0.011 -0.001***	0.014 0.013 -0.0014***	0.014 0.013 -0.0014***	0.011 0.009 -0.0009	0.009 0.008 -0.0011**
B.2: Binding Quartiles					
		1 (Most)	**2**	**3**	**4(Least)**
Before **After** **Net Change**		0.010 0.008 -0.0017***	0.011 0.009 -0.00008	0.012 0.010 -0.0017***	0.016 0.014 -0.0014
B.3: By Trade Size					
		<1,000	1,000 to 9,999	10,000 to 99,999	>99,999
Number of Firms with Trade Size		324	302	113	10
Before **After** **Net Change**		0.011 0.0098 -0.0012***	0.012 0.010 -0.0016***	0.009 0.007 -0.0010	0.017 0.006 -0.011

C. Regression Results							
Measure	**Intercept**	**Price**	**Volume**	**σ**	**Tick Dummy**	**Bind Dummy**	**F–Stat** R^2
Effective Spread	0.104 *6.327****	0.005 *18.166****	-0.0003 *-3.861****	2.312 *2.806****	-0.019 *-1.642*	-0.046 *-2.758****	76.09 0.367
Percentage Effective Spread	0.012 *17.489****	-0.00006 *-4.886****	-0.00002 *-4.784****	0.137 *3.943****	-0.001 *-2.285***	-0.002 *-2.269****	17.09 0.111

*** Denotes significant at the 0.01 level
** Denotes significant at the 0.05 level

Table 4.
Change in Time-Weighted NBBO Quoted Depth Following the Reduction in Tick Size

This table shows the average time-weighted NBBO quoted depth for AMEX stocks during the periods April 2 to April 29, 1997 (Pre-Period) and May 15 to June 12, 1997 (Post-Period). These periods surround the tick size reduction , which occurred on May 7, 1997. Also reported is the average change between the two periods. We define quoted depth as the sum of the inside ask and bid depths for firm *i* at time *t*. Stocks are grouped by price (Panel A) and binding (Panel B) quartile. Binding is define as the percentage of $1/8 quotes in the pre-period. Tests of significance are a paired *t*-test.

A: Price Quartiles					
	All Firms	**1 (Lowest)**	**2**	**3**	**4(Highest)**
Before	72.913	85.846	89.739	62.378	53.687
After	68.777	81.027	87.345	59.531	47.204
Net Change	-4.136	-4.819	-2.394	-2.847	-6.483
B: Binding Quartiles					
		1 (Most)	**2**	**3**	**4(Least)**
Before		142.033	68.175	54.229	27.212
After		119.523	73.941	51.681	29.962
Net Change		-22.511**	5.767	-2.548	2.749

*** Denotes significant at the 0.01 level
** Denotes significant at the 0.05 level

Table 5.
Change in Share Volume Following the Reduction in Tick Size

This table shows the average share volume for AMEX per stock during the periods April 2 to April 29, 1997 (Pre-Period) and May 15 to June 12, 1997 (Post-Period). These periods surround the tick size reduction , which occurred on May 7, 1997. Also reported is the average change between the two periods. Panel A (Panel B) contains the results for stocks grouped by price (binding) quartile . Binding is define as the percentage of $1/8 quotes in the pre-period. Panel C contains results for stocks grouped by ranking by average price and separately by average daily volume for the period April 2 to April 29, 1997. Stocks were then placed in one of four quadrants according to their joint price and volume ranking (high or low). Tests of significance are a paired *t*-test.

A: Price Quartiles					
	All Firms	**1 (Lowest)**	**2**	**3**	**4(Highest)**
Before	434,368	167,218	208,073	467,745	894,436
After	392,290	185,417	210,938	516,575	656,231
Net Change – Actual	-42,078	18,198	2,865	48,829	-238,205
Net Change - %	-9.7%	10.8%	1.4%	10.4%	-26.6%
B: Binding Quartiles					
		1 (Most)	**2**	**3**	**4(Least)**
Before		1,279,193	303,965	100,048	54,267
After		1,083,250	326,054	107,443	52,414
Net Change – Actual		-195,941	22,089	7,395	-1,853
Net Change - %		-15.3%	7.3%	7.4%	-3.4%

C. Price/Volume Quadrants		
	Volume Level	
Price Level	**Low** **Before** **After** **Net Change** **Net Change - %** **N**	**High** **Before** **After** **Net Change** **Net Change - %** **N**
Low	35,778 52,791 17,012*** 47.5% 75	318,565 323,511 4,976 1.6% 87
High	27,664 51,267 23,602** 85.3% 87	1,439,065 1,207,161 -231,904 -16.1% 75

