Decimalization:
A Review of the Arguments and Evidence

Lawrence Harris
University of Southern California

Lawrence Harris
Professor of Finance
Marshall School of Business
University of Southern California
Los Angeles, CA 90089-1421

Voice: (213) 740-6496
FAX: (213) 740-6650
E-Mail: LHarris@USC.edu
Web: http://LHarris.USC.edu/

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Executive Summary

The minimum price increment (tick) determines what prices traders use. The tick is a decimal fraction in some markets and a fraction based on powers of two in other markets. The US Congress is presently considering a bill that would require the US stock markets to convert to decimal pricing. The likely outcome of decimalization would be a smaller price increment.

Proponents argue that decimal prices are easier to use than fractional prices and that decimalization is necessary to modernize US markets. More substantially, they argue that a smaller price increment would encourage price competition, narrow bid-ask spreads and decrease payment for order flow. Narrower spreads would ensure better prices for retail market orders, but less payment for order flow would raise retail brokerage commissions. Proponents also argue that decimalization is necessary for US markets to compete effectively against other markets.

Opponents argue that a smaller price increment would shift power from public traders to professional traders by making it easier for professionals to step in front of public limit orders. As a result, public traders will display their orders less and switch from limit order strategies to market order strategies. Quotation sizes will decline, transaction costs will rise and the markets will become less transparent.

The Canadian stock exchanges switched to decimal prices in April 1996. In the process, they decreased the tick from 12.5 cents to 5 cents for stocks priced above 5 dollars. Quoted spreads narrowed by about 4 cents but quotation sizes also declined substantially. Volumes did not change nor did the US market share of trading in cross-listed Canadian stocks. Several other international exchanges recently decreased their ticks with similar results.

The effect of tick size on market quality has also been studied by examining how stocks trade on different tick sizes. Small tick stocks have narrower spreads and less quotation size displayed than do large tick stocks. In markets that allow traders to submit limit orders that are not fully displayed, traders choose to display less size when the tick is small.

Some analysts have estimated the potential annual cost savings to the public of decimalization by multiplying half the projected decrease in spreads by annual trading volume. This method produces estimates of about 2 billion dollars per year for NYSE stocks. This is about 10 times larger than 1996 NYSE specialist profits, and about 2.5 times larger than their total revenues. This method grossly overestimates the potential cost savings because it implicitly assumes that the public trades only with dealers. Most trading, however, is between public traders. A cost savings to one public trader will represent an increased cost to another public trader.

All empirical results concerning tick size come from studies of exchanges in which a time-precedence rule encourages traders to improve price. Tick size is important in these markets because it determines the cost of obtaining precedence through price. The effect of tick size on trading in dealer networks is probablymuch smaller than in exchange markets because dealer markets do not enforce time precedence among dealer quotes. Decimalization is therefore unlikely to have much effect on payment for order flow or order preferencing in dealer markets.

The empirical results suggest that small market order traders and professional traders benefit from a smaller tick. A decrease in tick size hurts large traders and all public traders who use limit orders to compete with dealers.

1. Background

All markets have a minimum price increment (tick) that determines what prices traders use. In some markets, the increment is a decimal fraction, for example, 0.01, 0.05, or 0.1. In other markets, it is a fraction based on powers of two such as 1/2, 1/4, 1/8, or 1/16. In markets organized by exchanges or dealers, the organizer usually sets the tick. In other markets, traders set it themselves by common practice.

The tick varies substantially by market and location. Stock, bond and options markets in the US and Canada have traditionally used prices denominated in eighths. European and Asian markets typically use decimal prices. The practice in futures markets varies. Grains and some interest rate contracts use fractional pricing. Industrial commodities, stock indices, foreign exchange and some interest rate contracts use decimals.

Some decimal-denominated markets are de facto fractional markets. For example, the tick used to trade gas oil futures at the International Petroleum Exchange is 0.25 dollars. The tick used in most Italian stocks is 25 lira.

The size of the tick, expressed as a fraction of price, varies substantially across markets and also within markets. The variation does not depend on whether the market uses fractions or decimals. For example, a US government bond priced at 100 trades on 1/32 increments, which is 0.03 percent of price. In contrast, a Japanese stock priced at 1200 yen trades on 10 yen increments (0.83 percent). A Japanese stock priced at 800 yen, however, trades on 1 yen increments (0.13 percent). A typical 50 dollar stock at the New York Stock Exchange trades on a 1/8 increment (0.25 percent) as does a 10 dollar stock (1.25 percent).

Various markets are now experimenting with their minimum price increments. The American Stock Exchange decreased their tick from 1/8 to 1/16 dollar for stocks priced under 5 dollars in August 1992 and under 10 dollars in February 1995. In March 1997, its board voted to apply this change to all of its stocks. Canadian stocks switched to decimal pricing in April 1996. The Nasdaq board voted in March 1997 to permit quotations on sixteenths. US Representatives Oxley and Markey recently introduced a bill that would require decimal pricing in the US stock markets.

The next section of this paper briefly introduces the arguments for and against decimalization. Section 3 then surveys the evidence currently available. The paper concludes in

Section 4 with a brief discussion of the limitations of current research and with some suggestions for future research.

2. Issues

The arguments for and against decimalization fall into three categories[1]. Issues involving ease of use and market image are generally thought to be superficial. Issues involving competitiveness appear most substantial.

This section surveys each of these arguments as they are most commonly presented. Where appropriate, commentary on the economics underlying these arguments is also presented.

2.1 Ease of use

Argument in favor: Decimal prices are easier to use than fractional prices because arithmetic calculations are simpler with decimals than with fractions. For example, most traders find it easier to easily subtract 0.31 from 0.75 than 5/16 from 3/4.

Argument against: Fractional prices assist traders in their negotiations by making it easier to split the difference between a bid and an offer.

Since computers programmed to recognize fractions do most calculations, the issue is not significant. For example, investment tracking programs like Quicken and spreadsheet programs like Excel handle fractions seamlessly.

A change to decimals would incur substantial software costs for exchanges, dealers, and brokerages that use old systems.

If US markets thought that they could save costs by switching to decimals, they would do so without regulator intervention.

Commentary: The cost of changing to decimals is decreasing since most new security industry software systems support both systems.

