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Effects of Tick Size Change on the Intraday Patterns of Spread and Depth

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〈abstract〉

Using the extensive datasets, I analyze the effect of tick size changes on the intraday patterns of spread and depth. I show that intraday variations in spread (depth) are greater (smaller) with smaller tick size during the early hour of trading and become smaller (larger) during the last hour of trading. And the standardized spreads (depths) are quoted at the lower (higher) levels as the tick size becomes smaller. I also find that U-shaped intraday spread pattern changes to the reverse flat S-shape while inverted U-shaped depth pattern does to the flat S-shape.

Keywords : Spread, Depth, Liquidity, Intraday Patterns, Tick Size Changes

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Ⅰ. Introduction

Market microstructure studies are rested on the market with transaction cost, a paradigm aberrant from the efficient and frictionless market. Conceptually, liquidity is closely related to the transaction cost because people can trade at low cost and exchange ownership titles quickly in liquid market. Thus, liquidity is one of the most important characteristics of well functioning markets. In addition to academic importance, liquidity has practical implications as well. It can help explain market breakdowns because they could occur due to illiquid market operations.

Tick can be defined as the smallest amount by which a trader may improve a price. By the exchange rule, most U.S. exchange listed stocks used $1/8 minimum price variation. Even though it may not be binding for high-priced stocks, it could be binding for low-priced stocks. Faced increased criticism, regulators switched $1/8 to the $1/16 rule at July 1st 1997. Decimal prices are easier than the fractional prices of $1/16 to the investors. After controversy, US Congress passed the bill, requiring decimal pricing and initiated at Jan 1st 2001.

Amihud, Mendelson and Wood (1990) study the relation between liquidity and stock prices around the market crash of October 19 in 1987 and conclude that stock prices are positively related to the liquidity.[1] Understanding liquidity is the key to financial economists as well as traders, exchanges and regulators. In light of its significance, it is not a surprising that a growing body of literatures focuses on the liquidity issue.

Despite the academic and practical importance, little is known about time-series variations in spread and depth. In this study, I examine intraday spread and depth patterns as the tick size changes. Since the minimum price increment is one of the most important protocols in financial markets, numerous studies investigate the effect of tick size reductions on market quality. However, none of these studies have examined how changes of tick size affect the intraday patterns of spread and depth. In this study, I address the following questions using an extensive, long-period sample of New York Stock Exchange (NYSE) stocks : (1) How do the daily time-series spread and depth

1) Hasbrouck and Seppi (2001) and Chordia, Roll and Subrahmanyam (2000) also raise the possibility that the market collapses of 1987 could be attributed to the sudden drop in liquidity.

change over time? (2) What do the intraday spread and depth patterns look like? Do the intraday spread and depth patterns behave differently under different tick sizes? (3) How do market participants utilize both the spread and depth in managing their liquidity? (4) How do the tick size reductions affect spread and depth management? Answers to these questions would be interesting because they can help traders to implement better trading strategies, exchanges to attract more traders by reducing trading costs, regulators to make financial markets less volatile.[2)]

Few researches study the long-run spread and depth evolutions. It may be due to limited data availability or heavy data management. Most prior studies use noisy data or short sample periods. Chordia, Roll and Subrahmanyam (2001) perform the first study using the long-run high frequency data. They analyze the aggregate market liquidity and trading activity for a comprehensive sample of NYSE-listed stocks over an 11-year period (from 1988 to 1998). Their main finding is that daily variations in liquidity and trading activity are influenced by several factors, which include short- and long-term interest rates, bid-ask spreads, market volatility, recent market movements, day of the week effects, and select macroeconomic announcements.

While the sample period of Chordia et al. (2001) includes the \$1/8th and part of \$1/16th tick size periods, this research extends the study period to the post decimalization period, making it possible to compare the spread and depth changes under different tick sizes. A number of studies examine the intraday patterns of spreads and depths. McInish and Wood (1985, 1992), Brock and Kleidon (1992), and Chan, Chung, and Johnson (1995) show the U-shaped intraday pattern of NYSE spreads. Lee, Mucklow, and Ready (1993) find the U-shaped intraday spread variation and inverted U-shaped intraday depth variation. In contrast, Chan, Christie, and Shultz (1995) find that the bid-ask spread for NASDAQ stocks narrows abruptly during the final hour of trading. Chung and Zhao (2003) show that the intraday pattern of NASDAQ inside spread converges to that of NYSE spread following the implementation of the new order handling rules. However, these studies do not consider the effect of decimalization on the intraday spread and

2) Weaver (2002) argues that a number of affirmative obligations may serve as “shock absorbers”. Hence, NYSE listed stocks show lower volatility than NASDAQ. For example, requirement of committing specialist’s own account is designed to reduce market volatility.

depth patterns. Because conversion to decimal pricing might have affected the behavior of market participants, decimalization could have exerted significant influence on the shapes of intraday spread and depth.

Numerous researches examine the effect of tick size changes on transaction costs. These studies typically employ the sample period over several months or less surrounding the events. The present study provides further evidence by investigating whether the transaction cost reduction associated with the tick size change is temporary or permanent phenomenon.

The results show that dollar bid-ask spreads have declined over time, especially after decimalization. In contrast, percentage bid-ask spreads exhibit significant temporal volatility, reflecting changes in share price. The well-known U-shaped intraday pattern of the spread does not hold any longer. Rather, the spreads drop near the close of the market after decimalization. On the other hand, the inverted U-shaped intraday depth pattern turns out to be “flat S-shape.”

