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Impact of optimization of the tick size for TOPIX Mid 400 constituents

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Impact of optimization of the tick size for TOPIX Mid 400 constituents

Hiroaki Wakamatsu[†]

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Abstract

The tick size is not just a price unit used when executing an order. It is also a vital component of the execution costs paid by investors. In 2014, the Tokyo Stock Exchange (TSE) started a pilot program to optimize the tick size for the TOPIX 100 constituents, thus optimizing the tick size of the high-liquidity stocks. After that, investors pointed out that medium-liquidity stocks, ETFs, ETNs, and others (ETFs, etc.) also had coarse tick size, and tick sizes were optimized for ETFs, etc. from November 29, 2021 and for TOPIX Mid 400 constituents, which are medium-liquidity stocks, from June 5, 2023.

Cutting investor execution costs by optimizing tick size for TOPIX Mid 400 constituents, which was a major objective of these measures, can be assessed as having been achieved (in the order of ¥120 billion per year). In addition, impacts such as reduced volatility and improved market efficiency measured by the variance ratio of volatility were also verified. For depth, we were also able to confirm that the depth also declines with a change in tick size. However, when looking at cumulative depth, we were able to confirm that the cumulative depth of the best quoted price (the distance from the midpoint of the best quoted price) declined by about -13 to -10% from before optimization, with no decline in cumulative depth for other points, but rather an increase.

We confirmed that the order volume for each order declines with a reduction in depth and dispersal of orders at each price level stemming from the optimization of tick size. However, even for orders with larger lot sizes after tick size optimization, there was no situation that adversely affected the execution costs compared to the cumulative depth after tick size optimization.

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Contents

1 Introduction

A “tick” represents the content of an investor's order for shares or other securities on a financial instruments exchange (Exchange), and the tick size is the smallest unit in the price of an order. Orders cannot be executed for shares or other securities on an Exchange at less than the minimum tick size limit. Hence, investors who want to prioritize trading in limit orders at the highest priority quote price[1] must execute orders at prices registered on the exchange order book[2] higher than the tick size (1 unit). As a result, the tick size is not merely a unit designating a price but also a crucial part of an investor's execution costs.

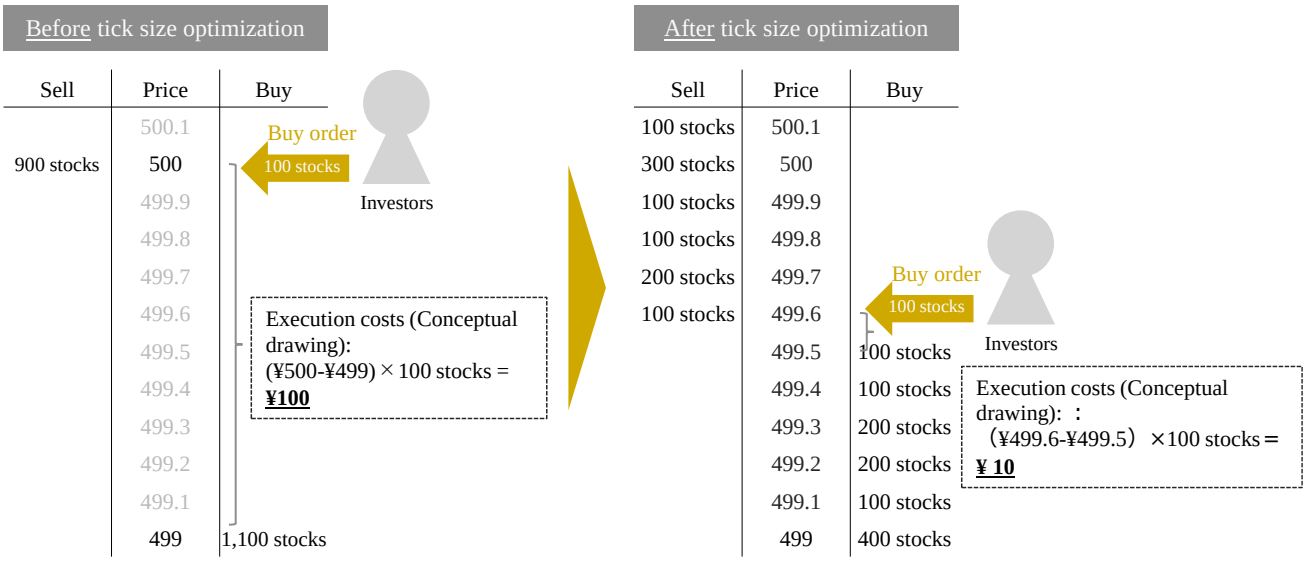

Figure 1.1 Image of execution costs before and after tick size optimization

From the standpoint of lowering investors' execution costs, smaller tick sizes are generally better. However, there are also drawbacks to having a tick size that is too small. Specifically, it makes it harder to place a large-lot order because it would be spread across several price ranges, leading to a prioritization of almost economically meaningless trades, and reduced trading predictability[3]. Thus, determining an appropriate tick size is essential to the trading rules.

