Dynamics of market liquidity of Japanese stocks: An analysis of tick-by-tick data of the Tokyo Stock Exchange

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Abstract

The purpose of this study is to study dynamic aspects of market liquidity of Japanese stocks. We use tick-by-tick data of the individual stocks listed on the first section of the Tokyo Stock Exchange (TSE) and examine three indicators of market liquidity corresponding to Kyle's three concepts of market liquidity: *tightness*, *depth*, and *resiliency*. The first indicator is the bid-ask spread, the difference between the best bid and ask prices. The second is market impact, calculated as quote changes triggered by trade execution divided by the corresponding trade volume. And the third is market resiliency, the convergence speed of the bid-ask spread after trades. We conduct a cross-sectional analysis over a sample period from October 2 1995 to September 30 1996 and explore the relationship between trade frequency and the three indicators of market liquidity. The results show that trade frequency and each of the three indicators are positively correlated. We also analyse the effects of the reduction in tick size (minimal price unit) of the TSE on April 13 1998. We examine various indicators for 55 days around the reduction and find that the tick size change reduced bid-ask spread and price volatility and increased trade frequency. These results imply that the reduction in tick size improved market liquidity and efficiency.

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1. Introduction

Among the various issues concerning market behaviour, this paper focuses on market liquidity. Market liquidity has been considered quite important by those who trade their assets in the market, although its clear definition is yet to be fixed and its quantitative measurement is still premature. Since market liquidity substantially affects the price discovery process in the market, it is supposed to have a close relationship with market efficiency. Muranaga and Shimizu (1999) explored the significance of market liquidity by considering the relationship between market liquidity and market efficiency or stability.

In finance theory, an efficient market is defined as "a market where all available information is reflected in prices." According to our definition, a liquid market is "a market where a large trade volume can be immediately executed with minimum effect on price." Therefore, by increasing the amount of information that can be deduced from price and by accelerating the speed with which information is reflected in prices, an improvement in market liquidity will enhance the extent to which available information is reflected in market prices, and thus will improve market efficiency. An increase in the extent to which information is reflected in prices implies that prices can be determined more easily than before and that the price discovery function of the market will operate smoothly.

Stability of the financial market is also a concept closely related to market liquidity. In this paper, we define a stable market as "a market where the probability of its price discovery function coming to a halt is quite small over a sufficiently long period of time." Destabilisation effects of the market caused by the decline of liquidity will materialise through various processes. In particular, what is worthy of attention is the possibility that a market can endogenously become unstable when market participants lose confidence in the price discovery function of the market. Such instability will materialise when market participants who try to avoid the risk of a market halt form a majority. This seems to occur when price changes and the speed of those changes exceed certain boundary values, and if the market has insufficient liquidity under normal conditions, it is more likely that sudden shocks will lead to a destabilisation of the market as a whole by the rapid exhaustion of liquidity. Therefore, the maintenance of sufficient liquidity under normal conditions would improve market stability autonomously by strengthening the participants' belief in the market function.

As determinants of market liquidity, market structure elements such as trading rules and various institutional arrangements play an important role.[1] In this paper, we conduct an empirical analysis based on tick-by-tick data of the Tokyo Stock Exchange (TSE). In our analysis, we focus on bid-ask spread as a static indicator of market liquidity and market impact and market resiliency as dynamic indicators. As a result, we show that: in understanding the dynamics of market liquidity, we need to analyse the market with monitoring frequency consistent with trade frequency; and that there is a positive relationship between trade frequency and market liquidity both in static and in dynamic sense. In addition, we conduct an event study on the reduction in tick size (minimal price unit) on the TSE. We investigate the effects of the reduction on the market behaviour and show a possibility that the change in tick size might reduce implicit trading cost and improve market liquidity and efficiency.

This paper is composed as follows. Following the study of Muranaga and Shimizu (1999), the concept of market liquidity is defined and indicators of market liquidity are introduced in Section 2. A cross-sectional analysis based on tick-by-tick data of Japanese stocks appears in Section 3. Section 4 shows an event study on the tick size change in the TSE on 13 April 1998. And finally, Section 5 summarises the findings and illustrates issues for future research.

[1] The research area which studies the effects of market structure on market behavior is called market microstructure theory. For a study which exhaustively reviews past studies of market microstructure, see O'Hara (1995).

2. Conceptual summary of market liquidity

2.1 Definition of market liquidity

For an individual market participant, a liquid market is generally defined as a market where a large volume of trades can be immediately executed with minimum effect on price. From the viewpoint of the overall market, market liquidity can be defined, as in Muranaga and Shimizu (1999), as the total volume and profile of effective supply and demand. The term "effective supply and demand" refers to each market participant's potential trade needs at a certain time which are not necessarily reflected in the observable order book profile or order flows. The reasons why effective supply and demand do not necessarily come to the surface include the existence of explicit trading costs such as taxes and transaction fees, and implicit costs whose magnitude is unknown as a result of the information asymmetry among market participants.[2] New effective supply and demand is induced by explicit declines in trading cost and reductions in information asymmetry. In addition, there is another mechanism by which the information about the price changes caused by trade execution itself motivates new transactions and reveals effective demand and supply.

2.2 Measuring market liquidity

The channel by which market liquidity affects the price discovery function of the market has static and dynamic aspects. Past studies of market liquidity have mainly focused on the static aspects and have adopted indicators which show static market depth, such as turnover and bid-ask spread, as measures of market liquidity. Observability in the market was an important factor in selecting such indicators for the sake of analysis. In the following, taking into account the market liquidity indicators proposed in the past studies, we take the TSE as an example and consider possible indicators for measuring market liquidity from available data.

According to Kyle (1985), market liquidity is represented by the three concepts of *tightness*, *depth*, and *resiliency*. Figure 1 illustrates the relationship between these three concepts summarised by Engle and Lange (1997). *Tightness* shows the difference between trade price and actual price, and is usually measured as the bid-ask spread. *Depth* shows the volume which can be traded at current price level,[3] and *Resiliency* is shown by the speed of convergence from the price level which has been brought by random price changes. In Figure 1, the best ask price is assumed to move up by a trade execution at time t. Since the market has a tendency to restore the condition, the best ask price will come down with a new limit order at time t+1. The convergence speed of bid-ask spread could be interpreted as *resiliency* of the market.

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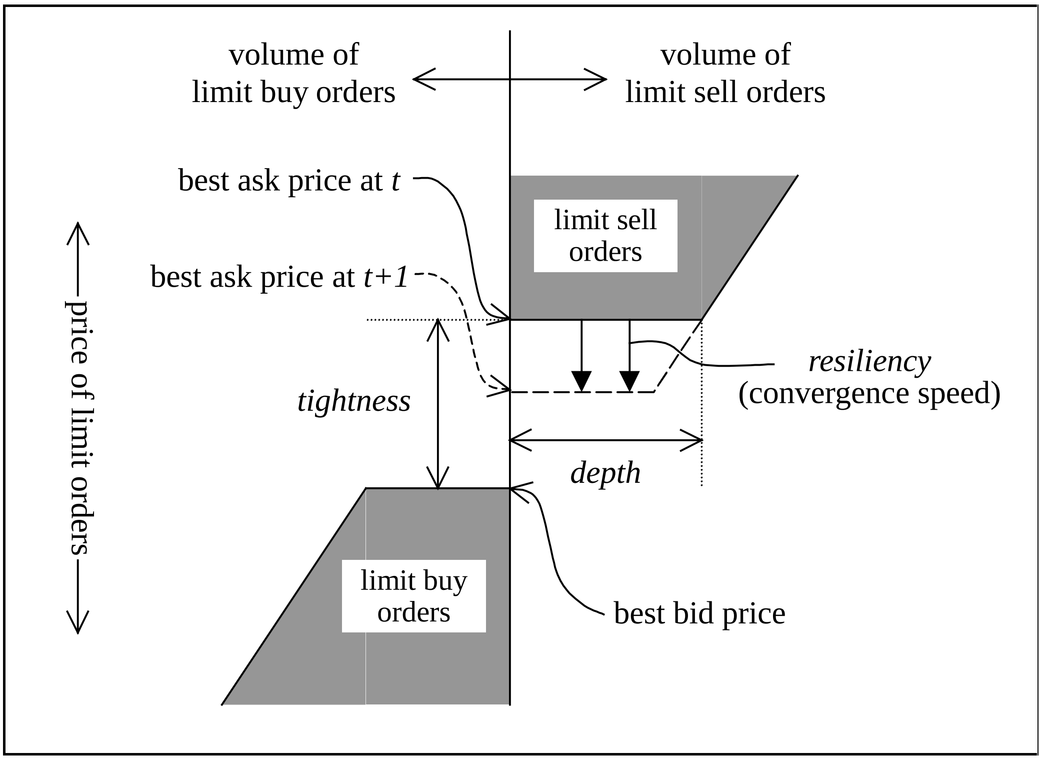
[2] Explicit costs refer to costs which are clearly known by the market participants before they trade, while implicit costs refer to those whose amounts are uncertain before the trade due to factors such as information asymmetry. This is a classification from the viewpoint of a market participant who only has only partial market information, and once he or she has complete market information, implicit costs will become zero and only explicit costs will remain.

[3] There are various definitions about market depth and market resiliency. For example, Kyle's definition of depth is different from that of Muranaga and Shimizu (1999) in that the former does not take into account of potential trade needs (effective supply and demand). In the following, we adopt Kyle's definition of market depth considering its facility of observing and estimating in empirical analysis.

Figure 1. Three concepts of market liquidity



Muranaga and Shimizu (1999) argue that, in order to examine how market liquidity affects the price discovery function in an actual market, not only the static aspects of market liquidity but also the dynamic aspects should be taken into account. In other words, since effective supply and demand can only be recognised during the dynamic process of trade execution, we need to observe dynamic indicators such as price changes upon trade execution (market impact) and/or the convergence speed of the bid-ask spread (market resiliency). These dynamic indicators reflect the actual results of the execution of a transaction and the process by which information derived from such results is digested in the market. Especially when discussing market liquidity under stress, which has a close relationship with market stability, it becomes essential to analyse such dynamic indicators as well as static indicators. In the following, what each indicators stand for is summarised.

First, turnover, or the number of trades, the most simple market liquidity indicator widely used to date, shows the volume or the number of trades which have been executed from among the trade orders explicitly placed in the market during a specified observation period, and refers to the tradable volume or number of trades in the market from a historical viewpoint. Therefore, these indicators neither reflect the state of effective supply and demand nor trade orders which were not executed despite having been explicitly placed in the market. From the viewpoint of time dimension, they do represent the market conditions of a certain period in the past. Although they do not provide timely information about the condition of market liquidity, such as “how much of a shock will there be if one executes a trade right now,” they could include a piece of information which is needed for market participants who are about to execute a trade.

Second, we turn to the bid-ask spread, a static indicator, although it is the one which has been most widely used in recent studies on market liquidity. The bid-ask spread corresponds to *tightness* in Kyle’s definition, and, time dimension-wise, the bid-ask spread provides better information about market liquidity than turnover and the number of trades in that it shows how much the cost will be in the case of an immediate transaction. However, the bid-ask spread only expresses the transaction cost for those who wish to execute a marginal trade in the market, and does not provide information about how many units will be absorbed (depth of order book) or about the extent to which a price will move after limit orders at the best quoted price have been digested (price continuity of order book). Such information can be gathered from the dynamic indicators which we plan to employ in this paper.

