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The Impact of Decimalization on Market Quality: An Empirical Investigation of the Toronto Stock Exchange*

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I address the ''decimalization'' debate, i.e., whether trading on cent ticks rather than fractions of a dollar reduces trading costs without diminishing liquidity. I use Toronto Stock Exchange data following their switch to decimal trading on April 15, 1996. For stocks whose minimum tick was reduced from one-eighth of a dollar to five cents, decimalization reduced spreads, while liquidity was not adversely affected. Investors' trading costs and liquidity providers' profits declined on average, but trading volume did not increase. For stocks whose minimum tick size declined from 5 cents to 1 cent, decimalization had little impact on market quality. *Journal of Economic Literature* Classification Numbers: G12, G15 © 1997 Academic Press

I. INTRODUCTION

The question of whether U.S. stock exchanges should move to decimal-based trading has recently been the focus of much debate. In its Market 2000 report, the Securities and Exchange Commission (SEC) recommended that U.S. exchanges move to a decimal pricing system. More recently, Commissioner Steven Wallman called for the decimalization of U.S. equity markets by January 1, 1999. In March 1997, The Common Cents Stock Pricing Act of 1997 was introduced into Congress which would require that U.S. equity markets quote prices in dollars and cents as opposed to the current system of pricing in fractions of a dollar. Supporters argue that

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TABLE I
PRE- AND POSTDECIMALIZATION MINIMUM TICK SIZE

Stock price	Predecimalization minimum trading increment	Postdecimalization minimum trading increment
<49.5 cents	$\frac{1}{2}$ cent	No change
\$0.50–2.99	1 cent	No change
\$3.00–4.99	5 cents	1 cent
Over \$5.00	12.5 cents (\$$\frac{1}{8}$)	5 cents

The minimum tick size before and after the April 15, 1996 move to decimal-based trading is given. The table is based on the Toronto Stock Exchange publication "One Simple Point, Explained." All numbers are in Canadian Dollars.

decimalization would result in lower transactions costs to investors by allowing liquidity providers to decrease the quoted bid–ask spread. Critics argue that lower bid–ask spreads would lead to a decline in liquidity as the provision of liquidity becomes less profitable. Currently, there is little empirical evidence to help settle this dispute since, prior to April 1996, no major exchange had transitioned to decimal-based trading.

On Monday, April 15, 1996, Canadian stock exchanges switched to a decimal-pricing system and reduced the minimum tick size. Table I provides a summary of the pre- and postdecimalization minimum tick sizes. The minimum tick size was reduced from 12.5 cents (1/8 dollars) to 5 cents for stocks trading above \$5.[1] For stocks trading between \$3 and \$5, the minimum tick size was reduced from 5 cents to 1 cent. The minimum tick size for stocks trading below \$3 was unaffected. The transition was completed over the prior weekend, with all orders being converted to decimal prices by rounding buy (sell) orders down (up) to the nearest decimal increment.[2] This development provides the first opportunity to empirically address the decimalization debate, which is my main objective in this paper. In particular, I examine the question of whether decimalization improves welfare by reducing trading costs without diminishing liquidity.

The available data permit me to directly test the impact of decimalization on market quality. If the supporters of decimalization are correct, spreads should decrease and volume should increase. However, liquidity-provider profits may fall if the increase in trading volume does not offset the decline

[1] All dollar figures given represent Canadian Dollars unless otherwise stated.

[2] As noted by Ahn *et al.* (1996), the change to decimal pricing from fractional pricing is a separate issue from a reduction in minimum price variation. Here, the move to decimal pricing was accompanied by a reduction in the minimum price variation. Thus, this study documents the effects of a move to decimal pricing which is accompanied by a reduction in the minimum price variation.

in per-share profits associated with the reduction in spreads, which, in turn, could lead to a reduction in market depth. Furthermore, Anshuman and Kalay (1993) predict that a reduction in the minimum tick size will further reduce market depth due to an increase in adverse selection. Harris (1994) argues that a reduction in tick size could lead to lower quoted depth as liquidity providers hide more of their orders to avoid "quote matchers." To address these issues, I use data from the Toronto Stock Exchange (TSE), the largest and most active Canadian exchange, to compare individual security statistics before and after the switch to decimal pricing. I also employ least-squares regressions to determine the relationship between the change in spreads and factors such as price, trading activity, volatility, and size. Finally, I estimate the Harris (1994) model of bid–ask spreads to assess its ability to predict the decline in spreads following a reduction in the minimum tick size.

To isolate the effects of decimalization, I partition the sample into cross-listed and non-cross-listed subsamples. For cross-listed stocks, a reduction in tick size may have two effects. The first arises from the ability of liquidity providers to quote tighter spreads, resulting in lower trading costs and increased *aggregate* trading volume. The second effect is that the TSE may be able to attract order flow from the U.S. markets, so that a portion of any increase in volume following the switch to decimalization may be due to a change in trading venue. Thus, assessing the impact of decimalization requires controlling for this "competition effect." Further, I partition these data by stock price since the predecimalization minimum tick size and the reduction in the minimum tick size differ across price groups.

The effect of a reduction in the minimum tick size on market quality was investigated in Harris (1994), Lau and McInish (1995), Ahn *et al.* (1996, 1997), Huson *et al.* (1997), and Porter and Weaver (1997). The Harris (1994) model predicts the change in spreads, depths, and volume which would result from a reduction in the minimum price variation from 1/8 to 1/16 for NYSE and AMEX stocks. Lau and McInish (1995) investigate the impact of a minimum tick size reduction using data from the Stock Exchange of Singapore. Ahn *et al.* (1996) focus on how market quality was affected when the AMEX reduced the minimum tick size to 1/16 from 1/8 for stocks trading between \$1 and \$5. Ahn *et al.* (1997) and Huson *et al.* (1997) examine the impact of decimalization on cross-market competition using Toronto Stock Exchange stocks cross-listed on major U.S. exchanges. Specifically, both studies focus on whether decimalization resulted in an increase in the Toronto Stock Exchange's share of the order flow of cross-listed stocks. Porter and Weaver (1997) use a proprietary data set to investigate how decimalization affects preferencing.

My work differs from these papers in a number of ways. First, unlike Harris (1994), the effect of reducing the minimum tick size on market statistics is estimated directly using pre- and postreduction data rather than fitting a model and *predicting* the impact of the proposed reduction on market quality. Second, although Lau and McInish (1995) and Ahn *et al.* (1996) use pre- and postreduction data, these studies include only a small class of stocks (i.e., Lau and McInish's sample includes only four stocks, while Ahn *et al.* investigate only stocks trading between \$1 and \$5). I cover a much broader range of stocks, particularly with respect to price level. Third, in contrast to Ahn *et al.* (1997) and Huson *et al.* (1997) who investigate how decimalization affects competition across exchanges, I focus on the direct impact of decimalization on market quality by analyzing stocks that trade predominantly in Toronto, thereby controlling for the ‘‘competition effect.’’ Unlike Porter and Weaver (1997), I do not address the preferencing issue, but instead, focus exclusively on the more general market quality issues.

My main findings are the following.

• For stocks trading above \$5, bid–ask spreads, both quoted and effective, decreased significantly after decimalization. This decline was significantly related to stock price and trading activity.