This paper analyzes the impact on investor execution costs, etc. of applying a tick size table[4] with smaller tick sizes to TOPIX Mid 400 constituents, as of June 5, 2023.

In section 2, we give an overview of tick sizes. In section 3, we go over the data and analytical

[1] For a buy order, it refers to the highest price registered on the order book, and for sell order, it refers to the lowest price registered on the order book.
[2] Where the Exchange receives and records buy and sell orders from trading participants with annotations for each order by stock. Those orders are arranged by order price with time priority. This often simply referred to as the book.
[3] Securities and Exchange Commission (2005), etc.
[4] For listed shares, tick size tables with smaller tick sizes have been adopted for TOPIX 100 and TOPIX Mid 400 constitutions. A tick size table with smaller tick sizes was adopted for TOPIX 100 constituents up until June 2, 2022, and a tick size table with smaller tick sizes was also adopted for TOPIX Mid 400 constituents from June 5, 2023.

methodology used in our analysis, and in section 4, we discuss our analytical results. In section 5, we discuss the assessment of the impact forecasts using data for ETFs, etc., and section 6 presents our conclusions.

2 Tick sizes

Please see the JPX Working Paper published in August 2022 (How Changes in Tick Sizes Affect Investors' Execution Costs, Wakamatsu (2022)) concerning the development of the tick size at the TSE, etc.

The time weighted average spread of a stock for one day (bid-ask spread) and spread-to-tick ratio (STR) [5] are indicators of the appropriateness of a tick size, and the STR before optimization of the tick size for Mid 400 constituents, which are medium-liquidity stocks, was at levels close to 1 overall[6].

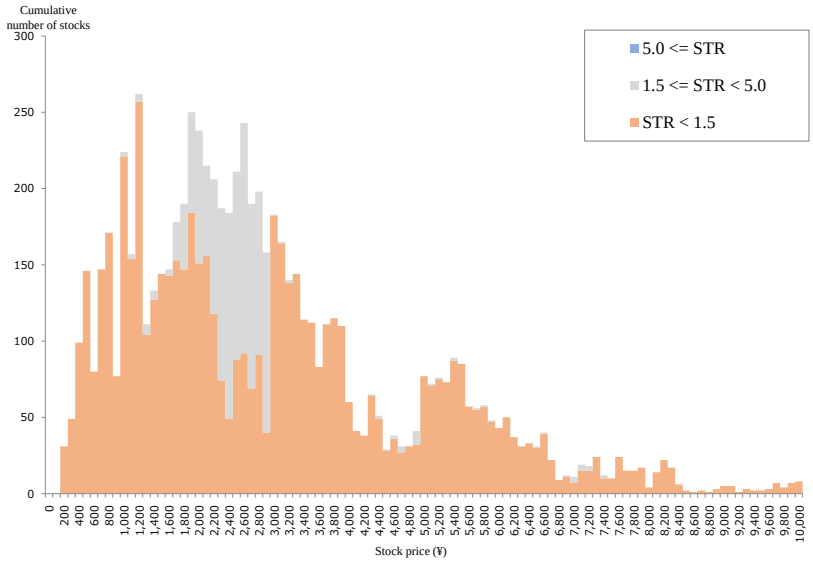

Figure 2.1 STR distribution of TOPIX Mid 400 constituents (May 8 to June 2, 2023)

Having a tick size that is too large means investors pay unnecessary execution costs. Optimizing the tick size will enable many individual and long-term investors to pay lower execution costs on their trades. Therefore, on January 30, 2020, the TSE unveiled its Action Program for Strengthening the Functions of the Cash Equity Market[7], which was meant to optimize tick sizes. On November 29, 2021, it revised the tick sizes in effect for ETFs, etc., so that all these stocks would, in principle[8], use the tick sizes applicable to TOPIX 100 constituents[9], while the tick sizes have been optimized for TOPIX Mid 400 constituents since June 5, 2023.

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[5] The calculation method is described later.

[6] If the tick size is too big, the spread will converge with the tick size, and the STR will approach 1. If the tick size is too small, the STR will increase to a figure larger than 1.

[7] For more information on the Action Program for Strengthening the Functions of the Cash Equity Market, please refer to the TSE website (https://www.jpx.co.jp/english/corporate/news/news-releases/0060/20200130-01.html).