[1] Peake (1993), Ricker (1996, 1997) and Wallman (1996) present the case for decimalization and provide some discussions of the case against decimalization. Before this survey, no study collects the arguments against decimalization into one place. Several studies discuss various elements of the case, although the discussion is often tangential to their primary purpose. These studies include Harris (1991a, 1993, 1994, 1996), Amihud and Mendelson (1991), Cordella and Foucault (1996), Seppi (1996), Battalio and Holden (1996).

2.2 Market Image

Argument in favor: Decimal prices present a more modern image of our markets than do fractional prices, the origin of which is often attributed to 16th century Spanish pieces of eight.

Argument against: The use of fractions may have more to do with a desire to split the difference than with Spanish pieces of eight.

How important could this issue be, given that the US is widely known to have the world's most liquid stock markets? In an analogous situation, note that the US economy does not appear to suffer significantly from the fact that we have not fully converted to the metric system of measures.

Commentary: The issue is not whether the US has the most liquid markets, it is whether decimalization can make these markets more liquid.

2.3 Competitiveness

Decimalization may have substantial effects on markets if the switch to decimal prices significantly decreases the size of the tick. The tick affects both the competition among traders within a market and the competition among markets to serve traders.

Argument in favor: The present tick limits the prices that traders can quote and therefore restricts price competition among traders. Traders cannot improve the best bid or offer when the spread is just one tick. A smaller increment would lead to smaller bid-ask spreads, especially in stockswith one-tick spreads. Since market orders submitted by small traders typically trade at the best quoted price, tighter spreads will lower transaction costs for small market order traders. Trading volumes should increase with lower transaction costs.

US markets will be more competitive relative to foreign markets, especially in cross-listed securities like Canadian stocks and ADRs. A small tick would solve arbitrage problems associated with currency rate translation. More foreign stocks would list in the US if our markets were more similar to their local markets.

If spreads narrow, order flow will be less valuable to dealers. The payments that some dealers make to brokers to attract their order flows will therefore decrease.

Argument against: Security markets have a minimum price increment for the same reasons that all oral auctions do. The increment keeps the market moving and it requires traders to make an economically significant contribution to price if they are to obtain precedence over

other traders. In auctions for cars, art works, tobacco, farm machinery and real estate, the market organizer typically sets the minimum increment. Why not also in the securities markets?

Spreads provide information only about the cost of trading a quoted number of shares. If a decrease in the tick lowers the number of shares in the quotation, the market may be less liquid even if spreads narrow. The following argument explains why quoted size depends on the tick.

A smaller tick makes it easier for traders to step in front of one another at order-driven exchanges. This change favors traders who can see the order flow and who can react most quickly to price changes. Dealers and other professional traders are such traders. A decrease in the tick will therefore shift power from public traders to professional traders.

Exchanges use price, time, and public order precedence rules to arrange trades. The price rule gives precedence to the buyers who bid the highest prices and to the sellers who offer the lowest prices. At a given price, the time and public order rules give precedence to the traders who first display their willingness to trade at that price, and to public orders over member orders. These rules protect public limit order traders from front-running by dealers and by professional traders. They also encourage traders to display their orders early. When the tick is too small, the time and public order precedence rules are not meaningful. Any trader who wants precedence merely improves price by a trivial amount.

For example, suppose Public Trader L places a limit buy order at 30. When the tick is one cent, Professional Trader P can easily front-run this order by bidding 30.01. If a seller then arrives, P buys what L would have bought. If price rises a dollar, P will profit instead of L. If price falls a dollar, P will sell to L at 30. Trader P will lose only one cent and L will lose 99 cents. The public trader loses either way. The cost to the professional trader of playing this game is the tick he loses if prices fall.

Public traders defend themselves from front-runners by using floor brokers to hide their orders, by breaking up their orders, and by switching to market order strategies from limit order strategies. These responses increase their transaction costs, lower displayed sizes, and reduce market transparency.

The long-term effects of these responses can hurt both sides of the market. In the example above, the seller received a higher price because Professional Trader P stepped in front of Public Trade L's order. But if L had not shown the order or if L had submitted a market order instead, P

would not have bid at 30.01 and there would have been no buy order at 30. The seller might not have received even 30.

A decrease in spreads may cause dealers to exit. Liquidity might drop as a result.

If the tick does not vary by price level, corporations can adjust relative tick size by splitting their stock. For example, if the minimum price increment changes from 1/8 to 0.05, a 5:2 stock split will keep the tick constant in percentage terms. If issuers like the markets as they are, a change in tick size will impose unnecessary costs upon them.

Commentary:

At the NYSE, public limit orders almost exclusively determine spreads in the most actively traded securities. Specialists rarely trade these stocks because they must yield to public orders. Narrower spreads will not hurt these specialists because they now act more like brokers than like dealers. Narrower spreads will hurt their regional and third market competitors, who are largely unconstrained by their limit order books. These dealers will pay less for order flow, and they may even be forced out of business.

A smaller tick will tighten spreads in Nasdaq only if traders compete on quoted price to obtain order flow. Presently, most dealers do not compete on price because they have little incentive to do so without a time precedence rule. A dealer who improves price does not get much more order flow because all other dealers will match the price for their clients. Brokers route most retail orders to dealers by prearranged preferencing agreements. Dealers compete on the payments for order flow they make to brokers to obtain their order flows.[2]

Nasdaq spreads will narrow if public limit orders have sufficient precedence to compete effectively with dealers. The new limit order exposure rules now being implemented in Nasdaq are a step in this direction. If public limit order traders are able to narrow spreads, dealer payments for order flow will decrease and order preferencing arrangements will weaken. A decrease in payments for order flow, however, will increase retail commissions[3].

Only traders who use market orders benefit from narrower spreads. Narrower spreads hurt public traders who use limit orders. This is especially true if a smaller tick makes it harder for them to compete with professional traders.

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[2] Battalio and Holden (1996) provide a theoretical model with implications for the relation between the minimum price increment and payments for order.

Market orders often trade at better than quoted prices in exchange-listed stocks. This phenomenon is called price improvement. If spreads narrow, the rate of price improvement will likely decline.