The remainder of this paper is organized as follows. Section Ⅱ discusses market microstructure models and develops hypotheses. Section Ⅲ describes data sources, sample selection procedures, and presents descriptive statistics. Section Ⅳ investigates daily liquidity variations. Section Ⅴ analyzes intraday variations in the spread and depth. Section Ⅵ provides concluding remarks.

Ⅱ. Market Microstructure Models and Testable Hypotheses

1. Microstructure Models of the Intraday Patterns in the Spread

According to the reverse J-shaped intraday pattern for NYSE stocks, the average spread is widest at the open, drops rapidly during the first hour of trading, and increases slightly near the market close. Madhavan (1992) suggests that wider spreads at market open may be attributed to greater informational asymmetry between specialists and informed traders. Stoll and Whaley (1990) propose that wide NYSE spreads at the open may be explained by specialists’ privileged knowledge about order imbalance. Chung, Van Ness, and Van Ness (1999) present another possible explanation for the intraday pattern of NYSE spreads. The authors argue that the U-shaped intraday pattern of NYSE spreads is largely determined by limit orders placed by outsiders rather than by specialists' quotes.

Brock and Kleidon (1992) develop the model where wide NYSE spreads at the close may be attributed to the specialists' monopoly power over traders to exploit inelastic transaction demand. Amihud and Mendelson (1982) propose the inventory model in which specialists respond to inventory imbalances by widening their spreads. They predict a wider spread at or near the close because of the exacerbated imbalance accumulation. As Hasbrouck and Sofianos (1992) and Chan, Christie and Schultz (1995) note that market makers wish to avoid the risk of holding the unwanted inventory overnight. This inventory effect is more important near the close, leading to the higher spread.

2. Testable Hypotheses for the Intraday Spread and Depth Patterns

I conjecture that tick size reductions affect the spread shape of early hour trading for two reasons. First, note that the minimum price variation determines the minimum bid-ask spread and thus no quoted spread could be less than the tick size. Although this constraint is not usually binding for high-price stocks, it is likely to be binding for low-price stocks. In other words, the coarse minimum price variation could be a binding constraint for the stocks with very narrow equilibrium spreads. I posit that the tick size is more likely to be binding during midday because the equilibrium spread is likely to be wider during early hours of trading. Consequently, the magnitude of spread reductions associated with the reduction in tick size is expected to be larger during midday.

Second, Chung and Van Ness (2001) investigate the intraday variations in bid-ask spreads surrounding the order handling rule and tick size changes from $1/8^{th}$ to $1/16^{th}$ for the NASDAQ listed stocks. They find that the rule changes intensify intraday variation in spreads and suggest that the greater intraday variation in spreads may be attributed to the less restriction on dealer's ability to change the quotes. For the particularly large rate of decline during the first three 30-minute intervals, they conjecture that added freedom in quote setting probably allows dealers to take more defensive positions during the early hours of trading. To the extent that the tick size plays a similar role in shaping the intraday pattern of spreads on the NYSE and NASDAQ, I expect greater intraday variations in spread during the early hours of trading with smaller tick sizes.

Lee, Mucklow, and Ready (1993) propose the theoretical relation between quoted spread and quoted depth, assuming the linear liquidity schedule. When any pair on the new schedule is selected, either spread or depth, in separation, is seldom considered. They note that the required affirmative obligations to keep a fair and orderly market cause the specialists to be reluctant to make extreme quotes in either dimension. Hence, both spread and depth are used for liquidity management. Empirically, they show that wider spreads are associated with lower depths during the beginning and end of trading day. The authors also note asymmetric utilization of spread and depth. When the binding constraints are imposed on spreads, shifts in liquidity might be more readily detected in depths. A logical extension of the model is that the more aggressive use of spread, the less reliance on depth for the liquidity management, or vice versa. So, I expect that greater spread will make it less necessary to lower the depth during the early hour. All these considerations lead to following hypothesis.

Hypothesis 1 : *During the early hour of trading, the intraday variations in standardized spreads (depths) will become greater (smaller) as the tick size becomes smaller.*

Harris (1997) notes that reduced tick size with the time precedence rule may encourage traders to improve price. Accordingly, the quote matchers who want precedence could improve price by a trivial amount after decimalization. Chung and Van Ness (2001) argue that NASDAQ dealers' ability to manage inventory through their quotes increases with the smaller tick size because reduced minimum variations make it less costly for dealers to jump in front of the existing quotes. Additionally, they provide empirical evidence that liquidity providers are more likely to do so during the last hour of trading rather than during the first hour when the information asymmetry is very high.

Lee, Mucklow, and Ready (1993) propose that higher volume is associated with larger depths and tighter spreads. They argue that the specialist may be able to discern whether a volume shock is due to a change in the demands of liquidity traders or informed traders. In cases where increased volume is due to identifiable liquidity trading, specialists would be expected to increase depths and decrease spreads. Harris (1994) analyzes the relation between the minimum price variation and volume. He suggests the large tick size will reduce trading volume if it forces dealers to quote a larger spread than they would otherwise quote. He also predicts that smaller spreads will be associated with larger volumes. From the above arguments, I infer that the higher volume triggered by smaller tick size makes spread narrower and depth greater near the market close to the extent that increased volume is motivated by liquidity trading arising from inelastic transaction or inventory management demand. These discussions lead to second hypothesis.