Market impact (λ) is a dynamic market liquidity indicator, providing information about the ability of the market to absorb trades as changes in price which take place upon trade execution. λ is an indicator which shows to what extent the bid-ask spread will be widened upon execution of a new trade, and it is measured as the ratio of price impact to trade volume standardised by the "normal market size.[4]" Normal market size is a measure which is represented by the total volume of the order book at a certain time. λ provides information about the order book-profile which is standardised by the normal market size. Although, from the viewpoint of time dimension, currently observable λ represents historical trade executions, it also includes forward-looking information about price changes resulting from future transactions and thus will be able to serve as useful measure of market liquidity in case the availability of current order book information improves.

$$\text{market impact}(\lambda)=\frac{\text{ratio of bid/ask price change}}{\text{trade volume}/\text{normal market size}}$$

Another dynamic indicator by which to measure market liquidity is market resiliency (γ). This measure provides information about potential trade needs (effective supply and demand) which is not explicitly placed in the market as an order. How to measure γ is yet to be clarified, although measuring an indicator which shows how the market autonomously restores its original state after a certain shock (trade execution) has been added to the market may be a way to measure γ. In physics, the restoration speed of a coil, for example, is measured as an indicator of resiliency. As an analogy, by measuring the widened bid-ask spread caused by trade executions and the period of time required for the spread to be restored to the state existing immediately before the execution, we can calculate the restoration speed, and be able to recognise market resiliency. This method captures the process by which trade needs, which was potential immediately before the trade execution, materialises upon trade execution, and enables us to measure market liquidity, taking into account potential trade needs. However, we should note that, in an actual market, γ may not be observable at every trade since new market orders could well be placed before the bid-ask spread has been restored by new limit orders. By taking into account such market orders occurring during the spread restoration period, the concept of market resiliency can come close to being an observable liquidity indicator.

$$\text{market resiliency }(\gamma)=\frac{\text{ratio of bid / ask price change}}{\text{restoration time of bid}-\text{ask spread}}$$

3. Cross-sectional analysis

3.1 Data profile

This Section provides a cross-sectional analysis based on tick-by-tick data of the stocks listed in the first section of the TSE.[5] The data observation period is one year, ranging from October 2 1995 to September 30 1996. The format of the raw data file is shown in Figure 2. Each column shows, from the left, security code, time stamp, trade execution price, trade volume, best-bid price, best-ask price, flag of best-bid, and flag of best-bid. The flag of bid/ask will take the form of 0 (trade volume information and has no relation to bid or ask), 1 (warning indication), 2 (normal indication), 3 (market indication), and 4 (special indication).[6]

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4 In this paper, we standardise trade volume using normal market size in order to focus on price continuity of order book rather than depth of order book. This adjustment seems useful in cross-sectional analyses of market impact.

5 The data are provided on magnetic tape from the Nikko Securities Co., Ltd. for the purpose of this research.

6 Waning and special indications are quoted when the market faces decrease in liquidity. On August 24 1998, the TSE stop quoting warning indication and ease the standard for special indication in order to increase continuity of price discovery.

Figure 2. Format of raw data file

AAAA	1331	100	10000	0	0	0	0
AAAA	1331	0	0	98	100	2	2
BBBB	1331	1020	2000	0	0	0	0
BBBB	1331	0	0	1020	1030	2	2
CCCC	1332	891	6500	0	0	0	0
CCCC	1332	0	0	889	891	2	2
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.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.

When using tick-by-tick data of the TSE, one should be aware of the following two technical features:

- There are cases when a quote (best-bid or best-ask) does not exist; and
- There is a shutdown system which halts trade execution with quoting warning indication or special indication.

These features are unique to the TSE, which has adopted a continuous auction system, a system in which an exchange-designated specialist or market maker does not exist.[7] In order to avoid the first problem, we select issues which have relatively high liquidity and constant quotes. The phenomenon that a quote for low liquidity issues disappears is indeed important and interesting topic to explore, although, in order to gain foothold in tackling such a topic, we consider it beneficial to clarify and summarise the facts about issues which are constantly quoted. Since Lehman et al (1994) concluded that the effects of the existence of warning/special indication on actual price formation are not significant,[8] we do not make a special treatment in this paper of the second problem. In addition, if we confine our analysis to issues with relatively high liquidity, we can avoid a considerable extent of the second problem.

Based on the above consideration, we picked data regarding the individual issues included in the TOPIX Electrical Machinery Index among those listed in the first section of the TSE. By analysing such issues, which have relatively high liquidity and are included in the same industry, we can avoid the problem of quote disappearance and reduce the effects of noise inherent in individual issues. As of end-February 1998, the TOPIX Electrical Machinery Index is composed of 133 issues. Of those

7 TSE carries members called exchange-designated *saitori*. *Saitori* members will match trade orders of member security firms and offer quotations such as warning and special quotations in the face of market liquidity decline, although they are prohibited from self-dealing and thus do not provide liquidity by themselves.

8 As specific factors, they have pointed out that (1) range of indications and restrictions on price fluctuations are as large as one to two percentage points on average, and (2) since indication terminates upon execution of even one trade, actual period of the indication to be on screen will not be so long (less than 2 minutes in 80% of all cases).

issues, 108 issues have been included in the Index and were traded through electronic trading[9] during the data observation period of October 2 1995 to September 30 1996. We have adopted these 108 issues for our analysis, only except measurement of market impact. In measuring market impact we used 102 issues by excluding 6 from these 108 issues which had a quote disappearance period of more than half of the observation period.[10] Summary statistics are shown in Table 1.

Table 1

Summary statistics

	TOPIX electrical machinery index traded through electronic trading
Number of stocks	108
Number of transactions per day	49.2
Daily price volatility (%)	1.97
Average bid-ask spread (%)	1.14
Quote appearance ratio (%)	86.9

Figures 3-5 show intraday trade volume, bid-ask spread, and volatility of price (every 15 minutes) of the selected issues.[11] Lehman and Modest (1994) analysed intraday trade volume and bid-ask spread for every 30 minutes, and pointed out that they form a U-shape. We can see from Figures 3 and 4 that they will form a W-shape, showing an increase in trade volume and spread before and after lunch break. In addition, we can see that trade volume, spread, and volatility are considerably increasing towards the close of the afternoon session. This is because market-on-close orders on the TSE have, unlike on the NYSE, the risk of those orders not being executed under restrictions on price fluctuations, and thus give traders who are eager to settle their trade within the day an incentive to go for the auction before the closing.[12]

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9 TSE carries two trading patterns: electronic trading by electronic screen and floor trading by open outcry; trade is executed in either way. Trading data of floor trading issues were not used in our analysis since they do not include data of best-bid and best-ask. TSE plans to close their trading floor on April 30 1999. From May 1999, all listed issues will be traded through electronic trading.

10 These 6 issues are all listed simultaneously on the Osaka Stock Exchange or the Nagoya Stock Exchange and are more actively traded in Osaka and Nagoya than in Tokyo.

11 Bid-ask spreads are calculated by the following formula:

$$\text{bid-ask spread} = \frac{(\text{ask price} - \text{bid price})}{(\text{ask price} + \text{bid price})/2}$$

12 Settled volume of market-on-close orders comprises 1 to 2 percent of the total daily trade volume, implying that market participants are trying to avoid this type of orders.