Even when the spread is one tick, it is possible for a trader to offer a better price. Those that do simply trade immediately. If they are willing to trade a large order, they will improve price. For example, suppose the market is 20 bid and 20 1/8 offered. A buyer who offers a limit order at 20 1/8 will trade with whomever is offering to sell. If the order is large, it may take all size offered at 20 1/8 and the remainder of the buy order will establish a new bid at 20 1/8.

3. Empirical Evidence

The question of how usage costs differ in fractional versus decimal systems has not been studied nor has any effort been made to quantify how the pricing system affects market image. Given that the decimal and fractional systems are both actively used, it is unlikely that any cost differences are obviously greater than the costs of changing. If they were, all markets would have already adopted the lower cost system.

Several sets of studies provide empirical results that address the competitive issues. These studies show how trader behavior varies with the minimum price increment, or tick size. Since the economic importance of the tick depends on its size relative to price, these studies all examine relative tick sizes. The **clustering studies** examine how traders use the sets of prices available to them. The **time-series studies** examine how traders respond to tick size changes in a given security. Finally, the **cross-sectional studies** examine the extent to which differences in relative tick size across stocks and markets can explain differences in trader behavior and market quality.

3.1 Clustering Studies

Clustering studies examine how traders use the prices available to them. When the tick is a small fraction of price, traders do not uniformly use all fractions. For example, in the US stock markets, traders use whole numbers more often than halves, halves more often than odd quarters, and odd quarters often more than odd eighths.[4] Similar results appear in decimal markets like

[3] Harris (1996b) presents the economics underlying payment for order flow and order preferencing arrangements.
[4] Harris (1991b) Figure 1 and Furbush and Smith (1996).

gold, silver futures, foreign exchange, and Australian stocks.[5] There the clustering is on tens and fives. Interestingly, it also appears on 25s, which suggests that traders have a natural affinity for fractions based on powers of two. When the tick is a large fraction of price, traders use all fractions equally.

These results suggest that traders often choose to use a larger price increment than the minimum increment, if the latter is too small. A desire to reduce transaction costs may explain the result.[6] A limited price set decreases the costs of negotiating by limiting the number of potential offers and counter-offers. It also reduces the amount of information that traders need to exchange and therefore also the potential for misunderstanding. The tick cannot be too large, however. A large tick may limit trade when trader valuations are very close. For example, if a buyer is willing to pay no more than 4.04 and a seller is willing to accept no less than 4.01, then no trade can take place if the tick is 0.05. This hypothesis has three significant predictions: Traders should use smaller increments when asset values are well known, traders should use larger increments when the market is volatile, and traders should use larger increments when trading face-to-face as opposed to anonymously. Studies have confirmed each of these predictions using data from various sources.

3.2 Time-Series Studies

Analysts study the effect of tick size on traders by examining stocks for which the tick has changed. Three events change tick sizes. First, the minimum price increment rule may change. Second, a price may rise or fall across a threshold that separates one tick size from another. For example, when a Tokyo stock rises from 999 yen to 1000 yen, the tick increases from one yen to 10 yen. Finally, a stock may split so that the tick size, expressed as a fraction of price, changes because the price level changes.

Analysts have studied all three event types. Rule changes have been extensively studied. Price transitions have only been slightly studied. Stock splits have been extensively studied, but usually for the purpose of examining other issues than tick size.

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[5] See Ball, Torous and Tschoegl (1985) for gold, Brown, Laux and Schachter (1991) for silver, Goodhart and Curcio (1992) for foreign exchange, and Aitken, Brown, Buckland, Izan and Walter (1995) for Australian stocks.
[6] Harris (1991b).

3.2.1 Evidence from Minimum Price Increment Rule Changes

Several studies examine recent decreases in the minimum price increments at the Toronto Stock Exchange, the American Stock Exchange, the Stock Exchange of Singapore and the Australian Stock Exchange. Unfortunately, these exchanges are all order-driven exchanges in which time-precedence encourages traders to improve price. Trading in this type of market is especially sensitive to tick size because the tick determines the cost of obtaining precedence through price when a trader does not have time precedence. The results of these studies are therefore most useful for predicting how decimalization might affect other order-driven exchanges like the NYSE and AMEX. They are much less useful for understanding how tick size affects dealer networks like Nasdaq that do not have time precedence rules.

3.2.1.1 The Toronto Stock Exchange

On April 15, 1996, the Canadian stock exchanges changed from mixed decimal and fractional pricing to pure decimal pricing. The exchanges also reduced the minimum tick from 1/8 dollar to 5 cents for stocks trading above 5 dollars. For stocks priced between 3 and 5 dollars, they reduced the tick from 5 cents to 1 cent. For stocks priced below 3 dollars and below 50 cents, the tick remained unchanged at 1 cent and ½ cent, respectively.

Six studies compare market quality at the Toronto Stock Exchange before and after the change. Tables 1 and 2 summarize their primary results concerning quoted bid-ask spreads and quotation sizes.

Spreads

For stocks priced between 3 and 5 dollars, spreads changed very little when the tick decreased to 1 cent.[7] The average spread for these stocks is about 11 cents. The former 5 cent tick apparently was already adequately small.

For stocks priced above 5 dollars, the studies report declines in average quoted spreads of from 2 to 5 cents per share. The results vary primarily because of differences in averaging methods. The smallest estimate is for an equal-weighted average. This averaging method gives most weight to the numerous infrequently traded stocks that tend to have large spreads. Before the rule change, the average spread for these stocks was 33 cents, or more than 2.6 ticks. These

[7] Bacidore (1997) Table 2, Huson, Kim and Mehrotra (1997) Table 1, and Weaver (1997) Table 2.

spreads did not decline much because the spreads were much larger than the tick. The largest reported decline in quoted spreads is for a volume-weighted average. This averaging method gives most weight to actively traded stocks that tend to have small spreads. The corresponding average spread was only 16.6 cents before the rule change, which is just larger than the minimum possible spread of 1/8 dollar.

Among the stocks priced above 5 dollars, the studies find that the greatest changes in spreads are for the lower price stocks and for the higher volume stocks. These stock characteristics are associated with low spreads. The former minimum price increment apparently was too large for traders in these stocks.