Hypothesis 2 : *During the last hour of trading, the standardized spreads (depths) will be quoted at the lower (higher) levels as the tick size becomes smaller.*

Ⅱ. Data sources and descriptive statistics

I obtain the data from NYSE's Trade and Quote (TAQ) and the Center for Research in Security Prices (CRSP) database. The sample period of TAQ data is from 1993 through 2003, inclusive. Only NYSE listed stocks and ordinary equities are included. So, certificates, ADRs, shares of beneficial interest, units, companies incorporated outside the United States, Americus Trust components, closed-end funds, preferred stocks, and REITs are deleted. I also follow the traditional filtering rules to minimize the errors : (1) exclude the bid-ask quotes if the spread is greater than $4 or less than zero; (2) exclude before-the-open and after-the-close quotes; (3) exclude trade price P_t if $|(P_t-P_t-1)/P_{t-1}| > 0.10$; (4) exclude ask quote A_t if $|(A_t-A_{t-1})/A_{t-1}| > 0.10$; and (5) exclude bid quote B_t if $|(B_t-B_{t-1})/B_{t-1}| > 0.10$.

I measure share price by the mean value of quote midpoints and return volatility by the standard deviation of quote-midpoint returns. Trade size is measured by the average of dollar transaction size. I measure the number of trades by the average daily number of transactions. I calculate the quoted dollar spread, percentage spread and depth as follows :

$$\text{Quoted Dollar Spread}_{it} = A_{it} - B_{it}, \quad (1)$$

$$\text{Quoted Percentage Spread}_{it} = (A_{it} - B_{it}) / M_{it}, \quad (2)$$

$$\text{Depth}_{it} = (\text{BidSize}_{it} + \text{AskSize}_{it}) / 2, \quad (3)$$

where A_{it} is the posted ask price for stock i at time t, B_{it} is the posted bid price for stock i at time t, M_{it} is the mean of A_{it} and B_{it}, BidSize_{it} is the posted bid size and AskSize_{it} is the posted ask size.

To measure the trading costs when trades occur at prices inside the posted bid and ask quotes, I calculate the dollar effective spread and percentage effective spread as follows:

$$\text{Effective Spread} = 2D_{it} \ (P_{it} - M_{it}) \quad (4)$$

$$\text{Percentage Effective Spread} = 2D_{it} \ (P_{it} - M_{it}) / M_{it} \quad (5)$$

where P_{it} is the transaction price for security i at time t, M_{it} is midpoint of the prevailing bid-ask quote for security i, and D_{it} is a binary variable which equals one for buy orders and negative one for sell orders. I determine the buyer-initiated or seller-initiated trading by applying the Lee and Ready's five second rule.[3)]

<Table 1> shows the descriptive statistics of liquidity measures and some other relevant variables for study sample. Both spreads and depths decrease with the tick size reduction.[4)] Trade size also declines while the number of trades increases as the tick

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3) Bessembinder (2002a) suggests that making no allowance for time lag is optimal when assessing whether trades are buyer or seller initiated. Piwowar and Wei (2001) compare five second rule, no time lag and their own algorithms. Their empirical evidence finds that the effective spread estimates for the NYSE stocks are not as sensitive as to the Nasdaq stocks between five second rule and Bessembinder's suggestion.

4) I use the quoted and effective bid-ask spreads, the proportional quoted (effective) spreads, quoted depth and liquidity index as measurement proxies for liquidity. However, proxies depend on the research purposes. Jones (2001) use the bid-ask spread and turnover as the proxies. Huberman and Halka (2001) report four proxies for the liquidity such as spread, percentage spread, depth (number of shares) and dollar valued depth.

<Table 1> Descriptive Statistics

This table presents summary statistics for NYSE stocks from 1993 through 2003 across the whole sample period as well as the each minimum price increment period. I measure quoted spread by the difference between ask and bid prices and percentage spread by dividing the spread by the midpoint of the bid and ask prices. Effective spread is obtained by the difference between the transaction price and the midpoint of the prevailing spread. Share price the mean value of the midpoints of quoted bid and ask prices. Depth is calculated by the average value of the bids and asks sizes. Trade size is the average dollar transaction value. Return volatility is measured by the standard deviation of daily returns.

Tick Size	Variables	Quoted Spread ($)	% Quoted Spread	Effective Spread ($)	% Effective Spread	Depth (100 shares)	Price ($)	Trade size ($)	Number Of Trades	Risk
Overall	Mean	0.1406	0.0098	0.1014	0.0066	39	28.34	38,535	294	0.0262
	Standard Dev	0.1041	0.0159	0.0707	0.0108	86	26.35	48,882	526	0.0321
	Min	0.0039	0.0001	0.0001	0.0001	1	0.04	7	1	0.0001
	Median	0.1307	0.0054	0.0987	0.0038	19	23.77	21,951	87	0.0210
	Max	4.0000	0.4000	4.0000	0.4000	11,113	808.25	8,519,910	7,686	4.7233
$1/8th	Mean	0.2058	0.0151	0.1321	0.0082	64	27.73	52,232	59	0.0211
	Standard Dev	0.0768	0.0160	0.0584	0.0119	96	25.44	71,284	89	0.0323
	Min	0.0039	0.0009	0.0001	0.0001	1	0.05	7	1	0.0006
	Median	0.1941	0.0094	0.1231	0.0051	34	24.93	32,457	29	0.0171
	Max	4.0000	0.4000	4.0000	0.4000	999	746.28	8,519,910	3,221	3.9037
$1/16th	Mean	0.1612	0.0107	0.1036	0.0067	45	29.90	46,062	170	0.0271
	Standard Dev	0.0961	0.0158	0.0737	0.0107	99	26.37	54,561	301	0.0269
	Min	0.0117	0.0001	0.0001	0.0001	1	0.04	16	1	0.0001
	Median	0.1466	0.0062	0.0896	0.0038	25	24.51	29,427	64	0.0223
	Max	4.0000	0.4000	4.0000	0.4000	11,113	626.84	5,932,888	6,354	3.0630
Decimal	Mean	0.0694	0.0059	0.0471	0.0039	16	26.42	20,481	596	0.0275
	Standard Dev	0.0686	0.0116	0.0502	0.0079	46	25.16	25,695	736	0.0379
	Min	0.0100	0.0001	0.0001	0.0001	1	0.05	36	1	0.0002
	Median	0.0553	0.0025	0.0370	0.0017	10	22.67	12,705	322	0.0214
	Max	2.8261	0.3667	3.5618	0.3959	6,318	808,25	3,727,386	7,686	4.7233