*** Denotes significant at the 0.01 level
** Denotes significant at the 0.05 level

Table 6.
Change in Volatility Following the Reduction in Tick Size

This table shows average volatility measures for AMEX stocks during the periods April 2 to April 29, 1997 (Pre-Period) and May 15 to June 12, 1997 (Post-Period). These periods surround the tick size reduction, which occurred on May 7, 1997. In Panel A, volatility is defined as the standard deviation of returns based on the midpoint of BBO quote revisions. In Panel B, volatility is defined as the standard deviation of return based on closing BBO spread midpoints. . Stocks are grouped by price (A.1 and B.1) and binding (A.2 and B.2) quartile. Binding is define as the percentage of $1/8 quotes in the pre-period. In Panels A and B, tests of significance are based on Wilcoxon tests. Panel C reports the results of the regression

$$\sigma_{i,t} = \beta_0 + \beta_1 N\_Trades_{i,t} + \beta_2 TickDummy_{i,t} + \beta_3 BindDummy_{i,t}$$

where $\sigma_{i,t}$ is the standard deviation of return based on closing spread midpoints for firm *i* in period *t* (pre or post,)

$N\_Trades_{I,t}$ is the number of transactions for firm *i* in period *t* (pre or post,) $TickDummy_{I,t}$ is a dummy variable assigned the value of 1 if the period is post, otherwise zero, and $BindDummy_{I,t}$ is a dummy variable assigned the value of 1 if the percentage of quoted spreads equal $1/8 in the pre period is greater than 50%, otherwise zero. Parameter *t* statistics are in italics. Panel D. presents results for the standard deviation of return measured at different times of day for the 25 highest volume firms in our sample. Open is the first price of the day. Close is the last price observed for the day. The remainder are the last prices observe in the interval. 10 AM is the interval 9:30 to 9:59; 11 AM is the period 10:00 to 10:59, etc. If an interval had no trade the previous day's interval price was used. Tests of significance are based on Wilcoxon tests.

A. Change in Standard Deviation of Quote Revision Midpoints					
A.1: Price Quartiles					
	All Firms	**1 (Lowest)**	**2**	**3**	**4(Highest)**
Before	0.37	.0.375	0.422	0.299	0.370
After	0.29	0.336	0.332	0.288	0.241
Net Change	-0.07***	-0.039***	-0.089***	-0.01***	-0.129
A.2: Binding Quartiles					
		1 (Most)	**2**	**3**	**4(Least)**
Before		0.245	0.341	0.487	0.395
After		0.199	0.300	0.293	0.405
Net Change		-0.0452***	-0.041***	-0.194***	0.009

B. Change in Standard Deviation of Daily Returns					
B.1: Price Quartiles					
	All Firms	**1 (Lowest)**	**2**	**3**	**4(Highest)**
Before	1.377	1.33	1.372	1.489	1.312
After	1.232	1.32	1.337	1.164	1.105
Net Change	-0.144***	-0.009	-0.035	-0.325***	-0.208**
B.2: Binding Quartiles					
		1 (Most)	**2**	**3**	**4(Least)**
Before		1.290	1.608	1.301	1.307
After		1.076	1.423	1.220	1.210
Net Change		-0.214	-0.185***	-0.081***	-0.097

C. Regression Results				
Intercept	**N_Trades**	**Tick Dummy**	**Bind Dummy**	**F–Stat R^2**
0.013	*0.000006*	-0.002	-0.005	39.6
*31.767****	*9.899****	*-2.784****	*-6.747****	0.152

Table 6. (Continued)

D. Change In Patterns Of Transitory Volatility	
Time Period	**Before After Net Change**
Open	0.0216 0.0148 -0.0067***
10 AM	0.0229 0.0150 -0.0079***
11 AM	0.0239 0.0145 -0.0094***
12 PM	0.0235 0.0147 -0.0089***
1 PM	0.0242 0.0151 -0.0091***
2 PM	0.0236 0.0150 -0.0086***
3 PM	0.0234 0.0146 -0.0088***
Close	0.0213 0.0142 -0.0070***

*** Denotes significant at the 0.01 level
** Denotes significant at the 0.05 level

Table 7.
Change in Transaction Price Location Following the Reduction in Tick Size

This table shows the equally-weighted proportion of trades occurring at , inside, or outside the NBBO quote for Amex listed stocks for the periods April 2 to April 29, 1997 (Pre-Period) and May 15 to June 12, 1997 (Post-Period). These periods surround the tick size reduction, which occurred on May 7, 1997. Stocks are partitioned by average price in the Pre-Period. Panel A reports the results for all trades, while Panel B reports the results for trades involving the specialist. . Stocks are grouped by price (A.1 and B.1) and binding (A.2 and B.2) quartile. Binding is define as the percentage of $1/8 quotes in the pre-period.