Four of the six studies examine how quickly spreads declined.[8] They all find that spreads narrowed immediately after April 15 and then stayed relatively constant at their new levels. Since these studies only examine data collected within five months of the rule change, they cannot provide evidence about the long-term effects of the tick change. It appears unlikely, however, that the long-term effects will be much different from the immediate effect.

Three studies compute average changes in spread classified by whether the Canadian stock was cross-listed for trading in the United States.[9] Spreads in the cross-listed stocks decreased slightly more than spreads in the other stocks. Although the difference may be due to more aggressive competition for order flow by Toronto traders, it is more likely due to the larger average size of the cross-listed stocks. The cross-listing difference is not statistically significant in an analysis that takes into account differences in trading activities and price levels.[10]

Two studies consider whether the Canadian decimalization had any effects on spreads in the US markets for cross-listed Canadian stocks.[11] At the NYSE, spreads did not change in the Canadian stocks.[12] In Nasdaq, spreads in the Canadian stocks dropped by 5 cents. The NYSE spreads for Canadian stocks were significantly higher on average than the TSE spreads for the same stocks, both before and after decimalization. In contrast, the Nasdaq average spreads were essentially identical to the TSE spreads before and after decimalization. The different results may

[8] Ahn, Cao and Choe (1997) Figure 1, Bacidore (1997) Figure 1, Huson, Kim and Mehrotra (1997) Table 1, and Ricker (1997) Exhibit V.
[9] Ahn, Cao and Choe (1997), Bacidore (1997) and Chung, Kryzanowski and Zhang (1997).
[10] Ahn, Cao and Choe (1997) Table 7.
[11] Ahn, Cao and Choe (1997) Tables 2 and 5 and Chung, Kryzanowski and Zhang (1997) Table 4.

be due to the different US market structures, but they are more likely due to differences in firm size: The NYSE-listed Canadian stocks are larger than the Nasdaq-listed Canadian stocks.

The effect of decimalization on spreads may vary by whether the stocks trade in the TSE CATS system or in the TSE Floor system. CATS maintains strict price-time precedence. The Floor system gives time precedence only to the first trader to arrive at a given price. All subsequent traders at that price share precedence on a pro-rata basis. Since it is easier to trade at a given price in the Floor system than in the CATS system, a smaller tick should affect price competition more in CATS than in the Floor system. The results of the one study that examined this issue show that spreads in the Floor system declined by more than spreads in the CATS system.[13] The result may be due to differences in stock characteristics between the two systems. Although the study provides no formal test, the difference does not appear to be statistically significant.

Another study shows that spreads decreased most for the above five dollar stocks for which spreads were equal to the minimum 1/8 dollar tick.[14] The median decrease in spreads for these stocks was 51 percent versus 30 percent for the other stocks.[15]

Quoted spreads can be poor indicators of liquidity conditions when many trades take place between the quoted prices. Since the tick sets the number of possible prices within a given spread, a small tick may effect market quality even without affecting the quoted spread. To address this issue, all six studies examine the average absolute difference between the trade price and the midpoint of the corresponding bid and ask prices. Twice this difference is called the effective spread. The effective spread results are similar to the quoted spread results. This indicates that price improvement at the TSE was not common either before or after the rule change. Before the rule change, only 8 percent of all trades were within the quoted prices. This increased only to 11 percent following the change.[16] Since price improvement is much more

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[12] The authors use a control sample of comparable NYSE listed non-Canadian stocks to adjust the results for the influence of other factors that might have affected all spreads.
[13] Weaver (1997) Table 4.
[14] Chung, Kryzanowski and Zhang (1997) Table 3.
[15] Although the result is consistent with those reported above for the most actively traded stocks, it may not be reliable. Table 3 reports that the average pre-decimalization spread for the above $5 stocks that were quoted more than 95 percent of the time at 1/8 dollar is 11.7 cents. Since the lowest this mean could be is 12.5 cents, either an error of transcription or an error of calculation took place.
[16] Ricker (1997) Exhibit XII.

common in US exchange-listed stocks, these results suggest that the TSE experience may not generalize well to the US markets.

Quoted Size and Market Depth

A narrow spread does not indicate a liquid market if the number of shares that traders can trade at the quoted prices is small. For large traders, depth is more important than width. Accordingly, all six of the studies examine how average quotation size changed following the rule change.

Quotation sizes decreased slightly for stocks priced between 3 and 5 dollars (Table 2). The decrease is small and might easily have been due to other causes. For stocks priced over 5 dollars, the studies report average declines in quotation size that range from 26 to 52 percent. The variation is due to differences in samples and averaging methods. The greatest decreases are for stocks that are cross-listed at the NYSE. These stocks are the most actively traded stocks and the ones that experienced the greatest decline in spreads. When the results are adjusted for differences in trade frequency, the difference between NYSE cross-listed stocks and the not cross-listed stocks essentially vanishes.[17]

In all markets, a natural relation exists between quotation spread and quotation size. As a rule, the greater the spread, the greater the size since traders will be willing to sell more at a higher price and buy more at a lower price. A decrease in quotation size therefore does not necessarily indicate less depth when the spread narrows. For example, suppose traders are willing to buy 5 lots at 20.05 and 5 more lots at 20. If 20.05 is a feasible price, the best bid will be 20.05 for 5 lots. Otherwise, the best bid will be 20 for 10 lots.

Since the TSE reports size at each of the best five prices, it is possible to compute a better measure of depth than size at the best quote. For example, given the size displayed at various prices, an analyst can determine the size of an order that would move prices one percent. It would be interesting to determine whether this broader measure of depth changed following decimalization. Unfortunately, no study has done this analysis yet. Two studies, however, examine the ratio between size and spread at the best quote. This ratio provides a crude estimate

[17] Ahn, Cao and Choe (1997) Table 7.

of the size of an order that would move prices one percent.[18] The results are mixed with some analyses showing increases in the ratio and others showing decreases.[19] The differences depend on the stock sample examined and on the averaging method used. In any event, it seems that the results easily could be due to unrelated factors.[20] Although the results are not reliable, they suggest that depth broadly defined did not decrease as much as did size at the best price.