size reduces. Price and volatility appear to be stable across the sample periods. As expected, effective spreads are smaller than quoted spreads, indicating that trades occur within the posted inside spread.

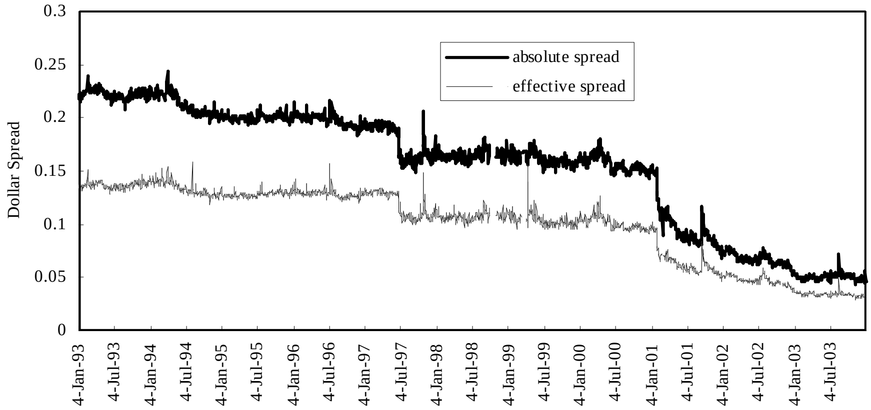
I find a higher percentage of declines in spread and depth when the tick size changed from $1/16 to one penny. For example, the average depth is 6400 during the $1/8th tick size period, 4500 during the $1/16th period, and 1600 during the penny pricing period. The rates of decline for each tick size reduction are approximately 30% and 65%. In the case of spreads, the corresponding rates of decline are about 22% and 57%. This observation is common among other variables. The inference is that decimal pricing may give rise to more influential structural break.

Ⅳ. Effect of Tick Size Reductions on the Spread and Depth

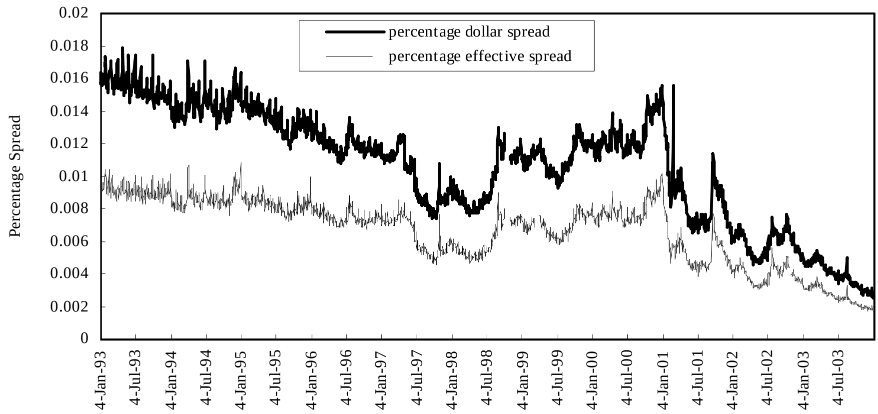
[Figure 1] through [Figure 3] show the daily time series data for the quoted (effective) dollar spread, quoted (effective) percentage spread, and quoted depth, respectively. The graphical results are consistent with the results of prior studies that document significant drops in the spread and depth after the tick size changes. Around the June 1997 and January 2001, sharp declines are observed in both spread and depth charts. The results indicate that the declines in spreads and depths after the tick size reduction shown in prior studies were not temporary phenomena. Chordia, Roll, and Subrahmanyam (2001) argue that there has been a downward trend in spreads on NYSE stocks, generally, with the major decline in mid-1997. The results using extended sample period reveal a similar trends.

During the $1/16th tick size period, the percentage quoted spreads and percentage effective spreads display intriguing patterns. Both spreads stay at the reduced level for a while following the tick size reduction. However, they rebound and remain high for a substantial period of time until decimalization news announced. In contrast, I observe less inter-temporal volatility in the dollar spread (see [Figure 1]). If the dollar spreads stay at almost a fixed level due to the binding or some other reasons, the declining