[8] The tick size table applied to TOPIX 100 constituents will include fractional yen amounts depending on the price range. Therefore, it is necessary to avoid the case where the trading unit is 1 unit ETFs and ETNs and the trading value contained less than one yen. For ETFs and ETNs with a trading unit of one unit, if the closing price falls below ¥5,000, the other tick size table(not TOPIX 100 stocks tick size table) shall, in principle, be applied form the day two business days later. After that, if the closing price subsequently reaches ¥7,000 or more, the TOPIX 100 tick size table will be applied from the day two business days after.

[9] See TSE website (https://www.jpx.co.jp/english/news/1030/20211125-02.html).

Table 2.1 Changes in tick sizes on the TSE

Price (JPY)	All	All	All	All	All	TOPIX 100 constituents			ETFs	TOPIX 500 constituents	Other stocks
	1985/12/2	1998/4/13	2000/7/17	2008/7/22	2010/1/4	2014/1/14	2014/7/22	2014/9/24	2021/11/29	2023/6/5	2010/1/4～
1,000 or less	1	1	1	1	1	1	0.1	0.1	0.1	0.1	1
>1,000 - 2,000 or less	10						0.5	0.5	0.5	0.5	
>2,000 - 3,000 or less		5	5	5							
>3,000 - 5,000 or less		10	10	10	5			1	1	1	5
>5,000 - 10,000 or less					10		1				10
>10,000 - 30,000 or less	100					5	5	5	5	5	
>30,000 - 50,000 or less		50	50	50	50			10	10	10	50
>50,000 - 100,000 or less		100	100	100	100	10	10				100
>100,000 - 300,000 or less	1,000	1,000	1,000			50	50	50	50	50	
>300,000 - 500,000 or less				1,000	500			100	100	100	500
>500,000 - 1,000,000 or less					1,000	100	100				1,000
>1,000,000 - 3,000,000 or less	10,000	10,000	10,000			500	500	500	500	500	
>3,000,000 - 5,000,000 or less				10,000	5,000			1,000	1,000	1,000	5,000
>5,000,000 - 10,000,000 or less					10,000	1,000	1,000				10,000
>10,000,000 - 20,000,000 or less						5,000	5,000	5,000	5,000	5,000	
>20,000,000 - 30,000,000 or less			50,000	50,000							
>30,000,000 - 50,000,000 or less			100,000	100,000	50,000			10,000	10,000	10,000	50,000
>50,000,000 -					100,000	10,000	10,000				100,000

* Unit: ¥

3 Description of analysis

3.1 Data employed

This analysis used detailed data replicated from the order book[10] from May 8 through June 30, 2023. This period constituted 20 business days before and after (a total of 40 business days) June 5, 2023, the date tick sizes for TOPIX Mid 400 constituents were changed. The stocks analyzed consisted of 397 TOPIX Mid 400 constituents (excluding stocks that transitioned to a tick size range with a completely different volume-weighted average price (VWAP) before or after the optimization of tick size[11]. In addition, for stocks that transitioned to a tick size range with a different VWAP during the period under analysis[12] the analysis only considered the data for the stock price range that was the longest during the period under analysis[13]).

3.2 Analytical methodology

We computed daily metrics for each business day before and after the tick size optimization. We calculated the means for the periods before and after the optimization and ran a multiple regression analysis on each metric after the tick size optimization using the mean for the period as the explained variable.

Since we assumed that the effect of the tick size optimization would vary with the degree of liquidity, we classified the stocks into three groups by liquidity (trading value[14]): a top group (Group 1), a middle group (Group 2), and a bottom group (Group 3)[15], in the same way as for the analysis of ETFs, etc. (Wakamatsu (2022)).

The degree of the tick size reduction depends on the stock price level, and Table 3.1 gives the degree of the tick size reductions by price range. Using the TOPIX tick size table, we can classify the degrees of tick size reduction as -50%, -80%, and -90%. Since this analysis considers that the impact of a tick size reduction will differ depending on its reduction size, we inserted a flag (dummy variable) for the group with a 50% reduction in tick size, the group with an 80% reduction in tick size and the group with a 90% reduction in tick size. Table 3.2 shows the respective number of stocks by trading category.

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[10] Detailed data in which data concerning each and every order and execution is recorded.

[11] In the event of transition to a tick size range with a completely different VWAP during the period before and after the optimization of tick size, it is not possible to analyze the impact of tick size optimization, therefore such stocks are excluded from the analysis.

[12] Of the TOPIX Mid 400 constituents, there were 67 stocks that experienced a transition to a tick size range that was different from VWAP at least once.