Markets are often deeper than they appear because traders do not always display their willingness to trade. We observe hidden size when a trade takes place that is larger than the prevailing quotation size. One study examined these events and determined that traders hid more size following decimalization than before.[21] This result suggests that the decline in quoted size overestimates the effect of decimalization on liquidity. It also suggests, however, that traders may be more concerned about front-running when the tick is smaller. It may also indicate that floor dealers more often step in front of the book when the tick is small by augmenting size at the best quote.

Trading Volumes and TSE Market Share

If transaction costs decreased at the TSE, TSE trading volumes and market share should both have increased. No study, however, finds significant changes in these variables.[22] The results on trading volumes are mixed, but generally indicate a minor decrease in volumes. The decrease is not large enough to distinguish from other causes of volume fluctuations. TSE market share also does not show any significant variation. If anything, market share trends down slightly during the sample period for the 5 to 10 dollar stocks for which decimalization has the greatest effect on spreads.[23] These results suggest that decimalization has not significantly affected TSE transaction costs, or that investors in Canadian stocks are not price sensitive in the short-run.

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[18] This interpretation of the ratio assumes that relation between total size and price is linear. The ratio is a crude estimate its numerator and denominator are both quite noisy.
[19] Bacidore Table 8 and Ricker Exhibit XIII.
[20] Many factors cause quotation sizes and spreads to vary through time. In general, variation in quotation sizes is greater than in quotation spreads. This makes these analyses of quoted size less reliable than the corresponding analyses of quoted spreads. Since Baciodore adjusts for variation due to other factors, his result are probably more reliable than Ricker's.
[21] Ricker (1997) Exhibit XIV.
[22] Ahn, Cao and Choe (1997) Tables 5 and 6, Bacidore (1997) Table 9, Huson, Kim and Mehrotra (1997) Table 4, Ricker (1997) Exhibit XII, and Weaver Table 12.
[23] Huson, Kim and Mehrotra (1997) Table 4.

Other Transaction Cost and Trader Profitability Estimates

Several studies examine other measures of transaction cost and trader profitability besides quoted spreads, effective spreads, quoted depths, and volumes. These measures include the Huang and Stoll (1996) adverse selection estimator,[24] measures of volatility,[25] and measures of dealer profitability inferred from TSE proprietary information about trader identities.[26] The results are generally too noisy to allow meaningful inferences. The noise is due to the poor quality of these estimators, to the short sample periods, and to other factors that may reasonably explain the results.

Decimalization did not significantly affect TSE seat prices.[27] This evidence indicates that traders did not expect that that the rule change would significantly impact dealer profitability.

Internalized and Crossed Trades

Two studies examine trade internalization rates and crossed trades.[28] An internalized trade is one in which a member firm trades with its client. A cross is a trade among a member firm's clients. The smaller tick may have two effects on the internalization rate. By lowering spreads, it decreases the value of internalization to the member. This should lower the internalization rate. Conversely, a smaller tick facilitates internalization by lowering the cost to the member of stepping in front of the book. This should raise the internalization rate. No theory predicts the effect of tick size on crosses. The empirical results are inconsistent and generally insignificant. Tick size does not significantly affect internalization and crossed trade rates.

The Ratio of Quotations to Trades

The ratio of the total number of quotations to the total number of trades increased by 10 percent following decimalization.[29] This increase suggests that negotiating trades may be more expensive when the tick is small, as suggested above. It may also indicate a greater degree of price competition among traders.

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[24] Bacidore (1997) Table 7.
[25] Ricker (1997) Exhibit XII and Weaver (1997) Tables 7 and 8.
[26] Weaver (1997) Tables 10 and 11.
[27] Huson, Kim and Mehrotra (1997) Figure 3.
[28] Ricker (1997) Exhibit XII and Weaver (1997) Table 9.
[29] Ricker (1997) Exhibit XII.

3.2.1.2 Rule Changes at Other Stock Exchanges

The American Stock Exchange

On September 3, 1992, the AMEX reduced its minimum price increment from 1/8 to 1/16 dollar for stocks priced between one and five dollars. Two studies examine the effects of this change on market quality. Using somewhat different samples and methods, both studies show that average quoted spreads decreased by about 1.7 cents (10 percent) for the affected stocks.[30] The decreases were greatest for the more actively traded stocks among this largely inactively traded group. For the most active third of the stocks, spreads narrowed by 2.9 cents (19 percent).[31] Not surprisingly, the lowest price stocks also had the largest percentage decreases.[32]

Effective spreads also decreased, but the decrease (1.3 cents) is slightly smaller than for quoted spreads.[33] The difference between the quoted and effective spread results suggests that traders received less price improvement on average following the change in tick size. The fraction of trade prices strictly within the quoted spread, however, increased from 14.2 to 18.8 percent.[34] If the typical price improvement is one tick, these fractions imply a difference of 0.6 cents between the changes in the two spread types.[35] This is close to the actual difference of 0.4 cents. These results suggest that traders received price improvement more often, but on average the improvements were smaller.[36] This pattern is consistent with dealers taking small steps in front of their books more often.

Both studies analyze quotation sizes and volumes. Average quotation sizes decreased 9 percent and volume essentially did not change.[37] The results are weak, however, and the studies provide no formal significance tests.

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[30] Ahn, Cao and Choe (1996) Table II examines data from June – November 1992 and Crack (1995) Table 2 examines data from January – December 1992.

[31] Ahn, Cao and Choe (1996) Table III. The least active of these "active" stocks traded only 4.9 times per day on average.

[32] Ahn, Cao and Choe (1996) Table IX.

[33] Ahn, Cao and Choe (1996) Table VI.

[34] Crack (1995) Table 4.

[35] The implied difference is computed as 0.142 (12.5) - 0.188 (6.25) = 0.6 cents.

[36] The spread results and the price improvement frequency results unfortunately come from different samples. The results therefore may not be strictly comparable.

[37] Ahn, Cao and Choe (1996) Table VII. To control for other factors that may affect these variables, the reported mean changes are adjusted by the corresponding means computed from the NYSE one to five dollar stocks. Although the adjustment is appropriate, it would have been better if the NYSE stocks were also matched on firm size. Since Crack's analysis does not control for other factors, his results are less reliable.