A. All Trades										
A.1: Price Quartiles										
	All Firms		**1 (Lowest)**		**2**		**3**		**4(Highest)**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
At Quote **Inside** **Outside**	76.1 % 22.6 1.2	73.3 % 25.2 1.5	76.2 22.6 1.2	74.0 24.8 1.2	77.1 21.7 1.2	72.4 26.0 1.7	78.2 20.5 1.3	74.7 23.5 1.8	74.3 24.5 1.2	72.4 26.5 1.2
A.2: Binding Quartiles										
			1 (Most)		**2**		**3**		**4(Least)**	
			Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
At Quote **Inside** **Outside**			80.2 18.9 1.0	76.9 21.9 1.2	71.8 26.9 1.3	69.4 29.0 1.6	69.6 28.7 1.7	69.3 28.9 1.9	64.5 32.5 3.0	66.5 31.3 2.2

B. Only Trades Involving the Specialist										
B.1: Price Quartiles										
	All Firms		**1 (Lowest)**		**2**		**3**		**4(Highest)**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
At Quote **Inside** **Outside**	52.5 % 41.3 6.2	50.6 % 43.8 5.6	60.7 37.4 1.9	55.4 42.0 2.6	62.1 35.5 2.4	56.9 40.0 3.1	62.9 34.3 2.8	58.7 38.0 3.3	58.7 38.6 2.7	55.0 42.4 2.6
B.2: Binding Quartiles										
			1 (Most)		**2**		**3**		**4(Least)**	
			Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
At Quote **Inside** **Outside**			62.2 35.7 2.1	56.7 40.8 2.5	60.1 37.2 2.7	53.8 43.1 3.0	59.9 37.5 2.6	58.4 38.5 3.1	58.1 37.8 4.1	60.1 36.2 3.7

Table 8.
Change in Specialist Profits Following the Reduction in Tick Size

This table shows specialist profits for Amex listed stocks for the periods April 2 to April 29, 1997 (Pre-Period) and May 15 to June 12, 1997 (Post-Period). These periods surround the tick size reduction, which occurred on May 7, 1997. Panels A reports total profit defined as

$$TP_i = \sum_{t=1}^{n} p_{it} x_{it} + m_{in} I_{it} - m_{i0} I_{i0}$$

where x_{it} is the signed volume representing specialist participation in stock *I* for transaction *t.* The sign is determined by the direction of the specialist's cash flow (+ for sell, - for buy). p_{it} is the price of transaction *t*, while I_{it} is the specialist's inventory in stock *i* at time *t*.. m_{it}. Is the quote midpoint for stock *i* at time *t,* and $I_{it} = \sum_{t=1}^{n} x_{it}$. We assume that I_{i0} = 0 due to data limitations. Panels B reports spread revenue, which is defined as $SR_i = \sum_{t=1}^{n} (P_{it} - m_{it}) x_{it}$. Stocks are grouped by ranking by average price and separately by average daily volume for the period April 2 to April 29, 1997. Stocks were then placed in one of four quadrants according to their joint price and volume ranking (high or low). Overall averages are also provided. Tests of significance are a difference of means *t*-test.

A. Total Profits

	Volume Level	
Price Level	**Low Before After Net Change**	**High Before After Net Change**
Low	$879.28 -82.57 -961.84	$1,122.13 3,192.62 2,070.49
High	-108.28 -632.63 -524.35	85,972.95 -8,005.32 -93,978.27
	Overall	$20,842.87 -1,238.54 -22,081.41

B. Spread Revenue

	Volume Level	
Price Level	**Low Before After Net Change**	**High Before After Net Change**
Low	$1,208.02 1,455.47 247.45	$4,436.52 4,650.40 213.88
High	$1,717.41 2,224.53 507.12**	$23,586.47 17,126.57 -6,459.90
	Overall	$7,499.09 6,217.25 -1,281.85