[13] For example, of the 40 business days subject to analysis, if the VWAP of "A" stock is below ¥3,000 for 25 business days and exceeds ¥3,000 for 15 business days, the data is analyzed for the business days when the VWAP of "A" stock is below ¥3,000.

[14] Calculating the average trading value for the period prior to the optimization of the tick size (May 8 to June 2, 2023), sorting in descending order of the average trading value, and classifying into three groups by tertile number.

[15] See (Reference) Descriptive statistics at the end of the paper for descriptive statistics by group.

Table 3.1 Tick sizes for TOPIX 500 constituents and other stocks (since June 5, 2023)

price				TOPIX 500 constituents (Units:¥)	Other stocks (Units: ¥)	Degree of tick size reduction (Other→TOPIX 500)
		¥1,000	or less	0.1	1	-90%
>¥1,000	-	¥3,000	or less	0.5		-50%
>¥3,000	-	¥5,000	or less	1	5	-80%
>¥5,000	-	¥10,000	or less		10	-90%
>¥10,000	-	¥30,000	or less	5		-50%
>¥30,000	-	¥50,000	or less	10	50	-80%
>¥50,000	-	¥100,000	or less		100	-90%
>¥100,000	-	¥300,000	or less	50		-50%
>¥300,000	-	¥500,000	or less	100	500	-80%
>¥500,000	-	¥1 million	or less		1,000	-90%
>¥1 million	-	¥3 million	or less	500		-50%
>¥3 million	-	¥5 million	or less	1,000	5,000	-80%
>¥5 million	-	¥10 million	or less		10,000	-90%
>¥10 million	-	¥30 million	or less	5,000		-50%
>¥30 million	-	¥50 million	or less	10,000	50,000	-80%
>¥50 million	-				100,000	-90%

Table 3.2 Number of stocks by degree of tick size reduction for each trading value category[16]

	Top group in terms of trading value (Group 1)	Middle group in terms of trading value (Group 2)	Bottom group in terms of trading value (Group 3)	Total
50% tick reduction	63	72	74	209
80% tick reduction	28	29	27	84
90% tick reduction	41	32	31	104
Total	132	133	132	397

Quoted spread (half)

This is the spread for the quoted price represented on the order book and, in the case of stocks with the highest liquidity, a situation where the spread is only equivalent to one tick. Used to verify if the quoted spread narrows due to the optimization of tick size.

We took the difference between the best quoted bid$P^i_{best\ ask}$ and ask prices$P^i_{best\ bid}$ each time there was a change in the best quoted price after trading commenced (the number of changes in the quoted price each business day was i = 1, 2, 3, …, n) and divided it by 2. We then divided this by the medianP^i_{mid} of the best quoted price and multiplied it by the durationΔt^i of the best quoted price. We calculated n iterations of changes in quoted prices, added them up, and then divided this by total

[16] When running multiple regression analysis, we also add data for the stock group for which tick size has not been optimized (TOPIX Large 70 constituents) as control data.

trading hours($\sum_{i=1}^{n} \Delta t^i$)[17] to get the time-weighted-average.

$$qs = \frac{\sum_{i=1}^{n} \left(\frac{\left(P^i_{best\ ask} - P^i_{best\ bid}\right)/2 \times \Delta t^i}{P^i_{mid}} \right)}{\sum_{i=1}^{n} \Delta t^i} \quad (1)$$

Effective spread (half)

The quoted spread represents the external spread, but the effective spread is the actual execution cost incurred when contracted by investors, so it is used to verify how execution costs changed due to investor transactions.

For the effective spread(es^j) for trade j executed during trading hours, we calculated the effective spread for trade j by dividing the difference between the absolute value of the midpointP^j_{mid} of the executed priceP^j_{exe} and the best quoted price prior to execution by the midpointP^j_{mid} for the best quoted price. We then calculated the weighted average pricees^d during one business day by weighting the executed volumesQ^j_{exe} for es^j.

$$es^j = \frac{|P^j_{exe} - P^j_{mid}|}{P^j_{mid}} \quad (2)$$

$$es^d = \frac{\sum_{j=1}^{n} \left(es^j \times Q^j_{exe} \right)}{\sum_{j=1}^{n} Q^j_{exe}} \quad (3)$$

Although the above equation assumes execution at one execution price, if it took place at several prices (k=1, 2, …, m), we took the execution volumeQ^j_{exe} to be the total volume executed at all pricesQ^k_{part} and took the execution priceP^j_{exe} to be the weighted average execution price from the execution volumeQ^k_{part} at each execution priceP^k_{part}.

$$Q^j_{exe} = \sum_{k=1}^{m} Q^k_{part} \quad (4)$$

$$P^j_{exe} = \frac{\sum_{k=1}^{m} \left(P^k_{part} \times Q^k_{part} \right)}{Q^j_{exe}} \quad (5)$$

[17] $\sum_{i=1}^{n} \Delta t^i$ is the time excluding the duration of a special quote, etc. if there is no special quote, etc., in the day, the time is about 18,000 seconds (5 hours) in total.