Traders used odd sixteenths for only 13 percent of their transactions in the four months following their introduction in 1992.[38] Had they used all sixteenths uniformly, the odd sixteenth usage rate would have been 50 percent. The odd usage frequency has since increased. During the week of March 16, 1997, one to five dollar AMEX stocks closed on an odd sixteenth 35 percent of the time.[39] The contrast between the 1992 and 1997 results suggests that the full effect of the rule change was not immediately realized. Unfortunately, no study has examined recent AMEX bid-ask spreads for these low price stocks.

The American Stock Exchange extended the 1/16 dollar minimum price increment to all stocks priced under 10 dollars in February 1995. The effects of this change have yet not been studied.

The Stock Exchange of Singapore

On July 18, 1994, the Stock Exchange of Singapore reduced the minimum price increment from 50 cents to 10 cents for stocks priced over 25 dollars. The rule change affected only five stocks, of which only three traded substantially both before and after the change. Quoted bid-ask spreads for these stocks decreased by an average of 40 percent in the five days following the rule change.[40] Quotation sizes at the best bid or offer decreased by an average of 70 percent but the total displayed size at all prices decreased by only 50 percent. There was no apparent change in volume. Although the small sample size makes the results unreliable, the smaller decrease in total size than quoted size is notable. It suggests that the decrease in quotation size presented in the Toronto and AMEX studies overestimates the total effect of smaller ticks on depth.

The Australian Stock Exchange

On December 4, 1996, the Australian Stock Exchange reduced the minimum price increment for stocks priced under 50 cents and for stocks priced over 10 dollars. The tick decreased from 1/2 cent to 1/10 cent for 84 stocks priced under 10 cents, from 1 cent to 1/2 cent for 234 stocks priced between 10 and 50 cents, and from 2 cents to 1 cent for 14 stocks priced between 10 and 50 dollars. A very preliminary (and unreleased) study examines trading in the 60

[38] Crack (1995) Section 4.1.4.
[39] Personal communication with Ryan Ciociola, American Stock Exchange research analyst.
[40] Lau and McInish (1995) Table 2.

days surrounding the rule change.[41] Quoted spreads declined 26 percent and 10 percent respectively for stocks priced under 10 cents and between 10 and 50 cents. Spreads for the 14 higher price stocks increased by 26 percent. This result is probably not reliable given the small sample size. The results concerning depth are not consistent. On balance, it appears that depth declined.[42] The latter results are especially interesting because the study measures depth by the dollar amount necessary to move price one percent. The study computes depth from an analysis of the complete limit order book and not just from size at the best bid and offer. The observed decrease in depth shows that traders were less willing to expose size at or within one percent of the best price when the tick became smaller.

3.2.2 Evidence from Price Transitions

The minimum price increment for a stock changes discretely when its price rises or falls through a price threshold that separates one tick size from the next. The effect of tick size on market quality can therefore be studied by examining stocks that made these transitions.

One study uses this method in an analysis of 26 Paris Bourse stocks that traded on two different ticks during January and February 1995.[43] Most of the stocks traded near 500 francs. The tick size above 500 francs is 1 franc; below it is 0.1 franc. The results show that quoted spreads were 12 percent smaller on average when the stocks traded on their smaller tick than on their larger tick. Average quotation sizes (at the best prices) were 46 percent smaller and the average ratio of quotation size to spread was 35 percent smaller on the smaller tick. There was no significant difference in volumes, however.

The Paris Bourse allows traders to place limit orders that display only a portion of their full size. An analysis of this feature of the Paris market therefore permits direct inferences about how traders respond to smaller ticks. When the stocks traded on the smaller tick, traders restricted the display of 43 percent of their orders. In contrast, they restricted the display of only 37 percent of their orders when the stocks traded on the larger tick. These fractions, and the differences between them, increased with the size of the order. They suggest that traders are reluctant to show orders when the tick does not provide much protection from front-runners.

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[41] McInish and McCorry (1997) Table 2.
[42] The ambiguity is probably due to data coding problems that appear to affect the results in this preliminary (and unreleased) version of the study.
[43] Harris (1996a) Table VII.

3.2.3 Evidence from Stock Splits

Since the tick is a constant 1/8 dollar for most US stocks, the tick expressed as a fraction of price decreases following a stock split in inverse proportion to the split factor. Studies of split stocks therefore can provide useful information about the effect of tick size on market quality.

Several studies of US stock splits have examined how spreads and volumes change following stock splits.[44] These analyses uniformly show that relative bid-ask spreads widen following stock splits.

The results on trading volumes generally show that dollar volumes decline, but these results are not uniform across samples. The change in the dollar value of the even lot size and the information released by the split announcement may influence the volume results.

No study has yet examined the effect of splits on quotation sizes.

3.3 Cross-Sectional Studies

Tick size, measured as a fraction of price, varies substantially across stocks and markets. The effects of tick size on market quality can therefore be studied by comparing stocks that trade on relatively small ticks to those that trade on larger ticks. Several studies pursue this strategy.

3.3.1 US Stock Exchanges

Since most US exchange-listed stocks trade on a 1/8 dollar tick, relative tick size is large for low price stocks and small for high price stocks.

Spreads and Quotation Sizes

Bid-ask spreads, measured as a fraction of price, are smaller for high price stocks than for low price stocks.[45] In 1989, the average spread for US exchange-listed stocks priced over 40 dollars was 0.44 percent of price. For stocks priced under 10 dollars, it is 3.5 percent of price. Much of the difference is due to the fact the higher price stocks are larger, more actively traded stocks for which we would expect lower spreads. However, after adjusting for various characteristics that vary among the stocks, spreads are still wider when the relative tick is large. This result is primarily due to the fact that spreads can be no smaller than the minimum price increment. For the under 10 dollar stocks, quoted spreads were equal to 1/8 dollar 67 percent of

[44] Copeland (1979), Masson (1985), Conroy, Harris and Benet (1990), Desai, Nimalendran, and Venkataraman (1994) and Arnold and Lipson (1996).
[45] Harris (1994), Table 1.

the time. They were 1/8 dollar only 33 percent of the time for the above 40 dollar stocks. Even after further adjusting for the effects of price discreteness, the higher price stocks still have smaller spreads.