• Quoted depths declined significantly for stocks trading above \$5 following decimalization. However, this is not necessarily evidence that liquidity has been adversely affected because of the concurrent decline in spreads (as noted in Lee *et al.* (1993)). In fact, my results indicate that liquidity was not adversely affected.

• The adverse selection component, as defined in Huang and Stoll (1996), *declines* following decimalization. This is inconsistent with the prediction of Anshuman and Kalay (1993) that a reduction in the minimum tick size will lead to more adverse selection.

• Average daily trading volume in the period following the move to decimal pricing did not increase significantly. This implies that liquidity providers were adversely affected by the move because the decline in per-share profits was not offset by an increase in trading volume. However, given that liquidity was not significantly impacted, the reduction in liquidity-provider profits is consistent with the dissipation of rents.

• For stocks trading between \$3 and \$5, decimalization had little or no impact on market quality even after controlling for price and trading activity. This suggests that the predecimalization minimum tick size for this group was not as binding as for the higher priced stocks. However, given the small sample size for this group and the relatively low cross-sectional variation in price and trading activity within this group, an alternative explanation is that the tests employed lack the power to reject the null hypothesis of no change in the market quality statistics.

- As in Ahn *et al.* (1996), the Harris (1994) model tends to overpredict the decline in spreads following a reduction in the minimum tick size.

The rest is organized as follows. Section II provides a brief description of the trading structures of the Toronto Stock Exchange. Section III outlines the market statistics analyzed in this study and the hypothesized effect of the move to decimal pricing on these statistics. Section IV describes the data. Section V presents the empirical results. Section VI concludes.

II. DESCRIPTION OF THE TORONTO STOCK EXCHANGE

The Toronto Stock Exchange is the largest equity market in Canada. For the first quarter of 1996, approximately 81% of the total dollar volume traded on Canadian exchanges was executed on the TSE. As of January 31, 1996, 1,258 companies were listed on the TSE, with a total market value of over $1 trillion. The average daily trading volume for the month of January 1996 was 89.5 million shares worth a total of $1.16 billion, and the average daily number of transactions was 35,404. For the same time period, the New York Stock Exchange (NYSE) had an average daily trading volume of approximately 417 million shares, average dollar volume of about $16 billion U.S. (or approximately $21.5 billion Canadian), and an average daily number of transactions of 295,536. A total of 2,675 companies were listed on the NYSE, with a total market value of approximately $6 trillion U.S. (or approximately $8.3 trillion Canadian).[3]

Trading on the TSE takes place either on the floor of the exchange or on the Computerized Automated Trade System (CATS). An open limit order book is maintained for both floor traded stocks and the CATS stocks. The rules governing the management of the electronic limit order book are virtually identical to those used on the Paris Bourse (see Biais *et al.* (1995)). For each listed stock, the exchange designates a trader, called the *registered trader*, who has obligations similar to the specialist on the NYSE. The registered trader is responsible for maintaining price continuity, adequate depth, etc. and is able to trade for his/her own account. However, because the TSE has an open limit order book, the registered trader does not have the same type of privileged information with respect to the limit order book as an NYSE specialist.

[3] Summary statistics for the Toronto Stock Exchange were obtained from *The Toronto Stock Exchange Review*, January 1996. Summary statistics for the New York Stock Exchange were obtained from the NYSE Homepage (http://www.nyse.com/).

III. MARKET QUALITY STATISTICS

The reduction in the minimum tick size is predicted to result in lower trading costs, as liquidity providers are able to tighten quotes beyond the level previously allowed. In both the pre- and postdecimalization periods, the average time-weighted quoted spread is calculated as in McInish and Wood (1991) for each stock, where the quoted spread is defined as the difference between the lowest quoted ask price and the highest quoted bid price with positive depths. Time-weighting is used to avoid the problems that may occur when the frequency of quotes is correlated with spread size.

Investors are guaranteed the quoted prices for orders which do not exceed the quoted depth when they transact, but the actual transaction price may differ from the posted quote. For example, an order could be crossed within the spread, resulting in a superior trade price relative to the quoted price. For orders exceeding the quoted depth, the average price per share may lie outside the quoted spread. To account for this possibility, the average effective spread is analyzed. The effective spread is defined as $2|P_t - Q_t|$, where P_t is the trade price, and Q_t is the midpoint of the prevailing quote at the time of the trade.[4] The average is calculated as an equally weighted average of the effective spread observations.

A reduction in spreads may diminish the gains to providing liquidity and thereby reduce the depths of the prevailing quotes, ceteris paribus. Harris (1994) argues that since quote matchers find it easier to improve upon the prevailing quote with a reduced tick size, one should expect depths to decrease. The intuition is that when the minimum tick size is relatively large and time priority is binding, an individual will need to improve upon the quote by at least one tick to attain priority. When the minimum tick size declines, quote matchers do not need to improve upon the quote by as much to attain priority. As a result, liquidity providers will be less likely to place limit orders following a reduction in the minimum tick size since it is more likely that their priority will be lost to quote matchers. Further, Anshuman and Kalay (1993) argue that a reduction in the minimum price variation will increase the probability that a liquidity provider will trade with an informed investor. As a result, liquidity providers will be less likely to post limit orders because the adverse selection problem is more severe following a reduction in the minimum tick size, leading to a reduction in the quoted depth. Thus, I test for differences in time-weighted average depths before and after decimalization is implemented.

[4] When a trade leads to a revision in the best quote, the trade and the revised quote are entered simultaneously into the system. Therefore, the prevailing quote is assumed to be the most recent quote which was posted at least one second before the trade was reported. The results did not change qualitatively using other lag lengths.

In response to the claim that per-share profits of liquidity providers are reduced, proponents of decimal pricing argue that the lower transaction costs will lead to an increase in trading volume that will more than offset the effects of diminished per-share profits. If spreads decline, trading activity increases, *and* liquidity-provider profits do not decrease, then the switch to decimal-based trading could be viewed as Pareto improving. However, if liquidity-provider profits decline, the gain to investors may simply be a wealth transfer from liquidity providers. To test this claim, I compare trading volume, the number of transactions, and liquidity-provider profits before and after the switch to decimal pricing. To estimate the impact of decimalization on liquidity-provider profits, the per-share trading profit and the total dollar profit accruing to liquidity providers are calculated. The per-share profit, or "liquidity premium" (LP), as defined in Lee (1993), is calculated as a volume-weighted average of the effective half-spread, i.e.,

$$LP_i = \frac{\sum_{k=1}^{T_i} V_{ik} \cdot |P_{ik} - Q_{ik}|}{\sum_{k=1}^{T_i} V_{ik}}, \tag{1}$$

where i denotes the ith stock, k denotes the kth trade, P_{ik} is the price of the kth trade for the ith stock, Q_{ik} is the midpoint of the prevailing quote at the time of the kth trade, V_{ik} is the number of shares traded in the kth trade and T_i is the number of trades for the ith stock. Liquidity-provider profits (in dollars) are estimated as the numerator of (1).