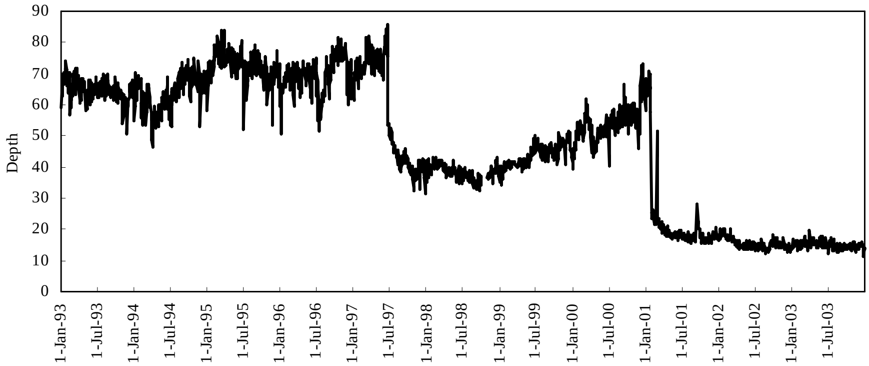
[Figure 1] Average Quoted and Effective Spreads from 1993 through 2003



[Figure 2] Average Percentage Quoted and Effective Spreads from 1993 through 2003



[Figure 3] Average Share Depth from 1993 through 2003



price level in down market naturally makes the percentage spreads higher.[5] A high level of proportional spreads coincides with the collapse of the market in the late 90's. Except for this particular period, the proportional spreads declines steadily.

[Figure 3] plots the time-varying daily depth behavior. Chordia, Roll, and Subrahmanyam (2001) contend that there has been an upward trend in depth. However, the graph exhibits mixed results, showing the consistent pattern for the identical sample period and the opposite one for the extended sample period. Specifically, under the coarse price grid of pre-decimalization, the depth shows increasing patterns, except for a sharp decline surrounding the tick size reduction announcement. However, during the one cent tick size period, the depth does not show upward trend anymore. Notice also that the depth shows upward or downward trend depending on the market reforms, despite the fact that the spread decreases steadily throughout the sample period.

<Table 2> Effect of Tick Size Changes on the Liquidity Proxies

This table shows changes of the liquidity proxies according to the tick size reductions. Liquidity is obtained by dividing the dollar depth quoted percentage spread with the quoted percentage spread, where dollar depth is defined as the average of the ask sizes times ask price and bid sizes times bid price. I select only stocks based on surviving through the sample periods.

Panel A : Changes in liquidity proxies from eighth to sixteenth

	Change in spread	Change in % spread	Change in depth
Mean Difference	0.2904	0.2531	0.1846
T-statistics	54.06**	22.45**	13.58**
Median Difference	0.2987	0.3152	0.0054
Total Stocks	1,843	1,843	1,843

Panel B : Changes in liquidity proxies from sixteenth to decimal

	Change in spread	Change in % spread	Change in depth
Mean Difference	0.8327	0.6184	0.7543
T-statistics	113.19**	42.96**	59.77**
Median Difference	0.8711	0.7819	0.8793
Total Stocks	1,561	1,561	1,561

5) The logic is straight forward. The percentage spread is calculated by the absolute spread in the nominator and midpoint (price) in the denominator. Given that the absolute spread is fixed, the denominator should be lower to obtain higher value of percentage spread.

<Table 2> shows how the market liquidity is related to the tick size changes. Both the quoted spread and depth declined after the tick size reduction, which is consistent with the findings of Lee et al. (1993), Harris (1994), Ahn, Gao and Choe (1996), Porter and Weaver (1997) and Goldstein and Kavajeck (2000).[6)]

Ⅴ. Intraday Liquidity Variations and the Tick Size Changes

I partition each trading day into 13 successive 30-minute time intervals and calculate the average spread during each time interval. As methodology employs a cross-sectional aggregation of the spread and depth, I normalize inter-stock differences while retaining variations in spreads and depths across the time of day. I calculate the standardized spread in the following way.

$$STSPRD_{i,j} = (S_{i,j} - M_i) / M_i, \quad (7)$$

where $STSPRD_{i,j}$ denotes the standardized inside spread, $S_{i,j}$ is the mean of posted inside spread of time interval j for stock i, and M_i is the daily mean of quoted spread. I calculate the standardized depth and trading volume using the same method.

<Table 3> shows intraday variations in the spread and depth during each of the three tick size periods, including both raw and standardized measures. [Figure 4] displays the standardized intraday spread patterns. Consistent with hypothesis 1, intraday variations in standardized spreads (depths) are larger (smaller) during the early hour of trading when the tick size is smaller. Thus, in relative terms, standardized spreads (depths) are greater around the market open with smaller tick sizes. Greater standardized quoted spreads can be explained by larger effect of tick size change on spread around middle of the day. Harris (1997) points that minimum price variation appears to be binding for low priced and frequently traded stocks because mandated minimum price

6) I only include the stocks that survive through the both comparing tick size periods. So, the number of stocks in <Table 2> is different from one in <Table 1> where all the stocks are comprised in each tick size period.

<Table 3> Intraday Variations in the Spread, Depth and Liquidity Index

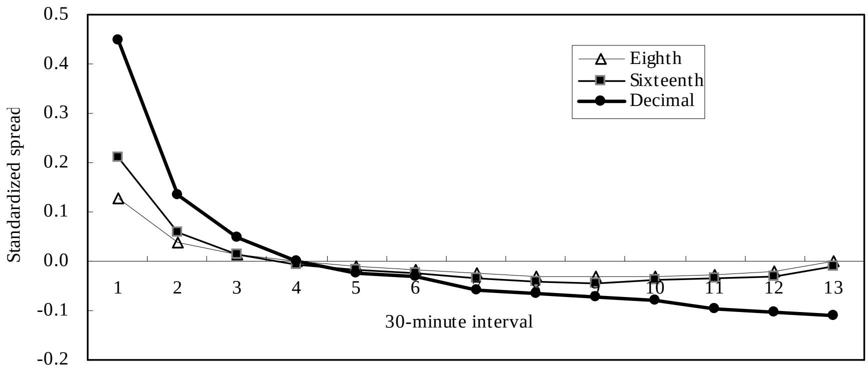
This table shows the absolute average spreads and depths of the one eighth, one sixteenth and decimalization during each 30 minute interval of the day. Raw (standardized) spreads and depths are also reported. To allow for the inter-stock differences, I define the standardized spread as (s-m)/m, where s is the quoted spread, m is the mean of s for the day. I calculate the standardized spread and depth by using both the dollar spread and depth. The dollar spread is the difference between ask and bid prices.