Quotation sizes depend on a number of factors, the most important of which is firm size. After controlling for the influence of these factors, quotation sizes are greatest for the low price stocks and for stocks that commonly have 1/8 dollar spreads. These results, taken together with the spread results noted above, show that traders quote tighter markets for smaller size when the relative tick is small.

Information from high price stocks for which the tick is a small fraction of price can be used to predict how low price stocks would trade if they could trade on smaller increments. For example, suppose the tick is lowered to 1/16 dollar for stocks priced under 10 dollars. The analyses suggest that spreads would decrease 38 percent, quotation sizes would decrease 16 percent, and daily volumes would increase 34 percent.[46] For stocks priced over 40 dollars, the effects would be much smaller. These predicted changes are larger than the changes actually observed in the four months immediately following the 1992 AMEX rule change.[47] No study has examined whether these effects grew through time as traders become more familiar with the using the smaller tick.

Limit Order Usage

When the tick is a small fraction of price, public traders may avoid using limit orders to hide their intentions from front-runners. An analysis of orders transmitted through the NYSE SuperDot order routing system shows that only 26 percent of all orders for stocks priced above 50 dollars are limit orders. In contrast, for stocks priced between 1 and 5 dollars, the limit order fraction is 46 percent.[48] Unfortunately, these results do not control for the size of the spread. When the spread is large relative to price, we also expect more limit order usage.

Whatever the reason, the greater use of limit orders when the relative tick is large demonstrates that the public supplies more liquidity when the tick is large than when it is small. Any presumption that a large tick benefits only dealers is not well founded.

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[46] Harris (1994), Table 5.
[47] Crack (1995) Appendix B.
[48] Angel (1997) Table IV.

3.3.2 The Paris Bourse

The average relative tick size at the Paris Bourse is only one-tenth as large as it is in the US. In US exchange markets, spreads are typically 1, 2 and occasionally 3 ticks wide. At the Paris Bourse, the average spread is 35 ticks wide for small stocks and 12 ticks wide for large stocks.[49] The minimum price increment rarely constrains Paris bid-ask spreads.

Tick sizes vary by price level at the Paris Bourse. Broadly characterized, they are proportional to price level. The correlation between relative tick size and price level therefore is not as great as in the US.

Spreads and Quotation Sizes

At the Paris Bourse, no correlation exists between relative bid-ask spread (spread as a fraction of price) and relative tick size (tick as a fraction of price).[50] The tick is apparently too small to have much effect on spreads.

Tick size does affect quoted size.[51] Traders display more size on average in stocks with large relative ticks. The average ratio of quotation size (at the best prices) to the relative spread is also larger for larger relative ticks. Perhaps most interestingly, the average ratio of block size to the block spread is also larger. The block spread is the difference between the prices at which standard sized block purchases and sales would trade. Since it is computed from the displayed order sizes at and behind the best prices, the block spread is a very good measure of market depth for large trades. These results show that traders are less willing to display order size when the tick size is small.

Undisplayed Limit Order Size

The Paris Bourse allows traders to place limit orders that display only a portion of their full size. Analysts therefore can directly observe the extent to which traders hide size when the relative tick size is small. When the relative tick is between 2 and 5 basis points, traders restrict display for 79 percent of their larger orders (orders larger than 500,000 francs or about US$100,000).[52] When the relative tick is between 20 and 50 basis points, traders restrict display

[49] Harris (1996a) Table I.
[50] Harris (1996a) Table V. This result is obtained after adjusting for the effects of stock characteristics like firm size.
[51] Harris (1996a) Table V.
[52] Harris (1996a) Table III, Panel B.

for only 50 percent of their larger orders. The analysis finds similar results for the smaller orders, although traders display smaller orders more often than larger ones. These results show that traders are less willing to display size when other traders can easily step in front of their orders.

Traders in the Toronto CATS system can also display only a portion of their full order size. The average relative tick size at the TSE, however, is about 12 times larger in Toronto than at the Paris Bourse.[53] Not surprisingly, CATS traders display much more of their orders. They restrict display for only 13 percent of their larger orders. In contrast, traders at the Paris Bourse restrict size for 74 percent of their comparable orders.[54] These results are consistent with results (cited above) that show that traders displayed less size following the Canadian decimalization.

3.3.3 Two Notable Empirical Regularities

Two notable empirical regularities characterize US stock prices. First, average stock price levels have remained essentially constant for the last 70 years despite a 10-fold increase in general price levels and a 25-fold cumulative return on equities. Second, price levels are strongly correlated with firm size. Small stocks have low prices and large stocks have high prices. The obvious fact that small firms get big when their prices go up does not adequately explain this correlation. These stock price regularities are largely peculiar to the United States. They are not found to the same degree in other national markets.

Price levels have remained constant because firms split their stock when prices get "too" high. At first glance, no obvious reasons explain why firms should split their stocks, and no rules require that they do so. Warren Buffett, for example, refuses to split Berkshire Hathaway's stock even though it now trades at just under $40,000 per share. Arguments in favor of splitting to maintain the affordability of the even lot size cannot explain why the lot size in real inflation-adjusted terms has been continuously declining.

Three authors suggest that firms split their stocks to control the size of the relative tick.[55] This control is possible in the US because the tick is a constant 1/8 for all prices above one dollar. Since most other markets have tick schedules for which the tick increases in proportion to price

[53] Harris (1996a) Table I.
[54] Harris (1996a) Table III, Panel A.
[55] Harris (1994), Anshuman and Kalay (1994) and Angel (1997).

levels, firms cannot control tick size to the same degree. Firms in such markets split less than in the US.

Firms presumably split their prices to obtain a relative tick that produces the best market quality for their stocks. Since market conditions are different for small stocks than for large stocks, the optimal relative tick size will vary by firm size. This observation can explain the persistent correlation between firm sizes and prices in the US.

Angel (1997) constructs a compelling empirical case for this theory based on a set of carefully organized international comparisons of markets with various tick schedules. If correct, the theory predicts that a uniform decrease in tick size will eventually lead to lower price levels.

4. Limitations and Suggestions for Further Research

Existing empirical studies of the effect of tick size on market quality leave several important questions unanswered. Perhaps most importantly, we know nothing about the effect in dealer markets. Tick size probably affects dealer markets less than exchange markets because the former do not enforce time precedence rules. This conjecture needs to be confirmed. The topic is especially important because many decimalization proponents hope that a decrease in tick size will affect order preferencing arrangements in dealer markets.