Intraday volatility and variance ratio

intraday volatility shows the standard deviation of the stock price volatility of the day and is used to verify whether stock price volatility is suppressed by tick size optimization. In addition, the variance ratio adjusts two variance values of stock price volatility measured at different time intervals to one time interval (here, to match the 10-minute volatility, the figure obtained by multiplying the 1-minute volatility by two is multiplied by 10), which is taken to the be the ratio. The closer the variance ratio is to 1, the more long-term price movements are an extension of short-term price movements, i.e., stock prices move closer to Brownian motion. Therefore, this is used to verify market efficiency.

Intraday volatility and the variance ratio were calculated per Borkovec and Heidle (2010). For intraday volatility, we calculated by the variance ratio $(\sigma_{1,10}^{d})^2$ for the applicable business day d using the natural logarithm of the rate of change in the midpointP_{mid}^{t} of the best quoted price starting at time t-1 for time t (t=1, 2, …, N[18]) at 1-minute and 10-minute intervals following the setting of the opening price. Here we take 1-minute volatility to be $\sigma_1^d$and 10-minute volatility to be σ_{10}^{d}.

$$\mu^d = \frac{1}{N}\sum_{t=1}^{N}(logP_{mid}^{t} - logP_{mid}^{t-1}) \tag{6}$$

$$(\sigma^d)^2 = \frac{1}{N}\sum_{t=1}^{N}(logP_{mid}^{t} - logP_{mid}^{t-1} - \mu^d)^2 \tag{7}$$

We also use 1-minute volatility $\sigma_1^d$and 10-minute volatility σ_{10}^{d} to calculate the variance ratio $vr^d$for each business day d.

$$vr^d = \frac{(\sigma_{10}^{d})^2}{10 \times (\sigma_1^d)^2} \tag{8}$$

STR (Spread to Tick Ratio)

STR is an indicator of how many multiples of tick size is the nominal spread, with the lowest value being 1. The tick size can be considered too big the closer it approaches 1 (tick size is a restriction on spread). It is used as an indicator to evaluate the appropriateness of tick size.

STR^d is calculated by dividing the time-weighted average price for the difference between the best ask and bid prices on each business day by the tick size (TS).

$$STR^d = \frac{\sum_{k=1}^{n}\left(\left(P_{best\ ask}^{i} - P_{best\ bid}^{i}\right) \times \Delta t^i\right)}{\sum_{k=1}^{n}\Delta t^i} \Big/ TS \tag{9}$$

[18] N differs om the case of 1-minute and 10-minute intervals. Since there are 5 hours of trading hours in a day, N is approximately 300 for every minute and 30 for every 10 minutes per business day.

Depth

This is the order volume registered for each quoted price and it is conceivable that orders are dispersed to each price due to the reduction in tick size stemming from tick size optimization, and consequently the order volume registered for each price could also be lower. However, we verify what type of change occurs due the level of reduction in tick size, etc.

For the ten prices above and below the best quoted price, we calculated for each change in the order volume (QQ^l_{ask}, QQ^l_{bid})recorded for $l$prices 1–10 from the best quotes and then calculated the time-weighted average for the applicable business days. For each order volume on a given business day (the time-weighted average price), we took the average of each price'sl bid and ask to be the level'sl depth[19].

$$QQ^l_{ask} = \frac{\sum_{p=1}^{n}\left(QQ^l_{ask} \times \Delta t^p\right)}{\sum_{p=1}^{n} \Delta t^p} \tag{10}$$

$$QQ^l_{bid} = \frac{\sum_{q=1}^{n}\left(QQ^l_{bid} \times \Delta t^q\right)}{\sum_{q=1}^{n} \Delta t^q} \tag{11}$$

$$depth^l = \frac{QQ^l_{ask} + QQ^l_{bid}}{2} \tag{12}$$

[19] Some analysis do not use the average depth of the bid and ask, but the time-weighted-average of the respective $l$levels of bid and ask as the depth.

4 Analytical results

4.1 Quoted spread (half)

Below are the results[20] of multiple regression analyses of quoted spreads after the optimization of tick sizes, with the variable for the optimization of tick size as the explanatory variable, while considering multicollinearity by group categorized by liquidity[21]. We do not adopt a separate model for each group for the variable in the multiple regression analysis, but apply a model using the same variable (The same applies to the following multiple regression analyses).