Time interval	OneEighth		OneSixteenth		Decimal	
	$ Spread	Depth	$ Spread	Depth	$ Spread	Depth
A : Raw						
09:30-10:00	0.2275	53.4423	0.1876	35.6149	0.0921	14.6183
10:01-10:30	0.2123	61.2634	0.1673	41.4843	0.0763	15.4374
10:31-11:00	0.2081	65.0658	0.1620	43.9680	0.0720	15.5563
11:01-11:30	0.2057	67.2245	0.1597	45.2004	0.0697	15.5758
11:31-12:00	0.2041	68.7645	0.1587	46.0449	0.0687	15.7030
12:01-12:30	0.2031	69.8407	0.1584	46.5438	0.0688	15.7457
12:31-13:00	0.2019	70.4627	0.1566	47.2742	0.0674	16.0391
13:01-13:30	0.2008	71.0156	0.1555	47.7212	0.0669	16.0163
13:31-14:00	0.2005	71.2529	0.1554	48.1025	0.0663	16.1985
14:01-14:30	0.2004	71.2343	0.1557	48.1200	0.0655	16.2627
14:31-15:00	0.2006	70.8691	0.1556	48.4301	0.0642	16.8772
15:01-15:30	0.2015	70.4861	0.1559	48.5620	0.0633	17.8333
15:31-16:00	0.2044	69.0682	0.1577	50.6961	0.0616	22.2947
B : Standardized						
09:30-10:00	0.1268	-0.2201	0.2089	-0.2085	0.4470	-0.0829
10:01-10:30	0.0393	-0.1090	0.0576	-0.0873	0.1352	-0.0499
10:31-11:00	0.0132	-0.0523	0.0126	-0.0415	0.0477	-0.0565
11:01-11:30	-0.0016	-0.0163	-0.0076	-0.0229	-0.0011	-0.0609
11:31-12:00	-0.0118	0.0063	-0.0183	-0.0115	-0.0253	-0.0633
12:01-12:30	-0.0181	0.0246	-0.0235	-0.0091	-0.0308	-0.0632
12:31-13:00	-0.0247	0.0373	-0.0361	0.0037	-0.0595	-0.0509
13:01-13:30	-0.0299	0.0443	-0.0427	0.0132	-0.0642	-0.0478
13:31-14:00	-0.0315	0.0549	-0.0432	0.0229	-0.0723	-0.0438
14:01-14:30	-0.0298	0.0612	-0.0383	0.0329	-0.0788	-0.0361
14:31-15:00	-0.0275	0.0641	-0.0362	0.0509	-0.0951	0.0082
15:01-15:30	-0.0206	0.0677	-0.0296	0.0721	-0.1038	0.0876
15:31-16:00	-0.0016	0.0660	-0.0112	0.1680	-0.1102	0.4043

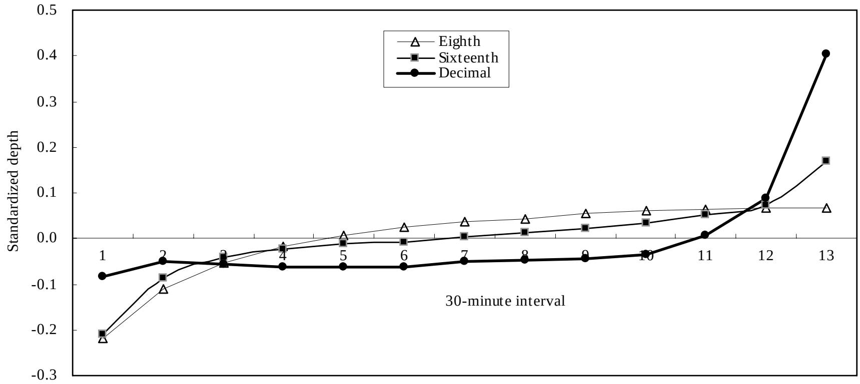
variation may be larger than the spread that dealers would otherwise quote for those stocks. Thus, once the binding constraint is relaxed, a greater spread reduction around the midday interval may lead to greater intraday variations in quoted spread at the market open. Another possible scenario for the greater spread variations, suggested by Chung et al. (2001), is that liquidity providers take more defensive positions during the early hour in facing increased adverse selection cost. They may manage such risk aggressively with the enhanced freedom in electing the quotes.