Figure 3. Intraday pattern of trade volume

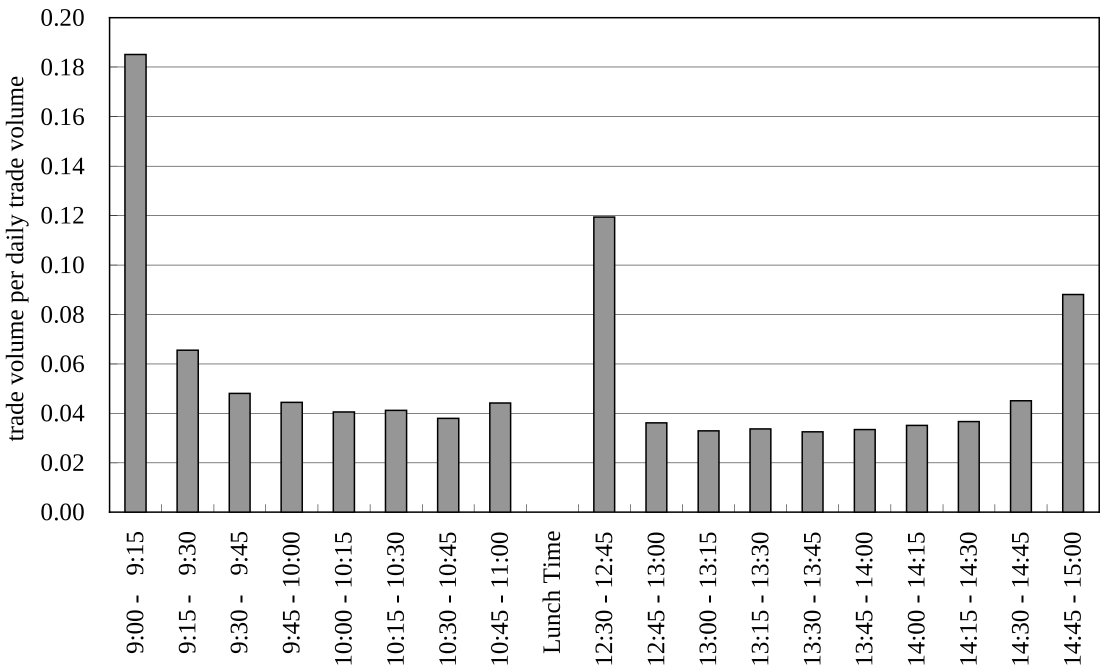


Figure 4. Intraday pattern of bid-ask spread

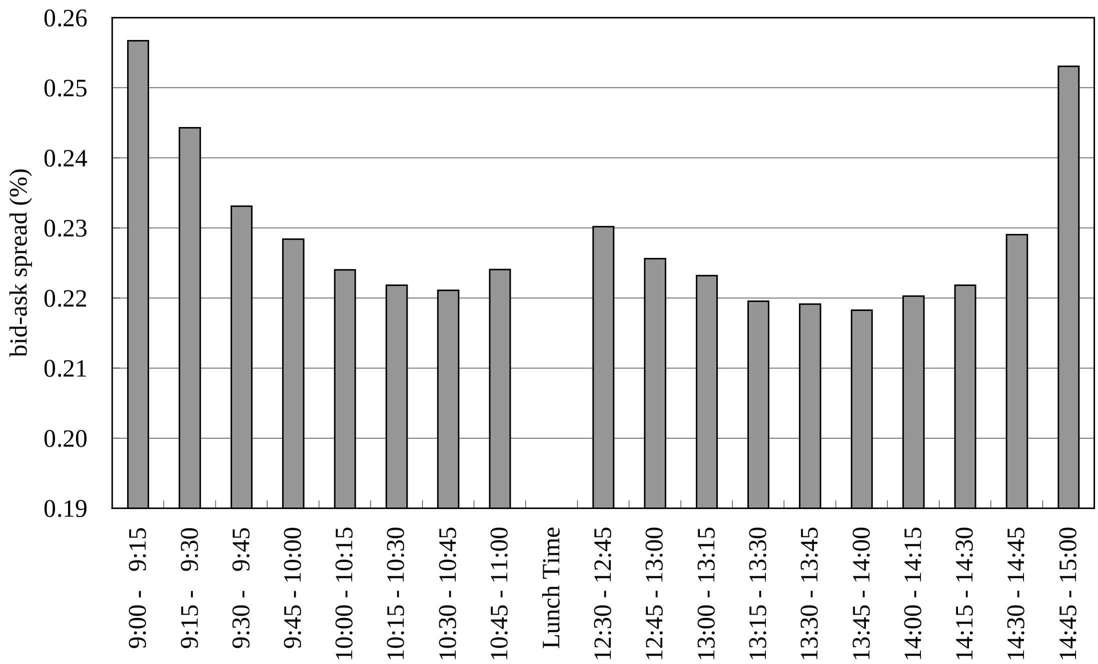
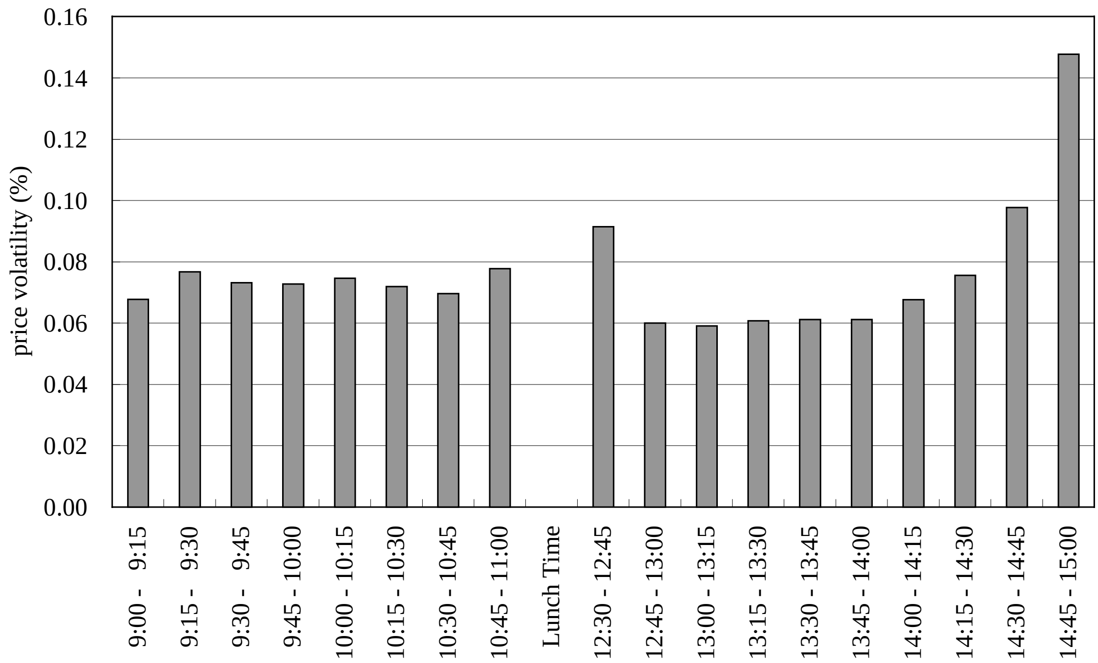


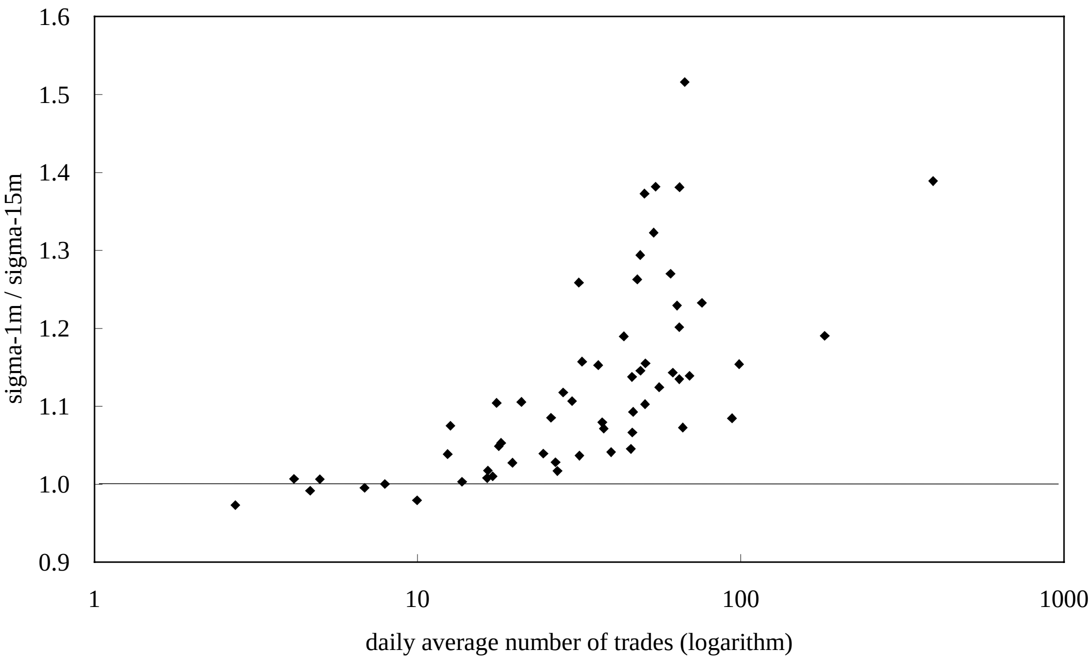
Figure 5. Intraday pattern of price volatility



3.2 Relationship between trade frequency and price volatility

In this Section we measure price volatility under different monitoring frequencies, based on actual market data. Specifically, an analysis is conducted to see whether there is a possibility of misjudging actual price variability if a stock with a high trade frequency has been monitored at a low frequency. Price volatility per minute is calculated by using the last execution price every 1 and 15 minutes (denote σ_{1m} and σ_{15m}, respectively), and relationship between the ratio of these two (σ_{1m}/σ_{15m}) and trade frequency. We can see from Figure 6 that a stock with a higher trade frequency tends to show larger difference between σ_{1m} and σ_{15m}. Therefore, empirical data imply that, in order to follow the dynamics of the market, a certain asset's monitoring frequency needs to be increased in accordance with its trade frequency.

Figure 6. Relationship between trade frequency and volatility



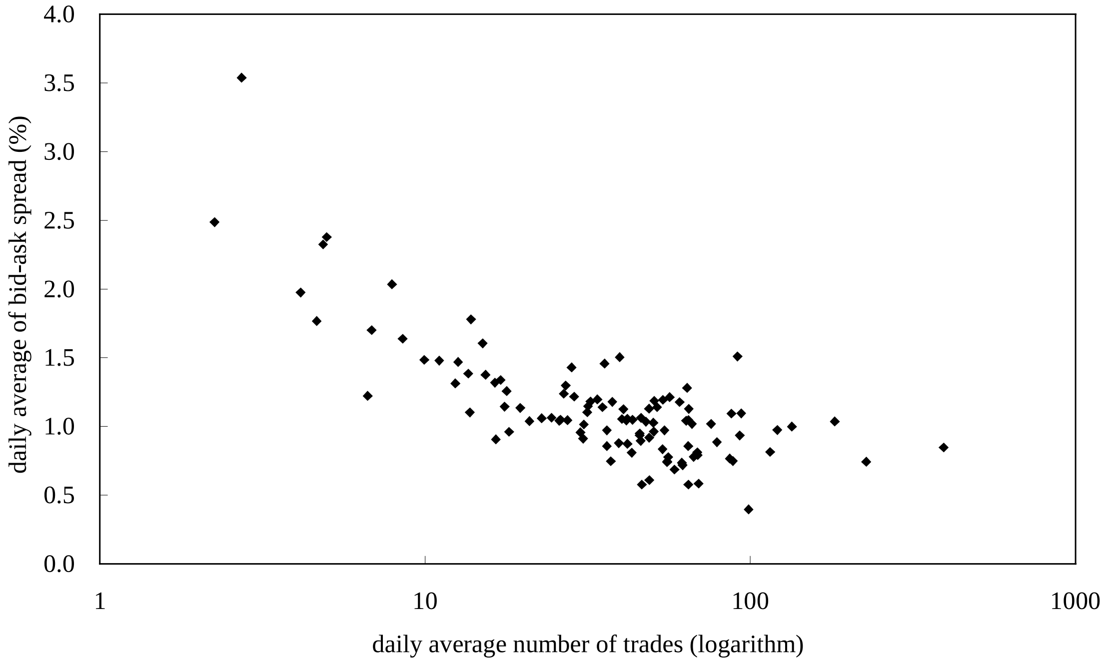
3.3 Relationship between trade frequency and market liquidity

Here a hypothesis, "an increase in trade frequency improves market liquidity," is examined. We focus on bid-ask spread as a static indicator of market liquidity as well as market impact and market resiliency as dynamic indicators.

3.3.1 Relationship between trade frequency and static market liquidity

By using data of 108 listed stocks included in TOPIX Electrical Machinery Index during the period from October 2 1995 to September 30 1996, Figure 7 depicts the relationship between daily average number of trades and bid-ask spread. One can see that a stock with a high trade frequency has high market liquidity in a static sense with a small bid-ask spread.