The results for the multiple regression analysis on the quoted spread showed that for all groups, an 80% tick reduction (dummy variable) and a 90% tick reduction (dummy variable) the ticks were significant and negative, and we found for stocks with large reductions in tick size that the significance of quoted spread reduced regardless of the liquidity of the stock. In addition, for a 50% tick reduction (dummy variable), there was no significance for any of the groups, which could be attributed to a limited impact on the nominal spread or the possibility that the model could not detect the impact.

Table 4.1 Results of the multiple regression analysis of the quoted spread (half) (Group 1)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
Quoted spread (pre-change)	0.40***	1.13***	0.000	0.31	0.49
Ratio of cancellation orders (pre-change)[22]	3.75**	0.12**	0.023	0.52	6.98
HFT ratio (pre-change)[23]	-1.93*	-0.10*	0.054	-3.89	0.03
Number of transaction units per contract	-3.00×10^{-4}	-0.12	0.136	-1.00×10^{-3}	-9.93×10^{-5}
Depth_1st (pre-change)	-2.72×10^{-6}	-0.09	0.283	-7.72×10^{-6}	-2.27×10^{-6}
STR(pre-change)	0.17	0.07	0.124	-0.05	0.38
50% tick reduction (dummy variable)	0.06	0.03	0.637	-0.18	0.30
80% tick reduction (dummy variable)	-1.15***	-0.40***	0.000	-1.66	-0.64
90% tick reduction (dummy variable)	-1.34***	-0.54***	0.000	-1.92	-0.75
No. Observations	202				
R-squared	0.54				
Adj. R-squared	0.52				

*** p < 0.01, ** p < 0.05, * p < 0.10

[20] The analysis data also includes the stock group for which tick size has not been optimized (TOPIX Large 70 constituents) as the control group.

[21] Calculate the Variance Inflation Factor and build a multiple regression analysis model while being careful not to generate multicollinearity.

[22] The number of cancellation orders divided by the number of all orders by stock

[23] The trading value of high-speed trading by high-speed traders (including financial instruments business operators, etc. or authorized firms for on-exchange transactions) who have been registered by the Prime Minister divided by all trading value.

Table 4.2　Results of the multiple regression analysis of the quoted spread (half) (Group 2)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
Quoted spread (pre-change)	0.45***	1.38***	0.000	0.36	0.53
Ratio of cancellation orders (pre-change)	0.56	0.02	0.789	-3.55	4.66
HFT ratio (pre-change)	-3.59**	-0.15**	0.018	-6.55	-0.63
Number of transaction units per contract	-8.00×10^{-4}***	-0.20***	0.010	-1.00×10^{-3}	-6.00×10^{-4}
Depth_1st (pre-change)	-1.56×10^{-5}***	-0.36***	0.000	-2.25×10^{-5}	-8.62×10^{-6}
STR(pre-change)	0.20*	0.09*	0.082	-0.03	0.43
50% tick reduction (dummy variable)	0.04	0.02	0.794	-0.24	0.31
80% tick reduction (dummy variable)	-1.21***	-0.42***	0.000	-1.80	-0.62
90% tick reduction (dummy variable)	-1.09***	-0.40***	0.001	-1.72	-0.46
No. Observations	203				
R-squared	0.65				
Adj. R-squared	0.64				

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 4.3　Results of the multiple regression analysis of the quoted spread (half) (Group 3)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
Quoted spread (pre-change)	0.62***	1.90***	0.000	0.54	0.71
Ratio of cancellation orders (pre-change)	4.54*	0.11*	0.055	-0.09	9.17
HFT ratio (pre-change)	-2.15	-0.08	0.236	-5.72	1.42
Number of transaction units per contract	1.10×10^{-3}**	0.21**	0.025	-2.00×10^{-4}	-2.00×10^{-3}
Depth_1st (pre-change)	-1.00×10^{-4}***	-0.52***	0.000	-1.31×10^{-4}	-6.94×10^{-5}
STR(pre-change)	0.24**	0.11**	0.046	0.01	0.48
50% tick reduction (dummy variable)	-0.21	-0.10	0.198	-0.52	0.11
80% tick reduction (dummy variable)	-1.50***	-0.51***	0.000	-2.12	-0.88
90% tick reduction (dummy variable)	-1.86***	-0.67***	0.000	-2.56	-1.15
No. Observations	202				
R-squared	0.79				
Adj. R-squared	0.78				

*** p < 0.01, ** p < 0.05, * p < 0.10

4.2　Effective spread (half)

Table 4.4 shows the effective spread for the periods before and after tick size optimization. The effective spread for all TOPIX Mid 400 constituents with optimized tick size declined by 4.32 bps (or by about 56%). Also, optimizing the tick size reduced execution costs for all TOPIX Mid 400 constituents by an average of ¥480 million per day, equivalent to about ¥120 billion per annum[24].