Ye and Harris (1994) show the empirical evidence that market makers would quote wide spread and small depth size when they are faced with well-informed traders. Lee et al. (1993) obtain the similar result that quoted spreads are negatively related with

[Figure 4] Intraday Variation in Standardized Spreads



[Figure 5] Intraday Variation in Standardized Depths



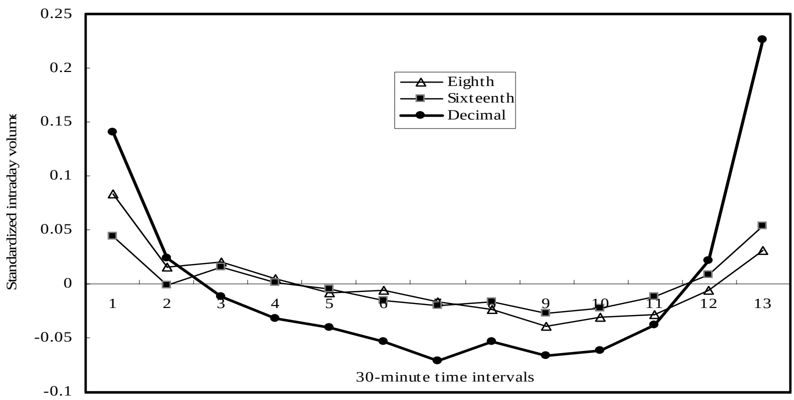
displayed market sizes for the market open and close. Given these findings, the question of how liquidity providers use both dimensions according to the market reforms is another empirical issue. From the intraday spread and depth graphs, I infer that during the post-decimalization, liquidity management might be more easily induced by spreads rather than depths. Although liquidity suppliers use both spread and depth simultaneously for liquidity provisions, they, presumably, depend on spread more heavily during the early hour of trading under the flexible quoting environment. Subsequently, it may be less necessary to reduce depth against the asymmetric risk. Asymmetric utilization of spread and depth might be the cause to the greater quotes of standardized depth with the smaller tick sizes. Thus, I have smaller intraday variations in depth during the early hour as tick size reduces.

Around the market close, standardized spreads (depths) are quoted at the lower (higher) levels with the smaller tick sizes, which is consistent with hypothesis 2. Graphical result in [Figure 4] is beyond my expectation that magnitude of slight increase in spread near the close will be smaller. It illustrates that standardized spread abruptly drops before the market close. Correspondingly, standardized spread does not follow the U-shaped pattern, finding inconsistent with voluminous prior studies. It appears to behave like “reverse flat S-shape” after decimalization. Likewise, I find similar transition in depth patterns. Inverted U-shaped depth pattern changes to the “flat S-shape” (see [Figure 5]), showing that standardized depth sharply rises around the market close. The market power story, proposed by Brock and Kleidon (1993), and the inventory model by Amihud and Mendelson (1982) are pertinent to explain slight spread increase during the coarse tick size periods. However, both models do not provide reasonable explanations for the fall of spreads near the close for the decimal pricing.

More efficient inventory management could be a suitable candidate for such patterns. The empirical evidence provided by Hasbrouck and Sofianos (1993) and Madhavan and Smidt (1993) show that it takes a number of trading days to reverse inventory imbalances. Accordingly, market makers elect to quote wide spreads to discourage the additional accumulation (see Amihud and Mendelson, 1982). However, after decimalization, market makers are able to manage the inventory accumulation risk more effectively, thereby leading to the narrow spread. In a similar line of increased inventory management ability, Chung et al. (2001) suggest that NASDAQ dealers become more aggressive in managing inventory near the close as smaller tick size facilitates inclination to jump in front of the inside spread with minor amount. Their empirical results also indicate that liquidity providers are less likely to do so during the early hour of trading when the information asymmetry is great.

For the transformations of spread and depth patterns around the market close during penny tick size period, I note the effect of volume on the spread and depth. Harris predicts higher volume with smaller tick sizes because large bid-ask spreads make transaction expensive. Increased volume affects negatively on the spreads and profit maximizing specialists will increase depths for the liquidity based trading. Trading demands due to inventory management and optimal portfolio holdings are regarded as liquidity trading. Thus, market makers may quote wider spread and greater depth levels.

[Figure 6] Intraday Variation in Standardized Volume



[Figure 6] exhibits standardized volume patterns. Volume follows the U-shaped pattern for each tick size. Compared with patterns of the $1/8^{th}$ and $1/16^{th}$ tick sizes, volume shape for the decimal pricing is strikingly pronounced during the early and last hour of trading. Consistent with my conjecture, the sharp increase in volume near the close might be the reason for tighter spreads and greater depths.

One more interesting point is the role of the volume for the early hour trading. Large increase in volume is also observed for the first 30 minutes. But, I have contradictory results of greater spread and lower depth. According to the model suggested by Easley and O'Hara (1992), specialists set the initial spread based on the ex ante probability of informed traders, and widen in response to the increased volume because market maker understands trading volume as a signal that information event has occurred. Depth should decrease with higher volume because specialists protect themselves against informed traders. Thus, during the early hour of trading, greater volume may be associated with wider spread and lower depth. Volume shock incurs the opposite outcomes depending on the trading hour.

Unlike liquidity provision during the pre-decimalization period, liquidity providers actively offer liquidities to liquidity based traders. Market liquidity is low immediately after the market open. It is attributed to the fact that liquidity providers are unwilling to trade during the price discovery period until the equilibrium prices reveal.

To confirm the observed patterns, I estimate the following model of the standardized spread (STSPRD) using the time-series data for each stock:

$$STSPRD = \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 D_6 + \varepsilon, \quad (8)$$

where dummy variables D_1, D_2, and D_3 represent the first three 30 minute intervals of the trading day: 09:30~10:00 a.m., and 10:01~10:30 a.m. and 10:31~11:00 a.m., respectively. Also, D_4, D_5, and D_6 represent the last three 30 minute intervals: 02:31~3:00 p.m., 03:01~03:30 p.m., and 03:31~04:00 p.m. The intercept terms measures the average standardized spread during the time period from 11:01 a.m. to 02:30 p.m. The coefficients for dummy variables, β_1 through β_6, measure the difference between the mean spread during the each interval and the average spread during 11:01 a.m. through 02:30 p.m..