Figure 7. Relationship between trade frequency and bid-ask spread

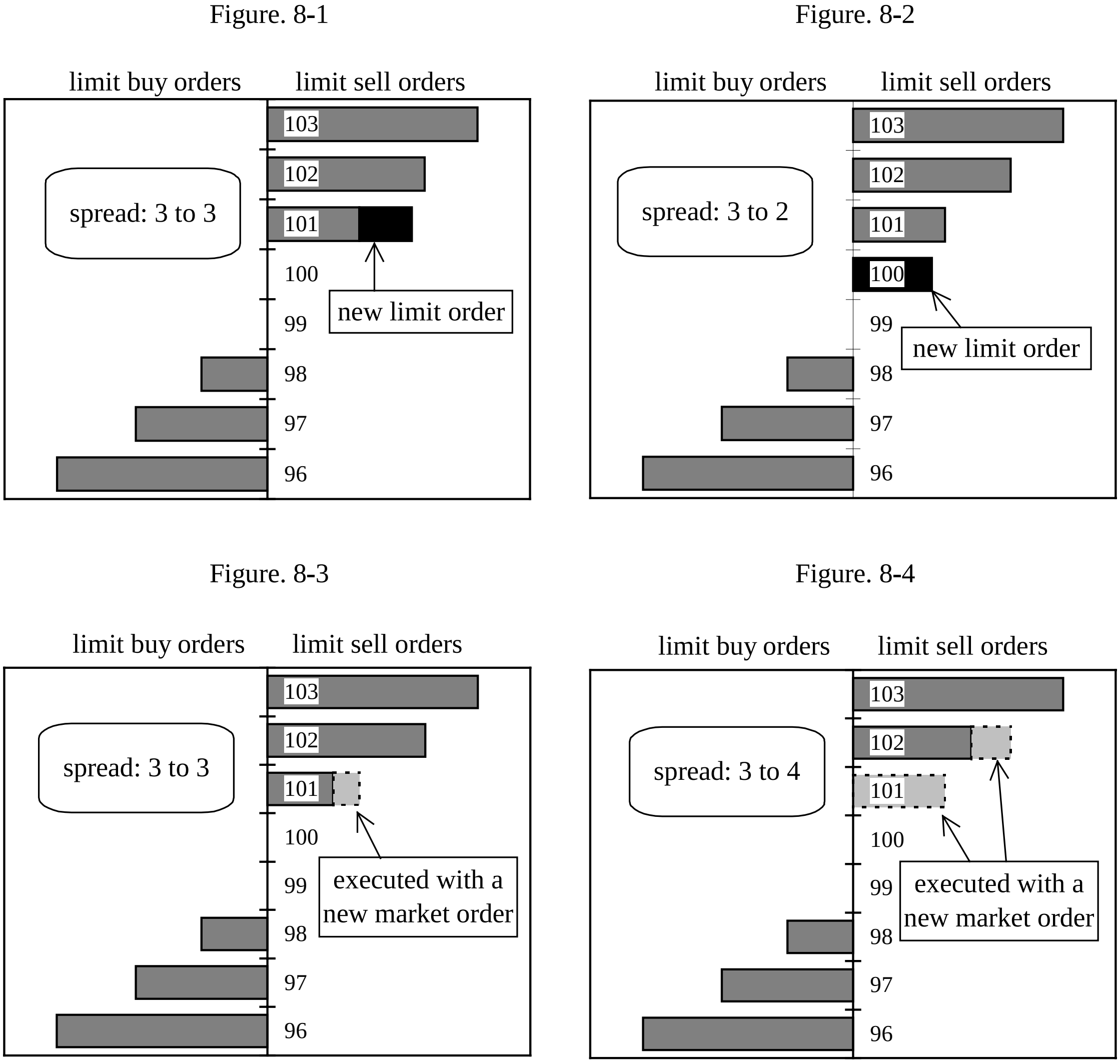


3.3.2 Relationship between trade frequency and dynamic market liquidity

Our proposal for dynamic indicators of market liquidity includes market impact and market resiliency. Since, as we mention in Section 2.2, it is difficult to measure market resiliency from empirical data, we focus on bid-ask spread rate-of-change. The basic idea behind this is shown in Figure 8, that is, changes of spread according to trade orders can be classified into the following 5 cases:

- A case in which a limit order is placed at or outside the best-bid or best-ask price. Spread rate-of-change is zero (Figure 8-1).
- A case in which a limit order is placed inside the best-bid or best-ask price. Spread rate-of-change is negative (Figure 8-2).
- A case in which (1) a market sell order or (2) a limit sell order at the price of best-bid (ask) is placed in a volume smaller than that on the best bid (ask) order book. Spread rate-of-change is zero (Figure 8-3).
- A case in which (1) a market order or (2) a limit order at a price lower or higher than the best-bid (ask) is placed in a volume larger than that on the best bid (ask) order book. Spread rate-of-change is positive (Figure 8-4).
- A case in which there is no trade order. Spread rate-of-change is zero.

Figure 8. Process of bid-ask spread changes



We next consider what aspect of market liquidity may have been captured by the spread rate-of-change. When the spread rate-of-change is positive, as shown in Figure 8-4, it suggests that an order book profile has decreased due to the execution of trade, and thus the magnitude of rate-of-change can be deemed to represent the market impact. When spread rate-of-change is negative, as shown in Figure 8-2, it suggests that an order book profile has increased due to the arrival of new trade orders and market participants' expectation of equilibrium price has converged: as such, negative spread rate-of-change captures a phenomenon of spread reduction resulting from new transaction needs and thus can be regarded as proxy for market resiliency. When spread does not change, it may either be an order book file increase due to the arrival of new orders (Figure 8-1) or an order book file decrease due to the execution of a trade (Figure 8-3), although we should note that the indicators we proposed cannot distinguish such conflicting phenomena.

Based on the actual data, we have monitored every minutes the spread rate-of-change for 20 issues with high trade frequency and 20 issues for low trade frequency; the results are shown in Figure 9.[13]

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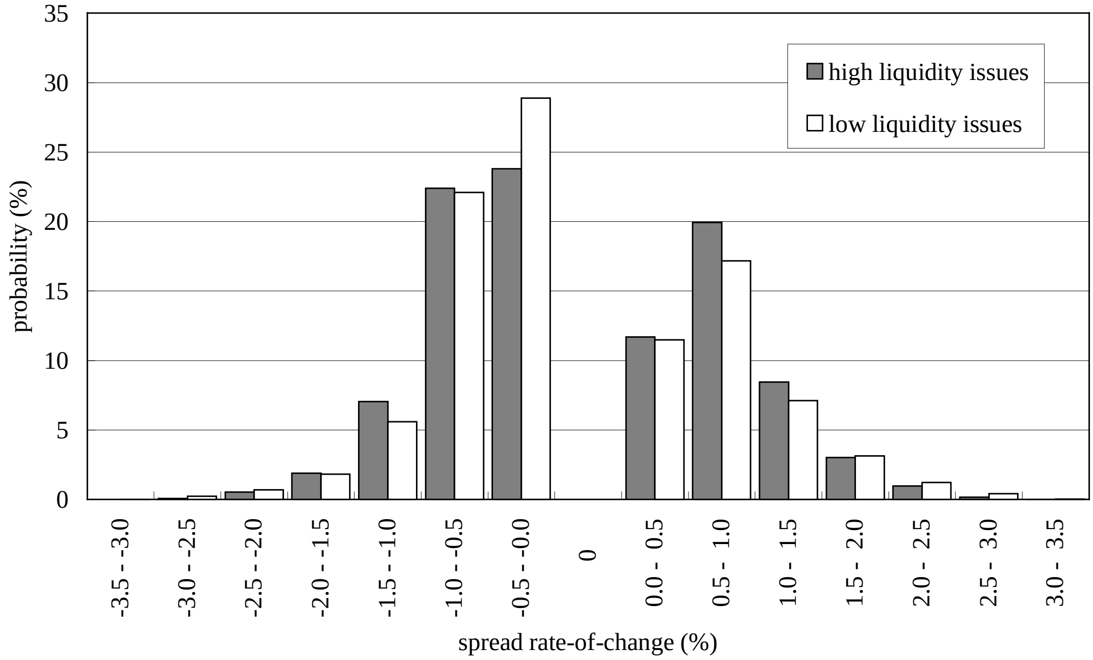
13 The distribution is not so smooth due to the restrictions on tick size (minimal price unit). By using measures such as ordered probit model employed in Hausman et al. (1992), Fletcher (1995), and Ohtsuka (1995), there is a possibility to covert discontinuous data to continuous one.

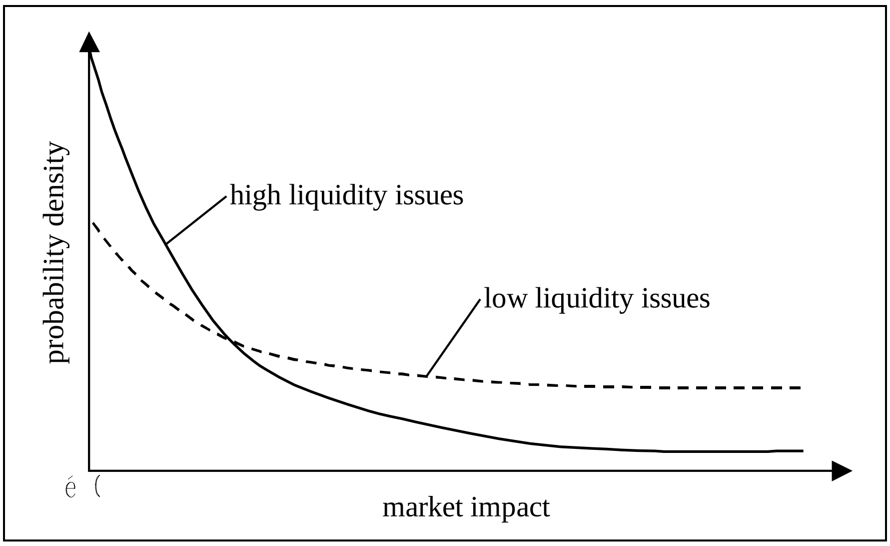
Figure 9. Histogram of spread rate-of-change



3.3.3 Relationship between trade frequency and market impact

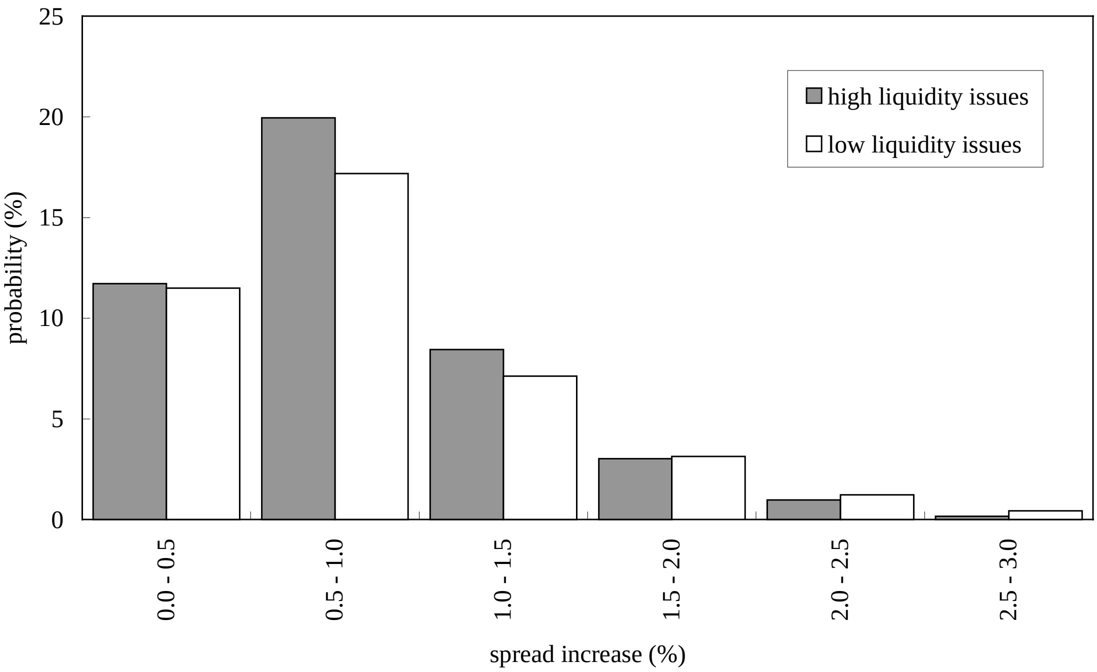
Given that market depth and average turnover per trade are constant during the observation period, we can, by analysing the histogram of spread rate-of-change, infer market impact from the portion at which such rate-of-change is positive. When we depict a histogram of rate-of-change, it is expected that, for issues with high liquidity, market impact tends to be small, and, in contrast, for issues with low liquidity, market impact tends to be large. Figure 10 is the conceptual histogram of market impact.