*** Denotes significant at the 0.01 level
** Denotes significant at the 0.05 level

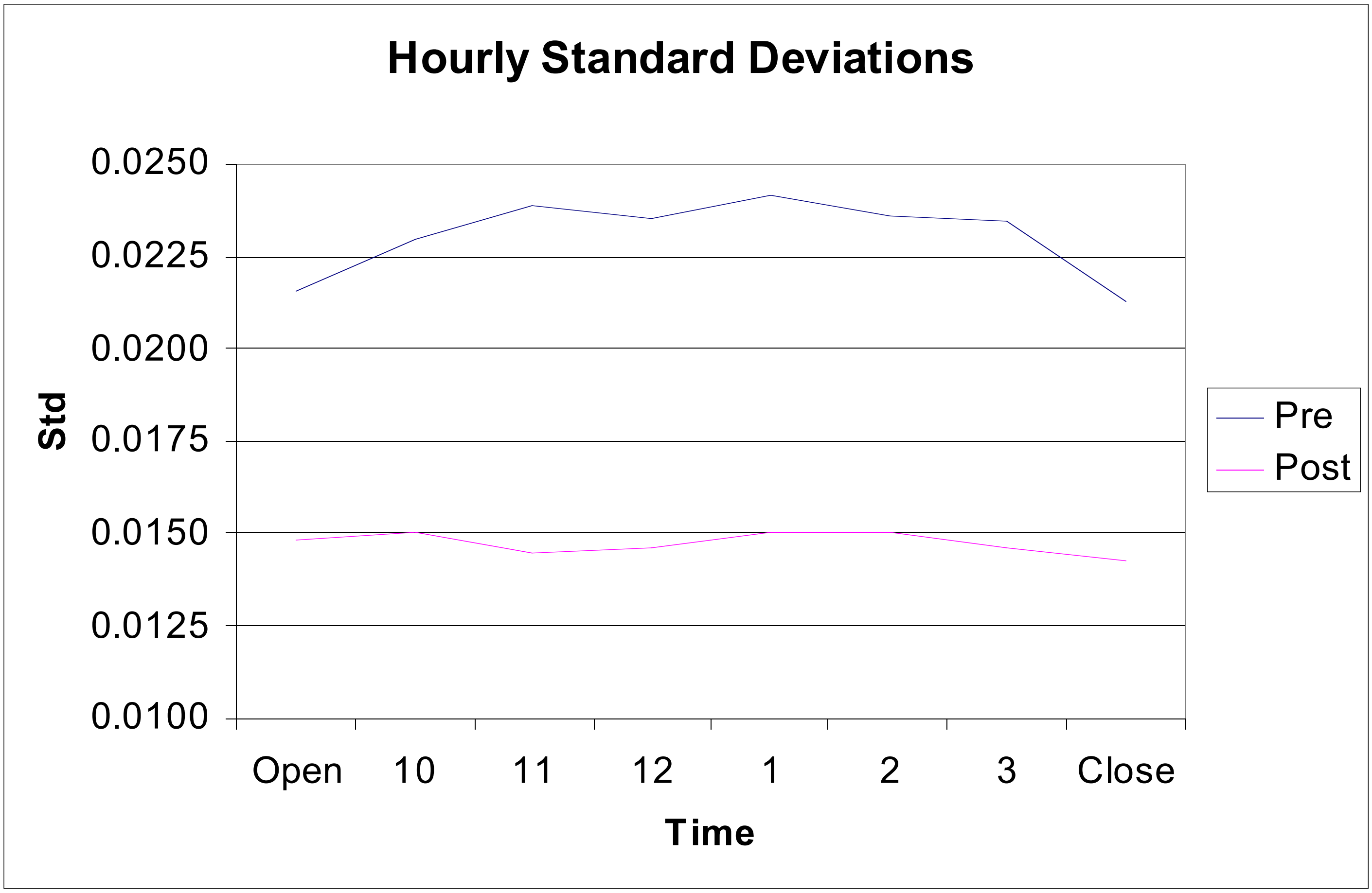

Figure 1 Patterns Of Transitory Volatility

This figure graphs the results for the standard deviation of return measured at different times of day for the 25 highest volume firms in our sample. Open is the first price of the day. Close is the last price observed for the day. The remainder are the last prices observe in the interval. 10 AM is the interval 9:30 to 9:59; 11 AM is the period 10:00 to 10:59, etc. If an interval had no trade the previous day's interval price was used.