I report the regression results in <Table 4>. For each dummy variable, the average coefficient and t-statistics are reported in each tick size. The regression results indicate that spreads for the first 30 minute are significantly greater than any other time interval across the whole sample period. During the last 30 minute, positive coefficients of standardized spread are observed for the respective \$1/8th and \$1/16th tick size period, implying the slight increase near the market close. On the other hand, negative coefficient

<Table 4> Regression Results of Intraday Liquidity Proxies Based on Each Tick Size

This table reports the results of the following regression model : STSPRD = $\beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 D_6 + \varepsilon$, where STSPRD is the standardized spread, dummy variables D1, D2, and D3 represent, respectively, the first three 30-minute intervals of the trading day : 09 : 30∼10 : 00 a.m., 10 : 01 ∼10 : 30 a.m. and 10 : 31∼11 : 00 a.m. and D4, D5, and D6 represent, respectively, the last 30-minmute intervals : 02 : 31∼03 : 00 p.m., 03 : 01∼03 : 30 p.m. and 03 : 31∼04 : 00 p.m. The intercept term measures the average standardized spread during the time period form 11 : 01 a.m. to 02 : 30 p.m..

Tick size	Variables		Time interval					
			D1	D2	D3	D4	D5	D6
One eighth	Standardized Spread	Coefficient	0.1474	0.0634	0.0365	-0.0101	-0.0027	0.0155
		t-statistics	469.83**	198.81**	113.63**	-30.92**	-8.45**	49.03**
	Raw Spread	Coefficient	0.0319	0.0121	0.0071	-0.0012	0.0004	0.0043
		t-statistics	420.84**	158.14**	91.78**	-14.67**	5.46**	57.07**
	Standardized depth	Coefficient	-0.2265	-0.1210	-0.0714	0.0331	0.0345	0.0209
		t-statistics	-372.11**	-195.34**	-114.46**	52.04**	55.11**	34.10**
	Raw depth	Coefficient	-24.2917	-12.9848	-7.8023	0.8854	-0.2378	-2.7727
		t-statistics	-256.99**	-135.85**	-81.21**	9.06**	-2.46*	-29.25**
One sixteenth	Standardized Spread	Coefficient	0.2387	0.0874	0.0424	-0.0064	0.0002	0.0186
		t-statistics	916.54**	334.88**	162.32**	-24.26**	0.84	71.90**
	Raw Spread	Coefficient	0.0355	0.0125	0.0062	-0.0010	0.0000	0.0025
		t-statistics	394.01**	138.19**	68.93**	-10.64**	0.10	27.60**
	Standardized Depth	Coefficient	-0.2125	-0.0913	-0.0455	0.0469	0.0681	0.1640
		t-statistics	-444.34**	-190.35**	-94.74**	96.69**	141.48**	344.49**
	Raw depth	Coefficient	-13.5211	-6.9650	-4.0996	1.3691	1.3852	3.1063
		t-statistics	-148.35**	-76.31**	-44.87**	14.83**	15.11**	34.24**
Decimal	Standardized spread	Coefficient	0.4943	0.1825	0.0950	-0.0478	-0.0565	-0.0629
		t-statistics	1,332.29**	490.33**	254.68**	-127.35**	-151.00**	-168.64**
	Raw Spread	Coefficient	0.0277	0.0104	0.0053	-0.0028	-0.0032	-0.0039
		t-statistics	346.00**	129.60**	66.47**	-34.86**	-39.37**	-48.55**
	Standardized depth	Coefficient	-0.0305	0.0025	-0.0041	0.0605	0.1400	0.4567
		t-statistics	-52.45**	4.26**	-7.03**	102.92**	238.52**	781.39**
	Raw depth	Coefficient	-1.8209	-0.8659	-0.6066	0.9656	1.9912	6.3860
		t-statistics	-26.27**	-12.46**	-8.71**	13.78**	28.49**	91.71**

is detected during the decimal pricing, indicating the "reverse flat S-pattern." All the other coefficients and t-statistics are consistent with the prior discussions and Figure 4 through 6.

Ⅵ. Conclusions

Using the extensive datasets, I analyze the effect of the tick size changes on the intraday patterns of spread and depth, focusing on decimal pricing period.

I confirm that spread and depth decline after tick size reduction with long-run time series data. The declining trend on both liquidity proxies continues even after decimalization. Unlike the U-shaped intraday pattern, standardized spreads show marked decline near the close of market after decimalization. Based on these findings, it is recommended to place orders around the close of the market in terms of saving the transaction costs.

It looks like reverse flat S-shaped pattern. Depth patterns shifts to the flat S-shape. In summary, intraday results indicate that minimum price variation rules strengthen intraday variations in spread and depth for NYSE stocks. I also show how liquidity providers respond to the asymmetric risk with differential use of spread and depth. Although they use both spread and depth for liquidity management, more reliance on one dimension makes less necessary to use another dimension. The contradictory responses to increased volume are also of interest. If liquidity providers treat volume shock as informed trading, they respond to increase spread and decrease depth. In contrast, they narrow spread and increase depth to the high volume at the end of the day because they interpret the volume shock as liquidity based trading. Lastly, when it comes to the comparison to the domestic market, KSE listed stocks also show U-shape intraday pattern. But since there has been no structural change in the tick size, domestic market will not show any similar change.

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