Figure 10. Conceptual histogram of market impact



Of the data used in Figure 9, those which show positive spread rate-of-change are extracted and compared as group of issues with high liquidity and those with low liquidity in Figure 11.

Figure 11. Relationship between trade frequency and spread rate-of-change



In order to use the spread rate-of-change as an index of market impact, we need to standardise it by taking into account the magnitude of each transaction.[14] Following such treatment, market impact for the above two groups are compared in Figure 12.[15] This Figure confirms the image of the relationship between trade frequency and market impact shown in Figure 10. In addition, Figure 13 depicts the relationship between trade frequency and market impact for individual issues. We can see that issues with higher trade frequency show smaller market impact. This suggests that trade frequency and depth, a dynamic indicator of market liquidity, have positive correlation.

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[14] Figures of normal market size or market depth are necessary in calculating market impact. However, our data do not include information about limit order book, we thus uses average turnover per unit trade as a proxy. Here we assume that TSE member security firms who can observe the order book information will alter the volume of their orders, especially that of market orders, taking account of market depth at the time.

[15] Muranaga and Ohsawa (1997) measured market impact of individual TSE issues and tried to quantify the so-called execution cost.

Figure 12. Relationship between trade frequency and market impact

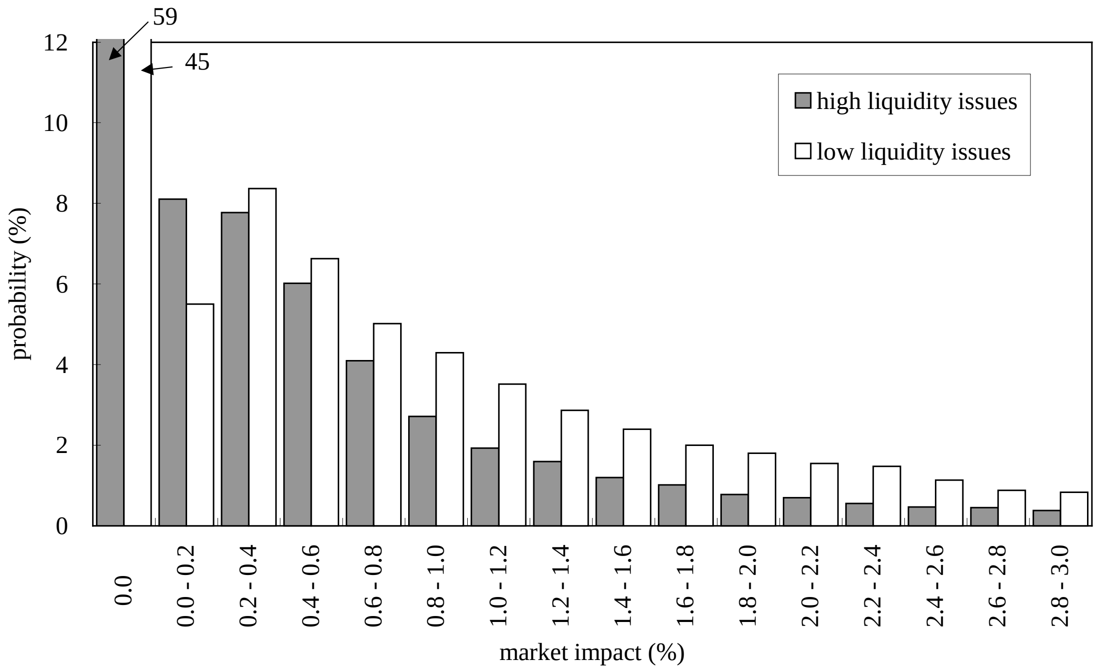
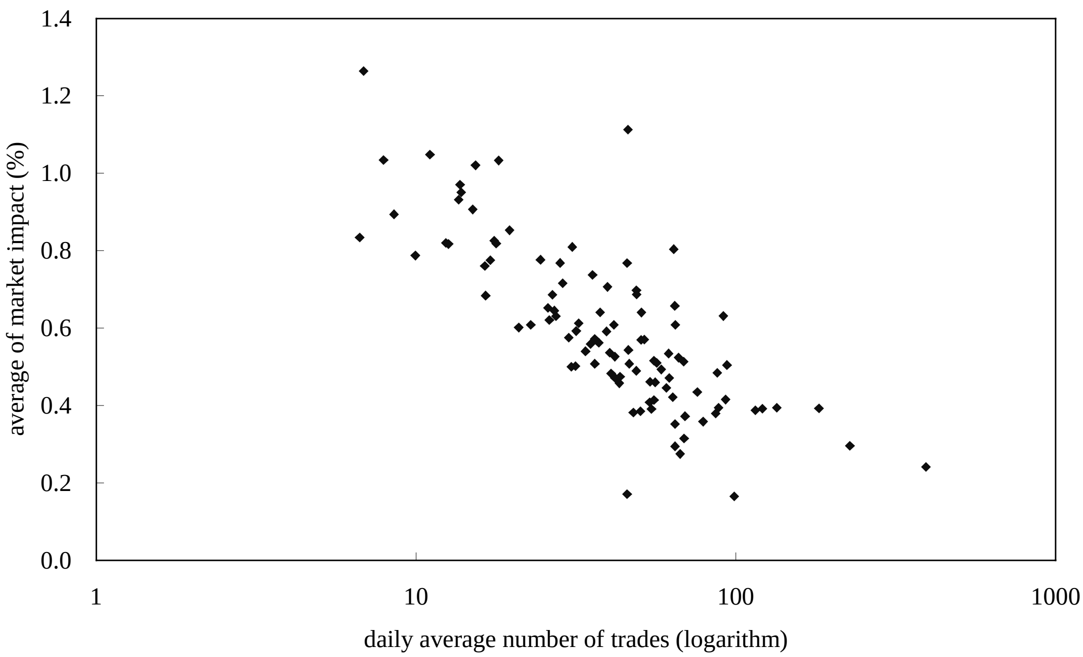


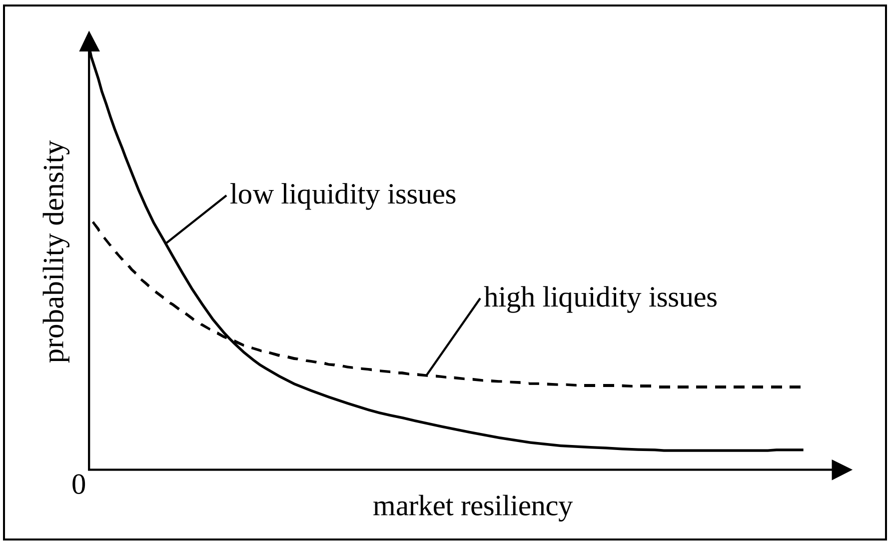
Figure 13. Relationship between trade frequency and market impact



3.3.4 Relationship between trade frequency and market resiliency

Given that market depth and average turnover per trade are constant during the observation period, we can, by analyzing the histogram of spread rate-of-change, infer market resiliency from the portion at which rate-of-change is negative. When we depict a histogram of rate-of-change, it is expected that, for issues with high liquidity, market resiliency to be large and for issues with low liquidity, in contrast, market resiliency to be small. Figure 14 shows the conceptual histogram of spread rate-of-change.

Figure 14. Conceptual histogram of market resiliency



Based on the actual data, Figure 15 compares the histograms of spread declining rate for the groups of issues with high liquidity and those with low liquidity. Figure 16 depicts the relationship between trade frequency of individual issues and spread declining rate, that is, market resiliency. From these Figures, one can see that trade frequency and market resiliency, a dynamic market liquidity indicator, has a positive correlation.

Figure 15. Relationship between trade frequency and spread declining rate

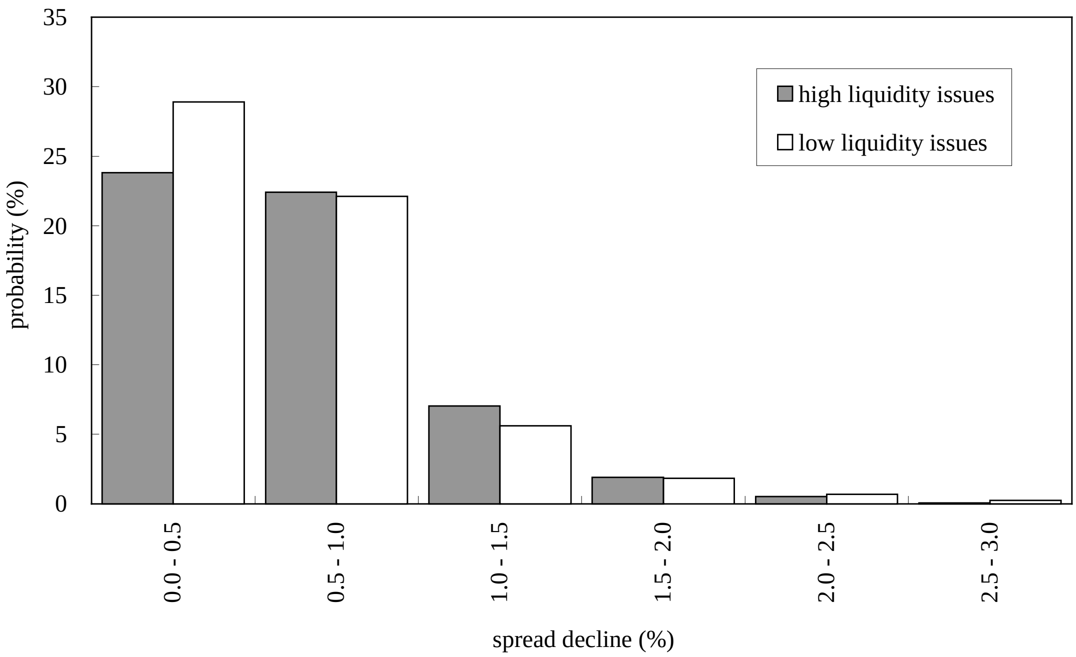
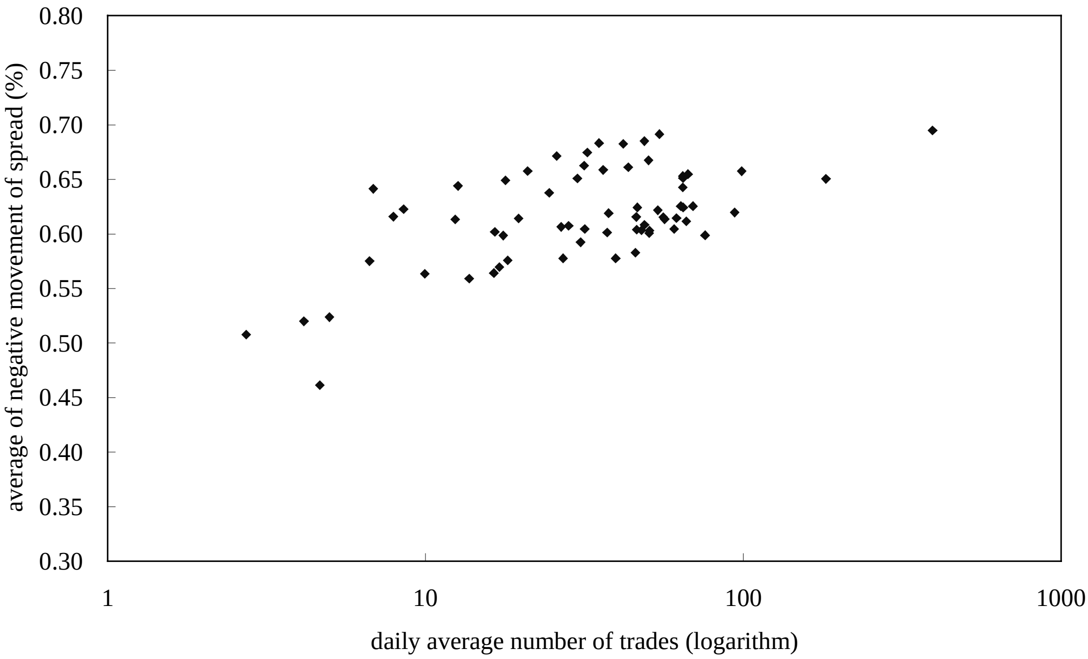