In testing these claims, the null hypothesis will be formulated in two ways. First, the null hypothesis is that there is no change in the statistic in question (e.g., quotes and volume). However, since changes can occur for reasons unrelated to decimalization (e.g., general market trends), the null hypothesis will also be stated relative to a control sample. Since stocks with prices under \$3 are not affected by the move to decimalization, these stocks are used as a control group. Thus, the revised null hypothesis is that the change in the statistic of the sample group is equal to the change of the control group. I provide (two-tailed) tests of both null hypotheses.[5]

[5] The control group may not have the same characteristics (e.g., price, trading activity, and volatility) as the higher priced shares and therefore may not be appropriate. However, a more appropriate control group comprised of Canadian stocks is not obvious given that the minimum tick size was reduced for all other issues on the TSE as well as on the other Canadian exchanges. Use of NYSE/AMEX stocks matched on price, trading activity, etc. is also inappropriate given the differing market structures, competitive nature of liquidity provision, etc. Further, if the factors which impact changes in spreads, depths, etc. differ across markets or if the *sensitivities* to these factors differ, comparisons made using the NYSE/AMEX sample may not control for general trends underlying the TSE sample statistics.

IV. DATA

I use intraday trading data for a sample period that begins on February 12, 1996 and ends June 14, 1996. The two-week period immediately before and two-week period immediately after the switch are excluded to avoid incorporating unusual behavior by traders due to the switch itself.[6] All common shares listed on the TSE at the start of the sample period are included with the following exceptions. As in Harris (1994), stocks which experienced a price change of more than 50% and those with an average price of less than $1 for the predecimalization period are excluded. Further, stocks which averaged less than one transaction per day are excluded. This restriction allows for more precise estimates of the effective spread and liquidity premium statistics since, unlike the quoted spreads, quoted depths, and volume, these statistics are measured with error. Finally, only quotes and trades recorded after the daily opening and before the close are used, except in the calculation of trading activity where opening trades are included.

The sample is then partitioned into three subsamples. The first includes non-cross-listed stocks with an average predecimalization price between $3 and $5, and the second includes non-cross-listed stocks with an average predecimalization price greater than or equal to $5. The third group contains cross-listed stocks with a predecimalization price above $5 and is constructed to control for any "competition effects," i.e., changes in market quality due to traders moving orders from one trading venue to another.[7] The $1–3 and $3–5 cross-listed subsamples were excluded from the analysis due to an insufficient number of stocks in each of these groups. After employing the screens above, the "$3 to 5" non-cross-listed sample contained 68 stocks, the "greater than $5" non-cross-listed sample contained 318 stocks, the "greater than $5" cross-listed sample contained 72 stocks, and the "$1 to 3" control group contained 103 stocks.

To determine the effect decimalization had on the market quality statistics given above, the statistics are calculated on a stock-by-stock basis, and the percentage change for each stock is calculated. The cross-sectional mean and median percentage change is then computed for each subsample.

[6] For the preswitch period, the statistics may be biased if traders change their behavior by reducing (increasing) trades just prior to the switch in anticipation of decreased (increased) costs under the new decimal system. Also, trading activity might diminish in the postswitch period as traders adapt to the new system. Although these data are excluded in the statistical tests, I present a graphical description of quote behavior around this date in Section V.

[7] Cross-listed stocks are identified using the TAQ database. Although this identification method does not perfectly control for trading across markets, it should result in the identification of stocks where cross-market trading is most pronounced.

V. RESULTS

A. *Pre- and Postdecimalization Comparisons*

Spreads. Table II shows average quoted and effective spreads for the stocks in the sample. A striking result is the decline in spreads for stocks trading above \$5, both in absolute terms as well as relative to the \$1–\$3 control group. The mean decline in quoted (effective) spreads for the non-cross-listed group was 20.18% (18.77%), while the mean decline for the cross-listed subsample was 26.88% (26.12%). Thus, for the greater than \$5 subsamples, decimalization had a significant impact in reducing the cost of trading as measured by the bid–ask spread. The null hypotheses that the change in quoted and effective spreads is equal across the two groups are both rejected at the 5% level using difference of means tests, but are not rejected using sign tests. The fact that spreads of cross-listed stocks decline more than those of non-cross-listed stocks suggests that cross-market competition leads to a greater reduction in spreads. However, this result could also be explained by other differences across the two groups (e.g, differences in price levels and trading activity). Ahn *et al.* (1997) attempt to control for differences across the two groups using cross-sectional regressions. Surprisingly, they find that, after controlling for price and trading activity, quoted and effective spreads of stocks cross-listed on the NASDAQ decline *less* than spreads of non-cross-listed stocks, while the decline in spreads for stocks cross-listed on the NYSE is not statistically different from the decline for non-cross-listed stocks. Thus, the difference across the two groups is more likely to be due to differences in prices and trading activity as opposed to cross-market competition.

For non-cross-listed stocks in the \$3–5 subsample and those in the \$1–3 control group, quoted and effective spreads *increased* on average following decimalization. The mean increase in quoted (effective) spreads for the \$3–5 subsample was 8.51% (2.36%). Only the difference of means test on quoted spreads was significantly different from zero. The mean quoted (effective) spread also increased for the \$1–3 subsample by 9.78% (8.12%). The increase for the \$1–3 subsample was significant using both a difference of means test (t test) and a sign test. The null hypotheses that the change in quoted and effective spreads was equal across the \$1–3 and \$3–5 groups are not rejected at conventional levels. These results suggest that, first, the minimum tick size of \$0.05 was not overly restrictive for the \$3–5 subsample. Second, because spreads increased for both samples, the increase in spreads could be due to factors unrelated to decimalization (e.g., a general upward trend in spreads). However, this is also consistent with cross-subsidization in that liquidity providers may have been earning rents on the greater-than-\$5 subsamples prior to decimalization, but were using these rents to

TABLE II

Comparison of Pre- and Postdecimalization Quoted and Effective Spreads

	Quoted spread											
	$1–3 Not cross-listed ($n$ = 103)			$3–5 Not cross-listed ($n$ = 68)			>$5 Not cross-listed ($n$ = 318)			>$5 Cross-listed ($n$ = 72)		
	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)
Mean	6.17	6.73	9.78***	10.34	11.10	8.51***	24.29	20.49	−20.18***	21.65	17.95	−26.88***
Standard deviation	2.73	3.34	28.28	4.20	4.95	25.08	12.66	15.44	27.86	12.88	16.78	26.56
Median	6.17	6.26	5.88	8.93	9.57	4.99	20.55	14.92	−26.61	16.64	11.28	−33.52
Percentage of stocks with decline		37.86%**			45.59%			79.56%***			83.33%***	

	Effective spread											
	$1–3 Not cross-listed ($n$ = 103)			$3–5 Not cross-listed ($n$ = 68)			>$5 Not cross-listed ($n$ = 318)			>$5 Cross-listed ($n$ = 72)		
	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)
Mean	5.53	5.86	8.12***	9.39	9.49	2.36	22.50	18.73	−18.77***	20.54	16.34	−26.12***
Standard deviation	2.44	2.59	25.11	3.36	3.77	23.52	12.74	13.03	28.00	9.67	13.18	27.03
Median	5.31	5.88	8.07	8.70	8.26	0.83	18.73	14.49	−21.67	16.97	10.71	−30.43
Percentage of stocks with decline		34.95%***			48.53%			77.67%***			79.17%***	