[24] The decrease in execution costs calculated by multiplying the increase or decrease in the effective spread for the period before and after the tick size optimization by the average trading value for the period before the tick size optimization, assuming 250 business days per year.

Table 4.4 Change in effective spread[25]

Level of reduction in tick size	Change in effective spread (One business day average, ¥)	Trading value in TSE auction trading[26] (average for the 20 business days after the change, ¥)	Effective spread (pre-change average, bps)	Effective spread (post-change average, bps)	After vs. before (bps)
90% reduction	-292,808,998	335,466,698,569	12.34	3.48	-8.86
80% reduction	-100,410,478	242,444,900,903	8.32	3.52	-4.80
50% reduction	-87,028,758	656,249,721,739	4.90	3.23	-1.67
All stocks with tick size optimized	-480,248,235	1,234,161,321,211	7.67	3.36	-4.32
No change (Large 70)	-36,030,837	1,093,478,324,199	2.92	2.51	-0.41

Figure 4.1 indicates the change in the quoted and effective spreads for all TOPIX Mid 400 constituents. This means all spread have also narrowed since the optimization of tick size on June 5, 2023. On the other hand, for the effective spread, there have been various business days when the effective spread has suddenly risen and these coincide with day[27] when the index has been rebalanced. Since the days when the index has been rebalanced are concentrated on the buy and sell at the close, there tends to be deviation between stock prices immediately before the close (final price during continuous trading) and contracted prices at the close (closing price), resulting in a tendency for the effective spread to become large. Therefore, in the following multiple regression analysis of effective spread we analyze using the median of the effective spread before and after optimization of tick size for each stock.

[25] The effective spread is calculated as a trading value-weighted average of each stock.
[26] Trading value in TSE auction trading is the total trading value per one business day by classification, where each stock is classified by the level or reduction in tick size.
[27] The MSCI index was rebalanced on May 31, 2023 and the S&P/TOPIX indices, etc. were rebalanced on June 16, 2023.

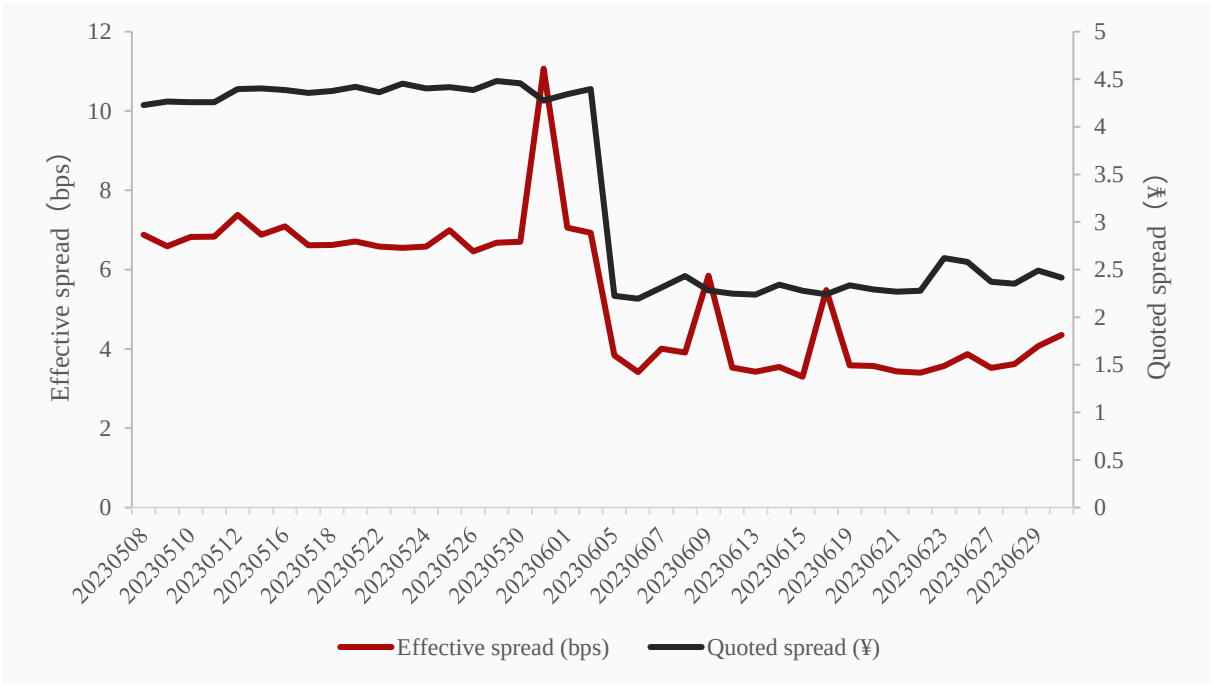

Figure 4.1 Change in quoted and effective spreads before and after optimization of tick size