Figure 16. Relationship between trade frequency and market resiliency



4. Event study: effects of tick size reduction on the TSE

The Tokyo Stock Exchange (TSE) changed the minimal price unit for trading (so-called "tick size") on April 13 1998. The changes are listed in Table 2. As the right column of the table indicates, there were three different changes depending on stock prices; those were 1/10, 1/5 and 1 (no change). Just as in Section 3, in this section we will try to analyse how these three changes may have affected the market in terms of market liquidity, by using stocks from the TOPIX Electrical Machinery Index.

Table 2

Changes in tick size

Stock prices (X; yen)	Before change	After change	Scaled-down rate
$X \leq 1{,}000$	1 yen	1 yen	1
$1{,}000 < X \leq 2{,}000$	10 yen	1 yen	1/10
$2{,}000 < X \leq 3{,}000$	10 yen	5 yen	1/5
$3{,}000 < X \leq 10{,}000$	10 yen	10 yen	1
$10{,}000 < X \leq 30{,}000$	100 yen	10 yen	1/10
$30{,}000 < X \leq 50{,}000$	100 yen	50 yen	1/5
$50{,}000 < X \leq 100{,}000$	100 yen	100 yen	1

4.1 Data

For this analysis, we use data from the TOPIX Electrical Machinery Index (134 issues as of end-March 1998) downloaded from Bloomberg database. We analyse 55 trading days' data, with a sample period from March 10 1998 to May 29 1998. Of these 55 trading days, 23 trading days were dated before April 13 and 32 trading days were after April 13. In Table 3, we categorised each issue in according to tick size reduced or unchanged. We analyse the data of 93 issues by subtracting the following issues from the whole sample: those with an average trading time of less than ten times per day (26 issues), and those with trading prices which fluctuated over several different price ranges during the sample period (from March 10 to May 29 1998) (15 issues).

Table 3

Grouping for analysis

	Stock prices (X; yen)	Scaled-down rate	Number of issues
Tick-size-reduced issues	$1{,}000 < X \leq 2{,}000$	1/10	19
	$2{,}000 < X \leq 3{,}000$	1/5	2
	$10{,}000 < X \leq 30{,}000$	1/10	2
Tick-size-unchanged issues	$X \leq 1{,}000$	1	60
	$3{,}000 < X \leq 10{,}000$	1	10
(n.a.)	$30{,}000 < X \leq 50{,}000$	1/5	0
	$50{,}000 < X \leq 100{,}000$	1	0

4.2 Effects on bid-ask spread

First, we analyse how changes in tick size affected a static market liquidity indicator, by examining the level of bid-ask spread. Theoretically, levels of bid-ask spread reflects both explicit trading costs such as commissions and taxes, and implicit trading costs caused by a result of information asymmetry among market participants. Besides these costs, however, there is a possibility that the tick size which relatively speaking had been regulated to be large, may have substantially influenced the level of bid-ask spread in practice. For example, in looking at the bid-ask spread of the TSE stocks before the size-change (Figure 17-1 and 17-2), there were some issues (with an actual market price over 1,000 and less than 2,000 yen) with bid-ask spreads of mostly “10 yen” (Figure 17-1). In such cases, we could consider the “largely regulated tick size (10 yen)” to have been the bid-ask spread’s minimum boundary, and as a result, all bid-ask spreads originally priced less than 10 yen had to be rounded up to 10 yen. Therefore, when the tick size was set up to be larger than “the explicit plus implicit costs,” inappropriate trading costs may have existed for market participants. If these tick size changes may have removed the minimum boundary of trading costs, the average level of bid-ask spread should have decreased significantly.

Figure 17-1. Histogram of bid-ask spreads (1):
A case where the tick size significantly affects the lower boundary of realised bid-ask spreads

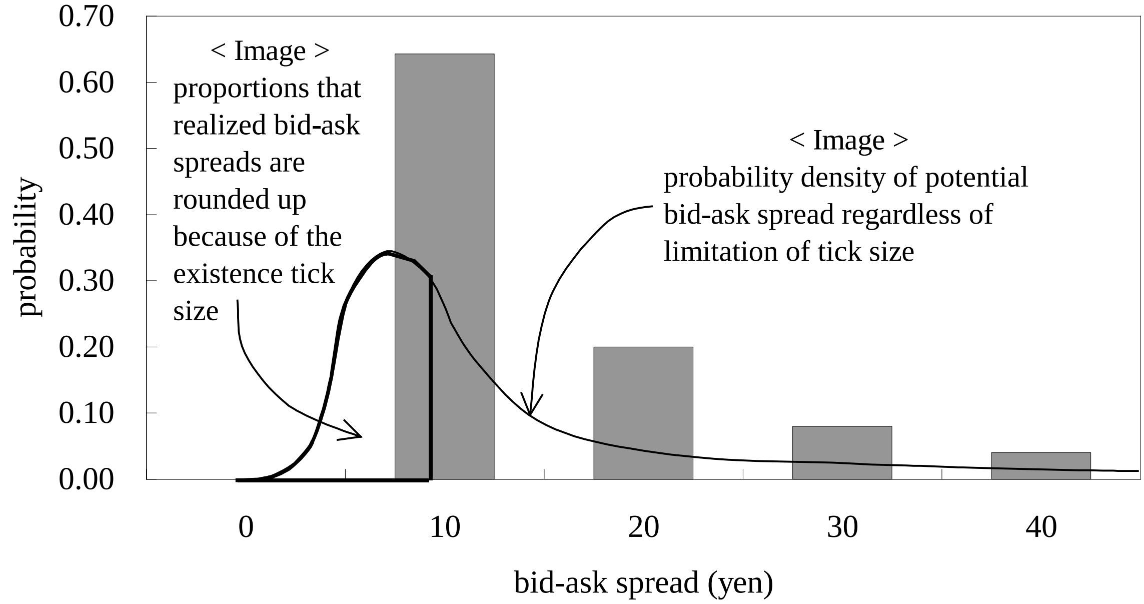


Figure 17-2. Histogram of bid-ask spreads (2):
A case where the tick size does not significantly affect the lower boundary of realised bid-ask spreads

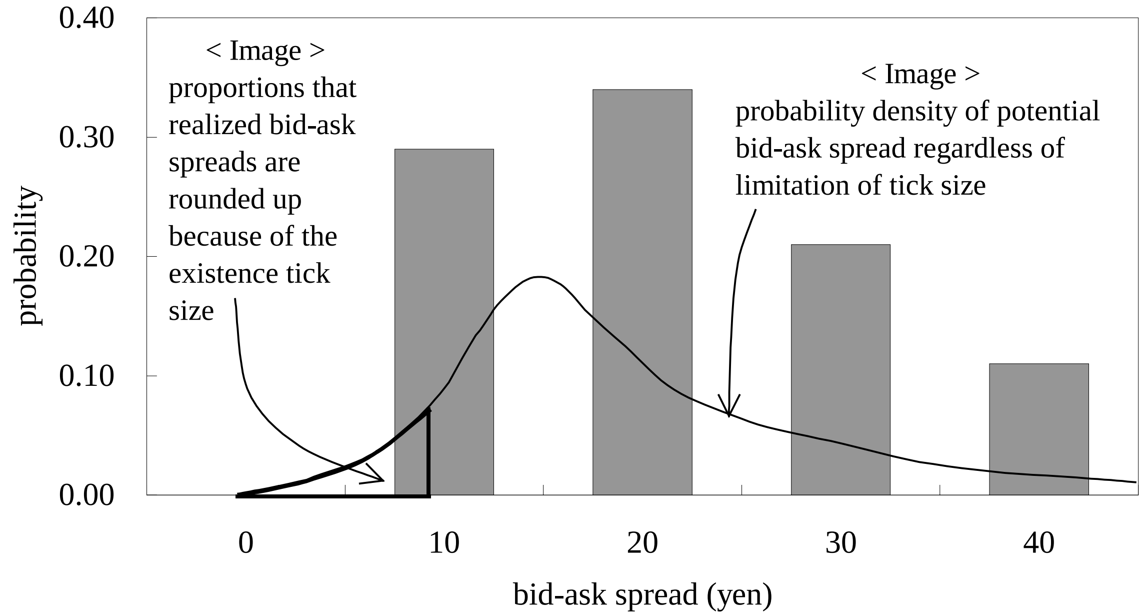
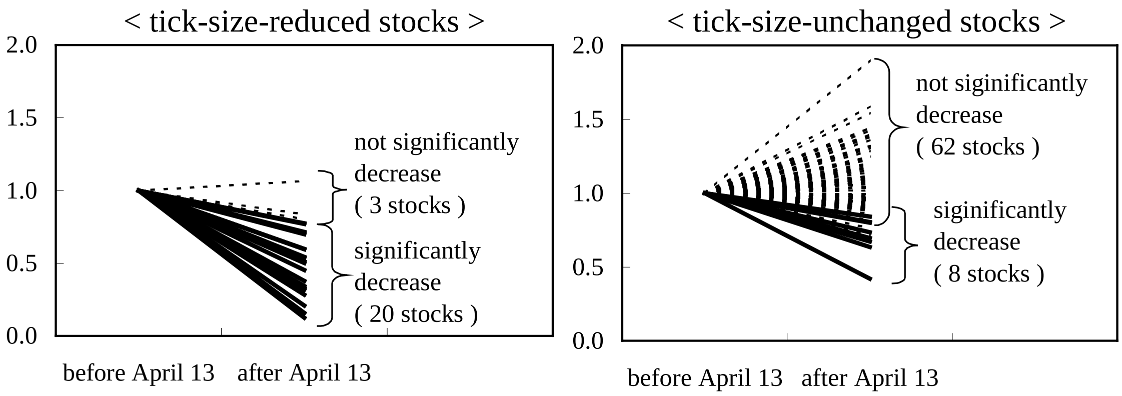


Figure 18 displays how changes in tick size might have affected the level of bid-ask spread, according to the categorisation in Table 3. While the tick-size-unchanged stocks show no apparent changes, the tick-size-reduced stocks show decreasing trends in those levels of bid-ask spreads. Next, we will test whether the trends found in the tick-size reduced stocks are statistically significant.