Note. The cross-sectional averages are computed for four subsamples of stocks trading on the Toronto Stock Exchange. The first three subsamples include stocks trading primarily in Toronto with an average price between $1 and 3, $3 and 5, and greater than $5, respectively. The fourth subsample includes stocks trading in both the United States and Toronto with an average price greater than $5. The cross-sectional average time-weighted quoted spread and effective spread summary statistics (in cents) are presented.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

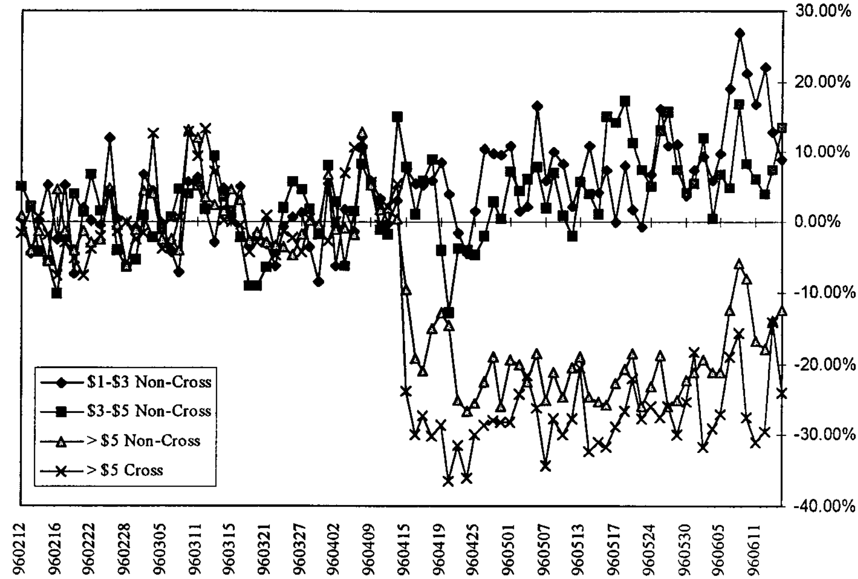

FIG. 1. Daily variation in average quoted spreads. For each of the four subsamples, the cross-sectional daily average quoted spread is calculated and presented as a percent of the predecimalization average quoted spread for each day of the sample period. The predecimalization average is calculated over the period starting on February 12, 1996 and ending on March 29, 1996. The event period is centered around the April 15, 1996 decimalization date.

subsidize the stocks trading below $5. The decline in spreads for stocks greater-than-$5 may have reduced or eliminated these rents, leading to a reduction in the subsidies provided to the stocks in the $3–5 and $1–3 subsamples.[8]

To determine whether the change in spreads was related to decimalization, the daily variation in quoted spreads over the entire event period is presented graphically. Figure 1 shows the change in quoted spreads relative to the predecimalization average spread for each day between February 12, 1996 and June 14, 1996. A value of 0% indicates that the spread on a given day is equal to the average spread measured in the predecimalization period. For cross-listed and non-cross-listed stocks trading above $5, there is a clear decline in spreads on the April 15th decimalization date, which supports the claim that the decline was a consequence of decimalization rather than other factors. For the $1–3 and $3–5 non-cross-listed subsamples, there does not appear to be major shift on April 15th, but spreads do appear to be drifting upward following that date.[9]

[8] Cao *et al.* (1997) document a similar cross-subsidization in their study of NYSE specialists.
[9] A similar pattern emerges for effective spreads.

As Harris (1994) suggests, the benefits of decimalization should be greatest for highly active stocks as well as for relatively low-priced stocks. For stocks with high trading activity, the minimum tick size is more likely to be binding because the high turnover decreases the *per trade* fixed cost component. Further, one would expect the minimum tick size to be more binding for stocks trading at lower prices since the costs associated with a minimum tick size are larger in *relative* terms. To test these claims, the subsample of non-cross-listed stocks trading with an average predecimalization price greater than $5 is partitioned into quartiles by trading activity, as measured by the number of transactions, and by price.

Table III presents the change in quoted and effective spreads for the trading activity quartiles. The decline in spreads is, in fact, greatest for the most actively traded stocks, as predicted by Harris (1994). The decline in quoted (effective) spreads for the least actively traded stocks was only 7.86% (3.49%) on average, while the average decline in quoted (effective) spreads for the most actively traded stocks was 36.08% (34.41%). The null hypotheses that the changes in quoted and effective spreads are equal across quartiles are rejected at the 1% level. This is not surprising when one considers that the average predecimalization quoted spread for the least active stocks was 32.97 cents, while the average predecimalization spread for the most active stocks was 15.83 cents, only slightly above the predecimalization minimum tick size of 12.5 cents. Table IV presents the change in spreads by price quartile. As predicted, the changes in both quoted and effective spreads are also greatest for low-priced stocks. The null hypotheses that the changes in quoted and effective spreads are equal across price quartiles are also rejected at the 1% level.

Depths. Anshuman and Kalay (1993) and Harris (1994) argue that a reduction in the minimum tick size could lead to a reduction in liquidity due to increased adverse selection and "quote matching," respectively. Consequently, quoted depths might decline following decimalization. Table V presents comparisons of quoted ask depths before and after decimalization. The results indicate that depths do decline significantly following decimalization for stocks trading above $5. For non-cross-listed (cross-listed) stocks trading above $5, average time-weighted ask depths declined by 33.43% (51.68%). For stocks trading between $3 and $5, the average quoted depths also declined following decimalization, but this decline is only significant using the *t* test. Furthermore, this decline was not significantly different from the decline in depths experienced by the $1–3 control group, suggesting that depths were not adversely affected by decimalization for this subsample.[10]

[10] The analysis was also performed using bid depth and total depth (i.e., bid depth plus ask depth). The results were qualitatively similar.

TABLE III

COMPARISON OF PRE- AND POSTDECIMALIZATION SPREADS BY TRADING ACTIVITY

	Quoted spread											
	$N_i < 4.11$			$4.11 < N_i < 8.47$			$8.47 < N_i < 19.80$			$N_i > 19.80$		
	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)
Mean	32.97	30.33	−7.86***	26.50	21.98	−19.27***	21.68	19.05	−17.46***	15.83	10.61	−36.08***
Standard deviation	15.79	18.94	32.52	11.19	14.01	27.16	9.37	12.66	24.09	4.93	6.66	18.39
Median	29.11	25.72	−10.92	23.08	17.16	−26.44	18.67	13.76	−20.00	14.29	8.66	−39.67
Percentage of stocks with decline		67.50%***			82.28%***			77.22%***			91.25%***	
	Effective spread											
	$N_i < 4.11$			$4.11 < N_i < 8.47$			$8.47 < N_i < 19.80$			$N_i > 19.80$		
	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)
Mean	28.89	27.07	−3.49	23.27	18.89	−19.96***	20.97	17.71	−17.21***	16.84	11.22	−34.41***
Standard deviation	18.67	16.97	33.45	9.82	10.62	24.45	10.16	10.92	23.29	5.39	5.99	20.31
Median	24.01	22.92	−5.35	20.46	16.18	−21.00	17.41	14.09	−17.20	15.46	9.16	−36.22
Percentage of stocks with decline		55.00%			84.81%***			74.68%***			96.25%***	