We also know nothing about the long-term effects of tick size changes. The studies surveyed here examine data only out to one-half year at most. The effect, if any, of tick size on trading volumes may take especially long to observe. Volumes should change if trading costs change, but it may take a long while before traders recognize a change in trading costs. Longer samples must be studied to determine how long traders require to adjust to a new tick size.

With a few exceptions, the studies do not adequately account for factors other than tick size that affect spreads, quotation sizes and volumes. The analyses need to be much more sensitive to differences in stock characteristics and to the normal variation of market quality variables through time. These concerns are especially important for long-term studies and for studies that contrast markets.

Studies of how market quality changes when a stock transitions from one tick size to another as its price changes should provide very reliable information about tick sizes. Because these events occur often and at random points in time, statistical analyses of their effects will be powerful and largely immune from extraneous influences.

The effect of tick size on market quality may vary by the amount of quotation information that an exchange publishes. US exchanges publish only size at the best bid and offer prices. Exchanges like the Paris Bourse and the Toronto Stock Exchange publish size at and behind the best prices. Since tick size affects quotation sizes, a change in tick size may affect traders differently in these two types of markets. Since order exposure is very important to large traders, analysts should investigate this issue further.

We presently know very little about how variation in tick size schedules affects markets. In the US, for most stocks, the tick size schedule is flat at 1/8 dollar for all prices. (It soon will be a flat 1/16 dollar at AMEX.) In other countries, a schedule of tick sizes keeps them roughly proportional to prices. We need to better understand the empirical effect of these differences on stock splits and on the relation between price level and firm size.

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Table 1

Changes in Toronto Stock Exchange Spreads Surrounding April 15, 1996

	Average Change in Quoted Spread	
	Cents	Percent
Ahn, Cao & Choe, February – June 1996		
Not cross-listed stocks above $5	-3.4¢	-17%
Cross-listed on NYSE above $5	-4.0	-27
Cross-listed on Nasdaq above $5	-3.8	-16
Cross-listed on NYSE above $5 *at NYSE*, measured relative to NYSE control sample	-0.3	0
Cross-listed on Nasdaq above $5 *at Nasdaq*, measured relative to Nasdaq control sample	-5.2	11
Bacidore, February 19 – June 7, 1996, excluding April 1-26.		
$1-3 stocks	0.6¢	10%
$3-5 stocks	0.8	9
Not cross-listed stocks above $5	-3.8	-20
Cross-listed stocks above $5	-3.7	-27
For above $5 stocks, the changes are greater for actively traded stocks and low price stocks.		
Chung, Kryzanowski and Zhang, February 2 – June 25, 1996, excluding April 5-22.		
Small Cap	n/a	-23%
Mid Cap	n/a	-32
Large Cap	n/a	-43
Former spread was 1 tick	n/a	-51
Former spread was above 1 tick	n/a	-29
Cross-listed stocks	n/a	-36
Cross-listed stocks, *US quotes*	n/a	-3
Huson, Kim & Mehrotra, February – September 1996		
$3-5 stocks, September versus March	-0.0¢	n/a
$5-10 stocks, September versus March	-5.9	n/a
$10-30 stocks, September versus March	-5.5	n/a
Above $30, September versus March	-4.8	n/a
Similar results are obtained for May, June, July and August contrasts with March with no obvious trend.		
Ricker, January – September 1996		
Above $5 stocks, equal-weighted average	-2.1¢	-6%
Above $5 stocks, volume-weighted average	-5.0	-30%
Before April 15, 23% of the stocks were quoted with the minimum $1/8 spread 75% of the time. Afterwards only 5% were quoted with the minimum $0.05 spread 75% of the time.		
Weaver, March and May, 1996		
$3-5 stocks, CATS	1.5¢	13%
$3-5 stocks, Floor	-0.1	-1%
Above $5 stocks, CATS	-1.7¢	n/a
Above $5 stocks, Floor	-3.5	n/a
In the floor system, the decrease in spreads is greatest for low price and high volume stocks. Similar results are found for CATS.		

Table 2

Changes in Toronto Stock Exchange Quotation Sizes Surrounding April 15, 1996

	Average Change in Quotation Size	
	Change	Percent
Ahn, Cao & Choe, February – June 1996		
Not cross-listed stocks above $5	-19 lots	-26%
Cross-listed on NYSE above $5	-68	-51
Cross-listed on Nasdaq above $5	-19	-26
Cross-listed on NYSE above $5 *at NYSE*, measured relative to NYSE control sample	- 2	-5
Cross-listed on Nasdaq above $5 *at Nasdaq*, measured relative to Nasdaq control sample	n/a	n/a
Bacidore, February 19 – June 7, 1996, excluding April 1-26.		
$1-3 stocks	-2 lots	-5%
$3-5 stocks	-6	-11
Not cross-listed stocks above $5	-24	-33
Cross-listed stocks above $5	-66	-52
Chung, Kryzanowski and Zhang, February 2 – June 25, 1996, excluding April 5-22.		
Small Cap	n/a	-21%
Mid Cap	n/a	-29
Large Cap	n/a	-40
Former spread was 1 tick	n/a	-53
Former spread was above 1 tick	n/a	-29
Cross-listed stocks	n/a	-37
Cross-listed stocks, *US quotes*	n/a	-1
Huson, Kim & Mehrotra, February – September 1996		
$3-5 stocks, September versus March	-1 lots	n/a
$5-10 stocks, September versus March	-21	n/a
$10-30 stocks, September versus March	-36	n/a
Above $30, September versus March	-17	n/a
Similar results are obtained for May, June, July and August contrasts with March with no obvious trend. The size differences are 2/3 smaller for the late April versus early April contrast, however.		
Ricker, January – September 1996		
Above $5 stocks, equal-weighted average	$-72,745	-39%
Above $5 stocks, TSE300 stocks only	-40,190	-44%
Weaver, March and May, 1996		
$3-5 stocks, CATS	-4 lots	-10%
$3-5 stocks, Floor	5	11%
Above $5 stocks, CATS	-16	n/a
Above $5 stocks, Floor	-28	n/a