Here, we consider the daily bid-ask spread (in logarithm) of each issue fluctuated stochastically around its mean, and test whether the level of the mean may differ significantly between its before and after scaled-down changes (April 13). We test *t* ratio by setting up the null hypothesis "there was no change in the mean of bid-ask spread before and after April 13", and the alternative hypothesis "the mean of the bid-ask spread decreased after April 13." Regarding the tick-size-unchanged stocks, only 8 out of 70 issues (11%) rejected the null hypothesis at the 1% significant level. On the other hand, for the tick-size-reduced stocks, 20 out of 23 issues (87%) rejected the null hypothesis. From these results, it is conceivable that a scale down in tick size significantly decreased the level of bid-ask spread.

Figure 18. Effects on the level of bid-ask spread



Note: Vertical axes show how the level of bid-ask spread changed after the reduction of tick size, as a proportion of the level before the reduction of tick size, e.g. 1.5 denotes that the level of bid-ask spread increased by 50%. 'Significantly' means that the null hypothesis "The reduction of tick size did not affect the level of bid-ask spread" is rejected at the 1% level of significance.

Regarding the above results, we can assume that tick size changes in the TSE on April 13 decreased the mean level of bid-ask spread, i.e. the average trading cost for market participants. This decrease in trading costs might have affected other indicators, by increasing market participants' motivation to trade. Next, we test whether the tick size scale-down may also have influenced the trade frequency, dynamic market liquidity indicators and volatility of the trade execution price.

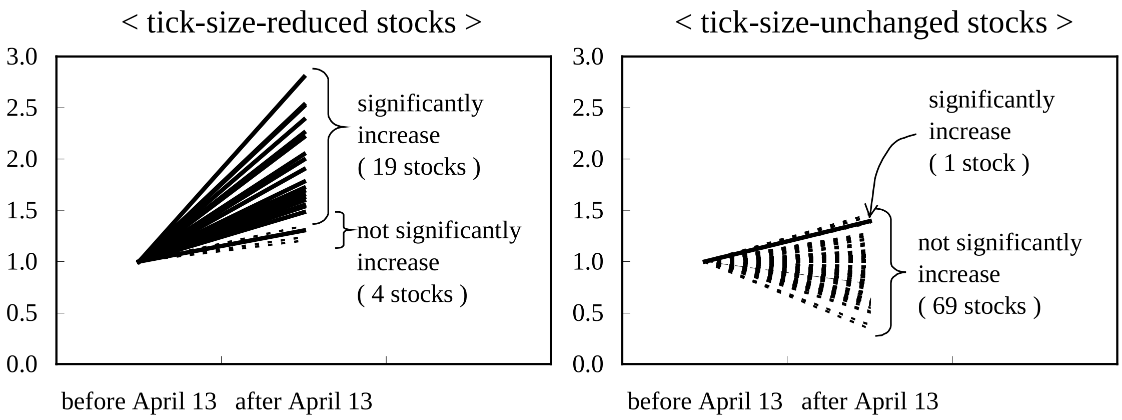
4.3 Effects on trade frequency

4.3.1 Effects on the number of quotes

If decreased trading cost results in increased motivation for market participants to trade, such mechanism should first appear in the increasing number of revision in quotes.[16] Figure 19 shows how changes in tick size might have affected the number of quotes, according to the categorisation in Table 3. While in the tick-size-unchanged stocks no apparent changes can be found, the tick-size-reduced stocks show an increasing trend in the number of quotes. In order to test whether these trends are statistically significant, here we again test *t* ratio by setting up the null hypothesis "there was no change in the number of quotes from before April 13 to after April 13", and the alternative hypothesis "there was an increase in the number of quotes after April 13." Regarding the tick-size-unchanged stocks, only 1 out of 70 issues (1%) rejected the null hypothesis at the 1% significant level. On the other hand, for the tick-size-reduced stocks, 19 out of 23 issues (83%) rejected the null hypothesis. From these results, it is conceivable that the tick size scale-down had significantly increased the number of revisions in quotes.

[16] Because of the limited data available, "the number of quotes" will be used here as a proxy of "the number of trade orders."

Figure 19. Effects on the number of quotes

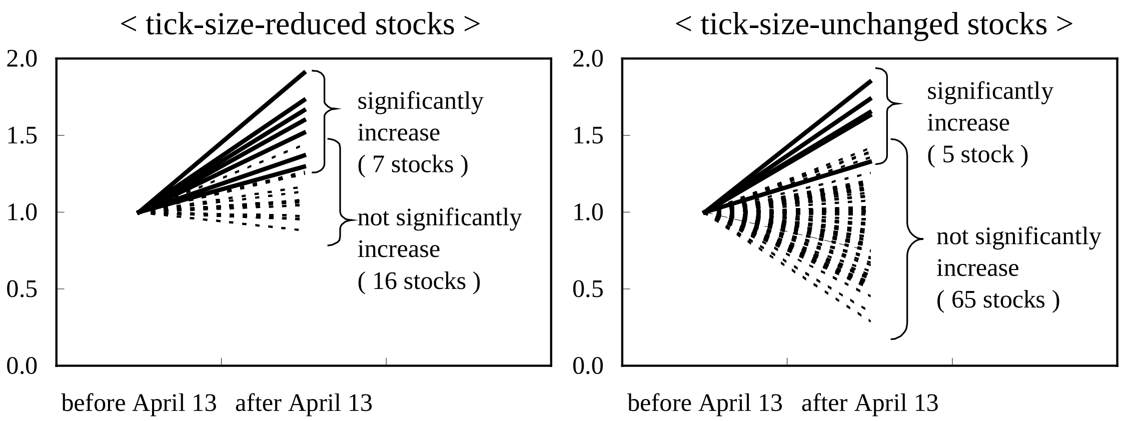


Note: Vertical axes show how the number of quotes changed after the reduction of tick size, as a proportion of the number before the reduction of tick size, e.g. 1.5 denotes that the number of quotes increased by 50%. 'Significantly' means that the null hypothesis "The reduction of tick size did not affect the number of quotes" is rejected at the 1% level of significance.

4.3.2 Effects on the number of trades

Here again, we see how changes in tick size might have affected the trade execution frequency in Figure 20. Although Figure 20 shows similarity to Figure 19, the significance of the *t* ratio test decreased more or less.

Figure 20. Effects on the number of trades



Note: Vertical axes show how the number of trades changed after the reduction of tick size, as a proportion of the number before the reduction of tick size, e.g. 1.5 denotes that the number of trades increased by 50%. 'Significantly' means that the null hypothesis "The reduction of tick size did not affect the number of trades" is rejected at the 1% level of significance.

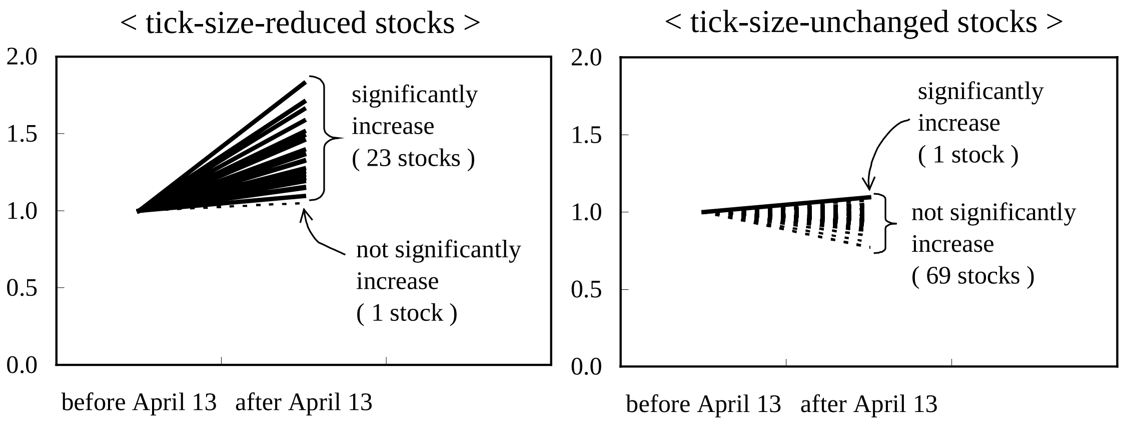
4.4 Effects on the dynamic market liquidity indicators

4.4.1 Effects on volatility of bid-ask spreads

Because of the reduction in tick size, more precise pricing in limit orders became available for market participants. As a result, we can expect that bid-ask spread's fluctuation might have become more dynamic, reflecting implicit trading costs more precisely. In this section, we see the volatility calculated from every five minutes' bid-ask spreads, regarding the influence of tick size changes on dynamics of the bid-ask spread.

Figure 21 shows how changes in tick size might have affected the intraday volatility of bid-ask spreads. The tick-size-reduced stocks show an increasing trend in the volatility of bid-ask spreads. Here, we test *t* ratio by setting up the null hypothesis "there was no change in the volatility of bid-ask spread from before April 13 to after April 13," and the alternative hypothesis "there was an increase in the volatility of bid-ask spread after April 13." Regarding the tick-size-unchanged stocks, only 1 out of 70 issues (1%) rejected the null hypothesis at the 1% significant level. On the other hand, for the tick-size-reduced stocks, 22 out of 23 issues (96%) rejected the null hypothesis. From these results, it can be said that the reduction in tick size had eased the degree of freedom in bid-ask spread fluctuation. And, we could conceive that the spread's fluctuation had become more sensitive to reflect changes in implicit costs caused by information asymmetry.