Note. The subsample of stocks with an average predecimalization price greater than or equal to $5 is split up into quartiles by predecimalization trading activity. The quartile breakpoints are 4.11, 8.47, and 19.80 trades per day. N_i denotes the average daily number of transactions. The cross-sectional average time-weighted quoted spread and effective spread summary statistics (in cents) are presented for each quartile.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

TABLE IV

COMPARISON OF PRE- AND POSTDECIMALIZATION SPREADS BY PRICE

	Quoted spreads											
	Avg. price < $8.85			8.85 < Avg. price < 12.96			12.96 < Avg. price < 20.12			Avg. price > 20.12		
	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)
Mean	20.07	14.92	−23.94***	22.28	17.17	−25.69***	24.60	22.53	−15.34***	30.26	27.40	−15.76***
Standard deviation	9.72	6.94	24.60	8.55	9.42	22.13	10.45	16.60	35.77	17.72	21.35	25.82
Median	17.94	13.97	−27.35	18.95	13.56	−30.52	21.77	18.08	−27.00	27.25	22.87	−15.29
Percentage of stocks with decline		87.50%***			82.28%***			76.25%***			72.15%***	
	Effective spreads											
	Avg. price < $8.85			8.85 < Avg. price < 12.96			12.96 < Avg. price < 20.12			Avg. price > 20.12		
	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)
Mean	18.73	13.42	−23.63***	19.99	15.79	−23.06***	21.65	20.48	−9.51***	29.67	25.25	−18.93***
Standard deviation	14.62	6.12	24.23	6.78	8.03	23.15	8.11	13.30	35.80	16.03	18.02	25.02
Median	15.95	11.55	−25.31	17.49	13.39	−25.27	19.56	17.65	−16.95	25.26	21.23	−20.21
Percentage of stocks with decline		82.50%***			84.81%***			67.50%***			75.95%***	

Note. The subsample of stocks with an average predecimalization price greater than or equal to $5 is split up into quartiles by predecimalization average price. The quartile breakpoints are $8.85, $12.96, and $20.12. The cross-sectional average time-weighted quoted spread and effective spread summary statistics (in cents) are presented for each quartile.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

TABLE V

Comparison of Pre- and Postdecimalization Quoted Depths

	Quoted depth											
	$1–3 Not cross-listed ($n$ = 103)			$3–5 Not cross-listed ($n$ = 68)			>$5 Not cross-listed ($n$ = 318)			>$5 Cross-listed ($n$ = 72)		
	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)
Mean	64.48	62.44	−4.98	64.21	58.10	−10.77*	61.25	37.60	−33.43***	127.64	61.24	−51.68***
Standard deviation	28.67	32.80	39.84	46.15	48.06	48.57	68.46	29.77	52.30	141.63	55.23	47.35
Median	57.98	56.78	−3.42	48.14	47.10	−16.63	37.00	28.76	−37.69	68.78	40.05	−52.15
Percentage of stocks with decline		55.34%			58.82%			74.53%***			91.67%***	

Note. The cross-sectional average change in time-weighted quoted ask depths (in board lots of 100 shares) are computed for four subsamples of stocks trading on the Toronto Stock Exchange. The first three subsamples include stocks trading primarily in Toronto with an average price between $1 and $3, $3 and $5, and greater than $5, respectively. The fourth subsample includes stocks trading in both the United States and Toronto with an average price greater than $5.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

Adverse Selection. To test the prediction of Anshuman and Kalay (1993) more directly, I estimate the adverse selection component for the pre- and postdecimalization periods. The adverse selection component is defined as the difference between the effective spread and the realized spread (see Huang and Stoll (1996)). Intuitively, the effective spread measures the cost to investors of transacting, while the realized spread measures the gain accruing to liquidity providers. Therefore, the difference between what investors pay and what liquidity providers actually earn is a measure of how much of the spread accrues to informed investors. The realized spread was calculated using the next trade occurring at least five minutes after the initial trade. In estimating the adverse selection component, only stocks which averaged at least two trades per day were included in the sample.[11] The results are presented in Table VI.

The results of this analysis do not support the Anshuman and Kalay (1993) prediction that adverse selection increases following decimalization. For both samples of stocks trading above \$5, the average adverse selection component *declines* significantly. The mean change in the adverse selection component for non-cross-listed and cross-listed stocks is −24.98 and −35.53%, respectively, while the adverse selection component is essentially unchanged for stocks trading between \$3–5. Interestingly, the adverse selection component for the \$1–3 control group increased significantly in absolute terms as well as relative to the effective spread (not reported) despite the fact that these stocks were not directly affected by decimalization. The mean increase in the adverse selection component was 13.56% for the \$1–3 control group. However, relative to the effective spread, the change was quite small. The average adverse selection component prior to decimalization was 73.95% of the effective spread, while the postdecimalization adverse selection component was 75.86%.

Spread vs. Depth. The fact that spreads and depths both decline for the greater-than-\$5 subsamples suggests that investors whose trade sizes did not exceed the reduced depths faced lower transactions costs after decimalization. However, the effect on large traders (i.e., those who typically trade in sizes exceeding the quoted depth) is unclear. The overall impact of decimalization on liquidity cannot be determined simply by focusing on the change in the quoted depth when there is a contemporaneous reduction in quoted spreads (as noted in Lee *et al.* (1993)). To see this,

[11] The analysis was run without this additional constraint, and, as expected, the precision of the realized spread (and, consequently, the adverse selection component) declined dramatically. Although the mean change in the adverse selection component differed substantially from those reported in *Table VI*, the medians were similar. Upon inspection, it was found that the difference in means was primarily due to outliers as opposed to a systematic shift in the distribution.

TABLE VI

COMPARISON OF PRE- AND POSTDECIMALIZATION ADVERSE SELECTION

	Adverse selection											
	$1–3 Not cross-listed ($n$ = 74)			$3–5 Not cross-listed ($n$ = 55)			>$5 Not cross-listed ($n$ = 266)			>$5 Cross-listed ($n$ = 61)		
	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)
Mean	3.63	3.98	13.56***	6.75	6.42	6.41	13.99	11.06	−24.98***	12.76	9.08	−35.53***
Standard deviation	1.97	2.02	29.91	3.50	3.30	58.57	8.56	9.39	37.63	8.46	10.28	37.07
Median	3.06	3.37	15.15	6.52	5.80	0.21	11.73	8.68	−26.41	9.81	5.93	−38.94
Percentage of stocks with decline		35.14%***			49.09%			78.95%***			83.61%***	

Note. The cross-sectional averages are computed for four subsamples of stocks trading on the Toronto Stock Exchange. The first three subsamples include stocks trading primarily in Toronto with an average price between $1 and $3, $3 and $5, and greater than $5, respectively. The fourth subsample includes stocks trading in both the United States and Toronto with an average price greater than $5. The adverse selection component of the bid ask spread is calculated using the methodology of Huang and Stoll (1996). For each stock, the average effective and average realized spread is computed. The adverse selection component is computed as the difference between the average effective and realized spreads.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

consider the following example. Assume that for a given stock the best bid was \$20 and the best ask was \$20 1/8 prior to decimalization, and there were 5000 shares available at each of these prices. Assume that following decimalization, the bid increased to \$20.05, the ask fell to \$20.10, and the depth at each price declined to 2500 shares. If a trader places an order to sell 5000 shares, the trader may still be better off following decimalization if, for example, there is an additional 2500 shares remaining at \$20.00, because 2500 shares will be executed at \$20.05, and the remaining will be executed at \$20.00, for an average price (\$20.025) that exceeds the predecimalization price (\$20.00).

More formally, a decline in market quality is indicated by an adverse shift in the depth-spread function, which is essentially the supply function for liquidity. The best bid–ask represents only one point on this function, specifically the lowest spread for which depth is positive. If quoted spread and quoted depth decline simultaneously, it is unclear whether the underlying supply function itself has changed or whether the new quote simply represents a point on the unchanged curve that could not be observed prior to decimalization. This makes it difficult to determine whether liquidity has increased or decreased.

To investigate the spread-depth relationship further, I conduct two additional analyses. The first focuses on how the change in effective spreads varies across trade sizes, as in Christie and Huang (1994). The second is an investigation of the ratio of depth and spread.[12] If market quality is adversely affected by decimalization, the effective spread should be increasing in trade size. Also, we would expect the depth-to-spread ratio to decline, implying that depth has become more costly.

Table VII reports the change in effective spread for various trade sizes. The results indicate that, although average quoted depth declines following decimalization, large investors do not appear to be worse off. The effective spread declines on average for all trade sizes for both the cross-listed and non-cross-listed stocks greater than \$5. Although the decline in effective spreads is not significant for all trade sizes, the noteworthy point is that the effective spread does not increase significantly for any trade size. This suggests that liquidity did not diminish.

The depth-to-spread ratio is also used to quantify the tradeoff between spreads and depth. A decrease (increase) in the depth-to-spread ratio would indicate that depth is declining (increasing) more than spreads on average or, more intuitively, that depth is becoming more (less) costly. The results for the depth-to-spread analysis are presented in Table VIII. For non-cross-listed stocks greater than \$5, the depth-to-spread ratio *increases* significantly both in absolute terms as well as relative to the control group. For the

[12] I thank Lawrence Harris for suggesting this analysis.

TABLE VII

CHANGE IN EFFECTIVE SPREADS BY TRADE SIZE

>$5 Not cross-listed									
Effective spreads									
Trade size:	100	200	300	400	500	501–1000	1001–5001	5001–10000	>10000
	Change (%)	Change (%)	Change (%)	Change (%)	Change (%)	Change (%)	Change (%)	Change (%)	Change (%)
Mean	−16.37***	−14.12***	−17.01***	−6.46	−14.06***	−16.74***	−11.06***	−8.28*	−8.67
Standard deviation	34.89	42.94	33.91	96.35	45.44	50.36	65.03	73.40	102.29
Median	−21.44	−23.30	−22.67	−23.23	−22.12	−22.68	−21.92	−22.20	−20.53
Percentage of stocks with decline	77.36%***	76.73%***	77.78%***	74.12%***	76.58%***	77.67%***	74.68%***	76.47%***	75.85%***

>$5 Cross-listed									
Effective spreads									
Trade size:	100	200	300	400	500	501–1000	1001–5001	5001–10000	>10000
	Change (%)	Change (%)	Change (%)	Change (%)	Change (%)	Change (%)	Change (%)	Change (%)	Change (%)
Mean	−25.29***	−24.50***	−23.60***	−7.26	−19.87***	−23.90***	−24.12***	−32.45***	−14.51*
Standard deviation	27.10	37.21	39.22	105.39	41.70	44.07	40.55	42.05	60.14
Median	−28.88	−32.65	−31.74	−37.15	−32.53	−31.79	−28.55	−35.88	−29.16
Percentage of stocks with decline	84.72%***	84.72%***	84.72%***	75.00%***	76.39%***	84.51%***	73.91%***	85.00%***	69.35%***

Note. The cross-sectional average effective spread statistics are computed for various trade sizes for non-cross-listed and cross-listed stocks with a predecimalization price greater than $5.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

TABLE VIII

COMPARISON OF PRE- AND POSTDECIMALIZATION DEPTH-TO-SPREAD RATIO

	Depth-to-spread ratio											
	$1–3 Not cross-listed ($n$ = 103)			$3–5 Not cross-listed ($n$ = 68)			>$5 Not cross-listed ($n$ = 318)			>$5 Cross-listed ($n$ = 72)		
	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)
Mean	37.15	38.31	6.08	18.50	18.66	19.99	8.27	9.51	40.10***	18.61	19.19	15.31*
Standard deviation	31.72	48.46	72.80	17.57	23.38	119.99	10.61	11.35	129.32	22.08	22.79	72.03
Median	27.30	21.76	−11.31	12.20	11.44	−3.20	4.67	5.17	10.68	8.37	9.95	1.46
Percentage of stocks with decline		61.17%**			52.94%			40.88%***			44.44%*	

Note. The cross-sectional averages are computed for four subsamples of stocks trading on the Toronto Stock Exchange. The first three subsamples include stocks trading primarily in Toronto with an average price between $1 and $3, $3 and $5, and greater than $5, respectively. The fourth subsample includes stocks trading in both the United States and Toronto with an average price greater than $5. The ratio is calculated by taking the outstanding total depth (ask depth plus bid depth) and dividing by the quoted spread (in cents) for each quote.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

other non-cross listed subsamples, the mean change in the depth-to-spread ratio is not statistically significant.[13] The fact that the average effective spread declined for all trade sizes and that the depth-to-spread ratio did not decline suggests that, for stocks greater than $5, market quality improved following decimalization.

Trading Activity. The joint observation that trading costs fell for stocks trading above $5 and that market quality was not adversely affected might be expected to produce an increase in volume. Table IX tests for differences in volume surrounding decimalization. The results indicate that trading volume did not increase significantly. In fact, for each non-cross-listed subsample, trading volume *declined* following decimalization, although the decline was insignificant. For cross-listed stocks greater than $5, the mean change in volume was 1.20%, while the median change was −9.05%. The mean and median changes were not significant at conventional levels. Thus, even though trading became less costly to investors, trading activity was statistically unchanged following decimalization, suggesting that trading activity was relatively inelastic with respect to the cost of trading.[14]

Liquidity Premia. The fact that trading costs declined following decimalization indicates that investors benefitted from decimalization. However, since this benefit is costly to liquidity providers, the effect on liquidity providers must also be investigated to determine whether decimalization was Pareto improving. Table X contains results of a test of whether liquidity providers were harmed by decimalization. The table indicates that per-share profits, as measured by the liquidity premium, declined significantly for both cross-listed and non-cross-listed stocks trading above $5. For the non-cross-listed sample, the mean decline in per-share profits was 15.35%, while the mean decline for cross-listed stocks was 24.07%. For non-cross-listed stocks in the $3–5 subsample, the liquidity premia increased by 3.88% on average, but this increase was insignificant. Consistent with the results for spreads, the liquidity premia increased by 18.17% on average for the $1–3 control group, which again is consistent with either a general upward trend in spreads or cross subsidization.