Figure 21. Effects on volatility of bid-ask spreads

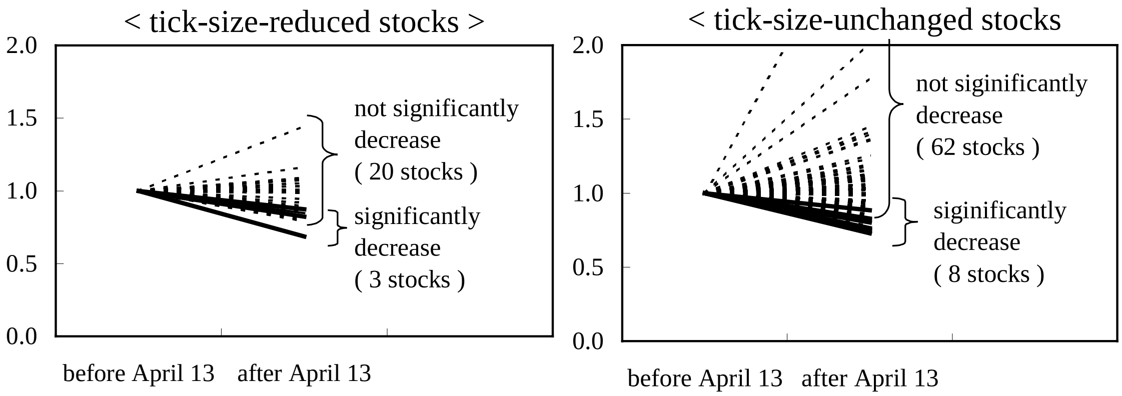


Note: Vertical axes show how the volatility of bid-ask spreads changed after the reduction of tick size, as a proportion of the level before the reduction of tick size, e.g. 1.5 denotes that the volatility of bid-ask spreads increased by 50%. 'Significantly' means that the null hypothesis "The reduction of tick size did not affect the volatility of bid-ask spreads" is rejected at the 1% level of significance.

4.4.2 Effects on market impact

Figure 22 shows the effects of the tick size reduction on market impact, which is one of the two dynamic indicators of market liquidity. Some of the tick-size-unchanged stocks show an increasing trend in market impact compare to the tick-size reduced stocks. We test *t* ratio by setting up the null hypothesis "there was no change in market impact from before April 13 to after April 13," and the alternative hypothesis "there was an decrease in market impact after April 13." The results show that the two groups are not significantly different. From these results, it can be said that the reduction in tick size did not affect averaged market impact.

Figure 22. Effects on market impact

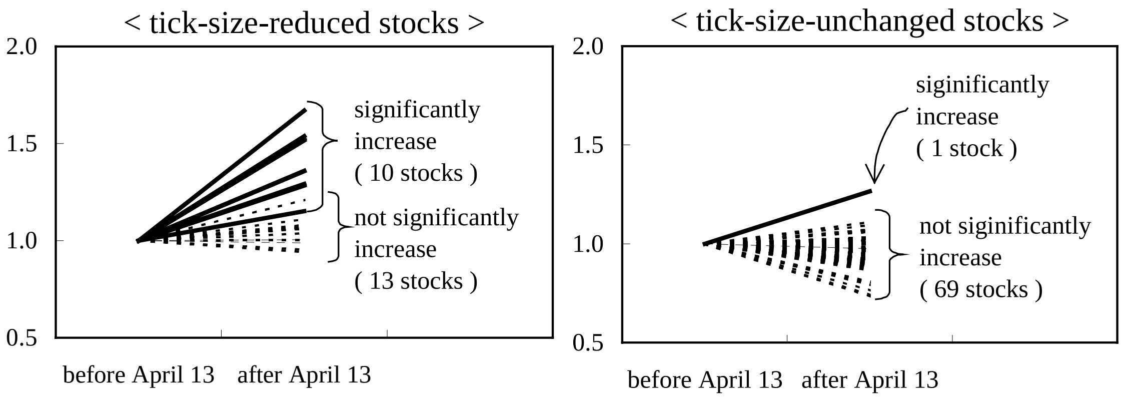


Note: Vertical axes show how the level of market impact changed after the reduction of tick size, as a proportion of the level before the reduction of tick size, e.g. 1.5 denotes that market impact increased by 50%. ‘Significantly’ means that the null hypothesis “The reduction of tick size did not affect the level of market impact” is rejected at the 1% level of significance.

4.4.3 Effects on market resiliency

Figure 23 shows the effects of the tick size reduction on market resiliency, another dynamic indicator of market liquidity. The tick-size-reduced stocks show an increasing trend in the convergence speed of bid-ask spreads, that is, market resiliency tends to increase by the reduction. Here, we test *t* ratio by setting up the null hypothesis “there was no change in market resiliency from before April 13 to after April 13,” and the alternative hypothesis “there was an increase in market resiliency after April 13.” Regarding the tick-size-unchanged stocks, only 1 out of 70 issues (1%) rejected the null hypothesis at the 1% significant level. On the other hand, for the tick-size-reduced stocks, 10 out of 23 issues (43%) rejected the null hypothesis. These results imply that the reduction in tick size motivated traders to submit limit orders more frequently and, as a result, increased market resiliency.

Figure 23. Effects on market resiliency



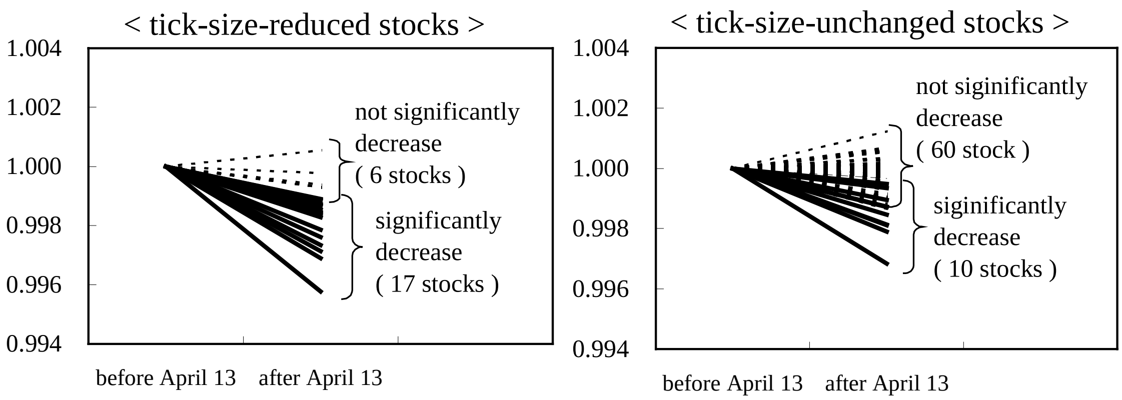
Note: Vertical axes show how the level of market resiliency changed after the reduction of tick size, as a proportion of the level before the reduction of tick size, e.g. 1.5 denotes that market resiliency increased by 50%. ‘Significantly’ means that the null hypothesis “The reduction of tick size did not affect the level of market resiliency” is rejected at the 1% level of significance.

4.5 Effects on price volatility

Finally, we analyse how changes in tick size might have affected the volatility in market prices. The reduction in tick size would induce more precise prices in ordering and provide more detailed price information for market participants at the same time. Therefore, we may assume that the reduction in tick size might have improved market efficiency (i.e. an increase in the amount of information which reflects on prices) and therefore decreased the volatility of market prices. Next, by using trade execution price as market price, we test whether size changes in tick size significantly decreased volatility of market prices as calculated every five minutes.

Figure 24 compares the daily averages of intraday volatility of trade prices before and after the change in tick size on April 13. In the *t* ratio test, we consider the null hypothesis "there were no changes in the daily average of intraday trade price volatility from before April 13 to after April 13," and the alternative hypothesis "the intraday price volatility had decreased after April 13." Regarding the tick-size-unchanged stocks, only 9 out of 70 issues (13%) rejected the null hypothesis at the 1% significant level. On the other hand, for the tick-size-reduced stocks, 17 out of 23 issues (74%) rejected the null hypothesis. From these results, we could assume that the reduction in tick size had improved market efficiency.

Figure 24. Effects on price volatility



Note: Vertical axes show how the level of intraday price volatility changed after the reduction of tick size, as a proportion of the level before the reduction of tick size, e.g. 1.5 denotes that intraday price volatility increased by 50%. 'Significantly' means that the null hypothesis "The reduction of tick size did not affect the intraday price volatility" is rejected at the 1% level of significance.

5. Summary and future work

This paper introduces both the definition of market liquidity and the methods of measuring market liquidity indicators proposed by Muranaga and Shimizu (1999), and, within this framework, analyses market liquidity of the individual stocks listed on the TSE. This paper is unique in that it utilises tick-by-tick data of the TSE in order to analyse dynamics of market liquidity. By conducting an empirical analysis based on the TSE tick-by-tick data, we have obtained results that if the monitoring frequency does not increase directly in accordance with the change in trade frequency, there is a possibility that the changes in market conditions may have been overlooked. Also there are positive correlations between trade frequency and each of the three indicators of market liquidity. Through the event study on the effects of the reduction in tick size of the TSE on April 13 1998, we have shown a possibility that the reduction in tick size might have reduced implicit trading costs and improved price discovery function in the TSE. Therefore, we can point out that (1) it is deemed necessary to take into account the effects of data monitoring frequency in analysing market dynamics, (2) trade frequency is positively correlated with market liquidity, and (3) the change in tick size could affect trading costs and market liquidity and efficiency.

In conducting empirical analysis, we first monitored intraday fluctuation patterns of trade volume, bid-ask spread, and price volatility of issues listed on the first session of the TSE. We observed that trade volume and bid-ask spread for a W-shape, and that trade volume, bid-ask spread, and price volatility all show an substantial increase towards the closing of the afternoon session. In addition, in analysing the relationship between trade frequency and market liquidity, we focused on a static market liquidity indicator (bid-ask spread) and dynamic indicators (market impact and market resiliency). We have considered how to estimate market resiliency in the absence of volume data such as trade order flows or order book profile, and found that declining rate of bid-ask spread can, with certain extent of explanatory power, be a proxy of market resiliency.

In order to avoid the problem of quote disappearance unique to the TSE at which exchange-designated liquidity providers do not exist, we have dealt only with issues with relatively high liquidity. However, disappearance of bid or ask signifies evaporation of market liquidity because it reveals the fact that market orders (sell/buy), which need to be traded immediately, will not be executed. Such phenomenon is indeed one of the most important issues to be explored when discussing market liquidity of the TSE. It will be our future work to explore and gain insights about this issue based on our results which were obtained by analysing issues with relatively high market liquidity. Since market liquidity is a total market depth which includes effective supply and demand, it changes dynamically according as the trading incentives of market participants change. In order to observe this kind of development, the further refinement of dynamic indicators, especially market resiliency will be necessary. Specifically, how to express market resiliency in cases where new market orders are executed continuously and the bid-ask spread fails to resume its stationary state.

Because of limitations on data availability, past studies mainly tried to extract information contents of the market by analysing market price changes along with time horizon. These studies were based on the assumption that all information, including trade volume, is reflected in market prices. However, market microstructure theory argues that information about order flows and trade volume not reflected in market prices is profitable for market participants, and that games based on such information affect market behaviour. In other words, when one wishes to analyse the market at a micro level, factors such as the budget constraints of individual market participants, restrictions on short-selling, and loss-cut rules may not be neglected. By making more use of information about the volume of order flows and trade executions, which has recently become increasingly available, market analysis in the future will be required to be conducted in three dimensions: time, price, and volume. If we can monitor tick-by-tick dynamics of the market liquidity by using more sophisticated indicators, we may be able to gain more insights about some critical issues such as the mechanism of market liquidity evaporation.

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