[13] Another way to interpret this is in the context of the spread-depth supply function (as in Lee *et al.* (1993)). If the spread-depth function is linear, an increase in the depth-to-spread ratio would be consistent with an increase in liquidity. If depth is viewed to be a nonlinear function of spread, the interpretation is less clear. An increase in the ratio is consistent with a movement along an unchanged curve or a movement along a curve associated with a positive shift in liquidity. In fact, the ratio could increase even if the shift in liquidity is adverse if the function is sufficiently concave or if the function is convex. Given the results of the effective spread-trade size analysis, the increase in depth-to-spread is consistent with the claim that liquidity is not adversely affected by decimalization.

[14] A similar analysis of the number of transactions yielded qualitatively similar results.

TABLE IX

COMPARISON OF PRE- AND POSTDECIMALIZATION TRADING VOLUME

	Volume											
	\$1–3 Not cross-listed (n = 103)			\$3–5 Not cross-listed (n = 68)			>\$5 Not cross-listed (n = 318)			>\$5 Cross-listed (n = 72)		
	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)
Mean	28.87	26.80	−3.70	26.56	25.69	−17.08	38.58	36.01	−6.72	124.04	108.20	1.20
Standard deviation	41.21	39.16	74.75	31.73	35.21	92.75	65.56	62.95	87.92	144.48	120.59	78.44
Median	14.94	14.31	−4.09	19.34	11.71	−22.96	14.51	12.96	−0.53	67.68	54.45	−9.05
Percentage of stocks with increase		45.63%			42.65%			49.37%			41.67%	

Note. The cross-sectional averages are computed for four subsamples of stocks trading on the Toronto Stock Exchange. The first three subsamples include stocks trading primarily in Toronto with an average price between \$1 and \$3, \$3 and \$5, and greater than \$5, respectively. The fourth subsample includes stocks trading in both the United States and Toronto with an average price greater than \$5. Average daily volume is calculated by summing the share volume for each stock for each day and dividing by the number of days in the period. Numbers are in thousands of shares.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

TABLE X

COMPARISON OF PRE- AND POSTDECIMALIZATION LIQUIDITY PREMIA

	Liquidity premium											
	$1–3 Not cross-listed ($n$ = 103)			$3–5 Not cross-listed ($n$ = 68)			>$5 Not cross-listed ($n$ = 318)			>$5 Cross-listed ($n$ = 72)		
	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)	Pre	Post	Change (%)
Mean	2.76	3.10	18.17***	5.35	4.98	3.88	12.25	9.79	−15.35***	11.31	8.26	−24.07***
Standard deviation	1.19	1.54	56.90	4.35	2.44	36.90	7.52	7.36	44.35	5.78	7.52	46.70
Median	2.69	2.92	9.33	4.36	4.17	5.05	10.16	7.57	19.21	8.88	5.87	−31.18
Percentage of stocks with decline		35.92%***			45.59%			73.90%***			81.94%***	

Note. The cross-sectional averages are computed for four subsamples of stocks trading on the Toronto Stock Exchange. The first three subsamples include stocks trading primarily in Toronto with an average price between $1 and $3, $3 and $5, and greater than $5, respectively. The fourth subsample includes stocks trading in both the United States and Toronto with an average price greater than $5. The liquidity premium is a volume-weighted average of one-half the effective spread and is, therefore, an estimate of per-share liquidity-provider profits.

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

The results above together with the volume statistics can be used to estimate the dollar saving to investors, which is equal to the dollar loss to liquidity providers if volume is unchanged following decimalization. This is done by multiplying the total predecimalization daily trading volume by the dollar change in the liquidity premium for each subsample and summing across the four subsamples. This implies a daily dollar cost savings to investors of $557,359, or annual savings of over $139 million (assuming 250 trading days).

To gauge the overall impact on liquidity providers, however, the effect of decimalization on trading volume must also be considered. The fact that per share profits declined following decimalization coupled with the finding that volume did not increase suggests that liquidity providers were harmed by decimalization as their total profits fell. In fact, a more formal analysis of total liquidity-provider profits confirms this, where total liquidity-provider profits are calculated by multiplying the number of shares by one-half the effective spread for each trade and summing over all trades (results available upon request). Thus, it appears that decimalization is not Pareto improving.

It is interesting that liquidity-provider profits declined following decimalization, but that market quality does not appear to have been adversely affected in other respects. Intuitively, if liquidity-provider profits declined following decimalization and liquidity provision is competitive, one would expect liquidity providers to respond by reducing the capital committed to providing services because the return on this capital has fallen. However, if liquidity providers are earning (noncompetitive) rents, one would not expect market quality to be affected unless the reduction in liquidity-provider profits is large enough to eliminate these rents. These results are consistent with the assertion that, prior to decimalization, liquidity providers were earning rents and that the move to decimalization reduced these rents.[15]

B. *Cross-Sectional Regressions*

The results of Part A indicate that quoted and effective spreads declined for the cross section of TSE stocks trading above $5, while for stocks trading between $3 and $5, spreads did not decline. However, the effect of decimalization on spreads may differ across stocks depending on factors such as price, trading activity, risk, and information asymmetry. To better understand the determinants of these changes, I estimated cross-sectional regressions similar to Harris (1994). The specification is

[15] This assumes, of course, that the other components of liquidity-provider profits (e.g., brokerage commissions) did not increase sufficiently following decimalization to compensate for the decline in liquidity premia.

$$y_i = \beta_0 + \beta_1 \frac{1}{P_i} + \beta_2 \frac{1}{\sqrt{N_i}} + \beta_3 \, Ln(DolVol_i) + \beta_4 \sigma_{5i} + \beta_5 Ln(MktValue_i) + \varepsilon_i, \tag{2}$$

where i denotes the ith stock, y_i is the percentage change in average time-weighted quoted spreads or percentage change in average effective spreads, P_i is the average price, N_i is the average daily number of transactions, $DolVol_i$ is the average daily dollar volume, σ_{5i} is the weekly (in-sample) standard deviation using overlapping daily data, $MktValue_i$ is the market value of equity, and $Ln(\cdot)$ denotes the natural logarithm.[16] All independent variables are measured in the predecimalization period. Note that the dependent variable is the *change* in spreads. Thus, a decline in spreads implies a *negative* value of the dependent variable.

The discussion in Part A suggests that the change in spread should be positively related to price (i.e., negatively related to $1/P_i$) and negatively related to trading activity (i.e., positively related to $1/\sqrt{N_i}$ and negatively related to $Ln(DolVol_i)$). The weekly standard deviation is included to capture risk. If liquidity providers are risk averse, the spread should be wider for more volatile stocks. Therefore, spreads should decline less for stocks with a high degree of risk because the minimum tick size is less likely to be binding for these stocks. Market value of equity is used to proxy the amount of public information available for a given firm. There should be a negative relationship between the amount of public information available and the size of the spread, *ceteris paribus*, because greater public information implies a lower adverse selection component. Thus, for larger firms, the minimum tick size is more likely to be binding, implying that the reduction in spreads should be positively related to market value (i.e., the coefficient on the market value variable should be negative).

The results of the cross-sectional ordinary least squares (OLS) regressions for non-cross-listed stocks trading above \$5 are provided in Table XI.[17] The coefficients of $1/P_i$ and $1/\sqrt{N_i}$ are both significant and have the predicted sign in both regressions.[18] This is consistent with the earlier results

[16] The regression equation does not include the predecimalization average spread because the size of the spread is endogenously determined by such factors as price, trading activity, risk, and information asymmetry. Therefore, the regression equation above could be viewed as the reduced form equation in a system where the spread is a function of the independent variables given above, and the *change* in spread is a function of the predecimalization spread.

[17] Part B focuses exclusively on non-cross-listed stocks because this study is attempting to isolate the impact of decimalization, net of the "competition effect" discussed earlier. A similar regression analysis of cross-listed stocks is presented in Ahn *et al.* (1997).

[18] Significance levels reported are calculated under the assumption that the errors are homoskedastic. Inferences based on a White (1980) heteroskedasticity-consistent covariance matrix, however, were not qualitatively different.

TABLE XI
CROSS-SECTIONAL REGRESSION OF QUOTED AND EFFECTIVE SPREADS FOR STOCKS TRADING ABOVE $5

Dependent variable	Parameter estimates						R^2	F test
	β_0	β_1	β_2	β_3	β_4	β_5		
Percent change in time-weighted quoted spreads	0.724* (1.901)	−2.046*** (−5.294)	0.452*** (3.545)	0.003 (0.115)	1.046 (1.562)	−0.051*** (−2.733)	0.2033	15.922***
Percent change in effective spreads	0.805** (2.128)	−2.121*** (−5.525)	0.479*** (3.779)	0.004 (0.243)	0.968 (1.456)	−0.055*** (−2.989)	0.2219	17.795***

Note. The change in the average spread is regressed on a price variable, trading activity variables, volatility, and market value of equity; i.e., the following regression equation is estimated

$$y_i = \beta_0 + \beta_1 \frac{1}{P_i} + \beta_2 \frac{1}{\sqrt{N_i}} + \beta_3 Ln(DolVol_i) + \beta_4 \sigma_{5i} + \beta_5 \ln(MktValue_i) + \varepsilon_i,$$

where y_i = percentage change in time-weighted quoted spreads or percentage change in effective spreads for stock i. P_i is the average price for the ith stock, N_i is the average daily number of transactions for stock i, $DolVol_i$ is the average daily dollar volume, σ_{5i} is the weekly (in-sample) standard deviation using overlapping daily data, $MktValue_i$ is the market value of equity, and $Ln(\cdot)$ denotes the natural logarithm. All independent variables are estimated in the predecimalization period. The coefficient estimates are provided above. The t statistics are in parentheses. The null hypothesis that the slope coefficients are jointly equal to zero is tested using an F-test.

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

that the decline in spread is related to both price level and trading activity. Further, the coefficient on market value of equity is significantly negative, which is consistent with the notion that the minimum tick size is more restrictive for stocks with more public information. The coefficients on the volatility of returns and average daily dollar volume are insignificantly different from zero at the 10% level.

For stocks trading between $3 and $5, there is no significant relation between the change in spreads and the independent variables (results not reported). The null hypothesis that the slope coefficients were jointly equal to zero was not rejected at conventional significance levels. This suggests that decimalization did not have a significant impact on stocks even after controlling for stock characteristics. An alternative explanation is that the tests employed lack the power to reject the null hypothesis of no relationship due to the relatively low degree of cross-sectional variation in the independent variables and the small sample size.

In addition to cross-sectional regressions, I also estimated the gamma model developed in Harris (1994) to test its predictive power (results available upon request). In this model, the underlying relative spread is described by Eq. (2). Because of the minimum tick requirement, however, these underlying spreads are not observed. Instead, the observed spread is equal to the underlying spread rounded to the nearest tick. Thus, the Harris model can be used along with predecimalization data to estimate the underlying spread function. This estimated spread function is then used along with the predecimalization data to project the observed spreads following decimalization.

The Harris model predicts that quoted spreads will decline by 27.77% on average, while the observed average percentage change in spreads is only 19.77%.[19] To account for the fact that some of the change in spreads could be due to changes in the conditioning variables (i.e., the variables on the right-hand side of Eq. (2)), projections of postdecimalization quote frequencies were also done using postdecimalization values of the independent variables. The results were qualitatively the same. Thus, consistent with the findings of Ahn *et al.* (1996), the Harris model tends to overpredict the decline in spreads that will result from a reduction in the minimum tick size.

VI. CONCLUSION

The TSE's move to decimal pricing resulted in a reduction in quoted and effective bid–ask spreads for stocks trading above \$5. This reduction was found to be significantly related to the price of the stock and to the level of trading activity. Quoted depths, however, also declined significantly following decimalization. Despite this reduction in depths, it does not appear that large investors (i.e., those whose trade size exceeds the quoted depth) were harmed by the move to decimalization. Furthermore, trading volume surprisingly exhibited no statistically significant change to offset the decline in per-share liquidity-provider profits. This is in contrast to the claims of decimalization proponents that the lower trading costs would lead to an increase in trading activity. Nevertheless, given that market quality did not appear to be adversely affected by the decline in liquidity-provider profits, one could argue that the transfer reflected a dissipation of rents earned by liquidity providers prior to decimalization.

For stocks trading between \$3 and \$5, decimalization appeared to have little effect even after controlling for factors such as price, trading activity, risk, and information asymmetry. This implies that the predecimalization minimum tick size of \$0.05 was not particularly restrictive or that the tests employed have relatively low power due to the small sample size and the

[19] Note that the Harris model utilizes *trade-weighted* averages as opposed to *time-weighted* averages. Consequently, the observed average decline in quoted spreads will be slightly different than those reported in *Table II*.

relatively low degree of cross-sectional variation in the independent variables.

The results for the greater-than-$5 subsamples are generally consistent with those documented by Ahn *et al.* (1996) in their study of the American Stock Exchange; they found that spreads declined significantly following the reduction in the minimum tick size, volume did not increase significantly, and liquidity-provider profits declined. The cross-sectional analyses of both studies find that the change in spreads is significantly related to stock price and trading activity as predicted by Harris (1994), but that the Harris (1994) model tends to overpredict the decline in spreads. Unlike Ahn *et al.*, however, I find that quoted depth declined significantly following the reduction in the minimum tick size. Thus, despite the fact that Ahn *et al.* focus on a reduction in the minimum tick size which affected only a small class of stocks, most of their results are confirmed using a much broader data set.

These results contribute to the debate of whether the U.S. equity exchanges should switch to decimal pricing. Decimalization led to a reduction in the cost of trading to investors, and liquidity does not appear to have been significantly impacted. Nevertheless, decimalization does not appear to be Pareto improving for the TSE due to the fact that liquidity providers experienced a decline in profits. Therefore, unless volume is expected to increase dramatically in contrast to the TSE experience, the move may not benefit all parties. However, to the extent that the decline in wealth reflects a reduction in rents earned by liquidity providers, the principal benefit of decimalization may be that investors' trading costs decline significantly without a concomitant loss of liquidity.

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