As with the analysis of quoted spread, the following shows the results of multiple regression analysis taking the following effective spread after tick size optimization as the explained variable. The results resemble the analytical results for the quoted spread, with a 50% tick reduction (dummy variable) significant and negative for Groups 1 and 2, while the effective spread also narrowed for stocks groups with a 50% reduction in tick size. In addition, an 80% tick reduction (dummy variable) and a 90% tick reduction (dummy variable) were also significant and negative for all groups. The effective spread narrowed for such stock groups regardless of liquidity.

Table 4.5 Results of the multiple regression analysis of the effective spread (half) (Group 1)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
Effective spread (pre-change)	0.39***	1.05***	0.000	0.29	0.48
Ratio of cancellation orders (pre-change)	5.54***	0.18***	0.001	2.32	8.76
HFT ratio (pre-change)	-2.28**	-0.11**	0.029	-4.32	-0.24
1-minute volatility (pre-change)	620.23**	0.14**	0.013	134.63	1,105.83
No. of orders (pre-change)	-2.78×10^{-6}***	-0.23***	0.000	-4.24×10^{-6}	-1.32×10^{-6}
Depth_1st (pre-change)	-3.64×10^{-6}*	-0.10*	0.052	-7.31×10^{-6}	2.63×10^{-8}
STR (pre-change)	0.07	0.03	0.523	-0.15	0.30
50% tick reduction (dummy variable)	-0.29**	-0.13**	0.036	-0.55	-0.02
80% tick reduction (dummy variable)	-1.60***	-0.56***	0.000	-2.13	-1.08
90% tick reduction (dummy variable)	-1.80***	-0.71***	0.000	-2.39	-1.22
No. Observations	199				
R-squared	0.56				
Adj. R-squared	0.53				

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 4.6 Results of the multiple regression analysis of the effective spread (half) (Group 2)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
Effective spread (pre-change)	0.51***	1.34***	0.000	0.41	0.61
Ratio of cancellation orders (pre-change)	3.91*	0.11*	0.054	-0.07	7.89
HFT ratio (pre-change)	-4.19***	-0.16***	0.007	-7.23	-1.15
1-minute volatility (pre-change)	642.72**	0.12**	0.023	91.05	1,194.39
No. of orders (pre-change)	-1.92×10^{-6}**	-0.16**	0.013	-3.43×10^{-6}	-4.11×10^{-7}
Depth_1st (pre-change)	-1.40×10^{-5}***	-0.15***	0.005	-2.38×10^{-5}	-4.26×10^{-6}
STR (pre-change)	0.19*	0.08*	0.077	-0.02	0.40
50% tick reduction (dummy variable)	-0.40**	-0.19**	0.012	-0.70	-0.09
80% tick reduction (dummy variable)	-1.89***	-0.67***	0.000	-2.52	-1.26
90% tick reduction (dummy variable)	-1.93***	-0.68***	0.000	-2.59	-1.26
No. Observations	200				
R-squared	0.67				
Adj. R-squared	0.66				

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 4.7 Results of the multiple regression analysis of the effective spread (half) (Group 3)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
Effective spread (pre-change)	0.47***	1.28***	0.000	0.36	0.58
Ratio of cancellation orders (pre-change)	2.51	0.06	0.411	-3.49	8.50
HFT ratio (pre-change)	-3.34	-0.12	0.150	-7.89	1.21
1-minute volatility (pre-change)	689.20**	0.13**	0.046	11.61	1,366.80
No. of orders (pre-change)	-2.11×10^{-6}**	-0.19**	0.039	-4.10×10^{-6}	-1.12×10^{-7}
Depth_1st (pre-change)	-2.86×10^{-5}	-0.09	0.237	-7.62×10^{-5}	-1.89×10^{-5}
STR (pre-change)	0.31**	0.14**	0.034	0.02	0.59
50% tick reduction (dummy variable)	-0.18	-0.09	0.410	-0.61	0.25
80% tick reduction (dummy variable)	-1.11***	-0.38***	0.006	-1.89	-0.32
90% tick reduction (dummy variable)	-1.53***	-0.53***	0.001	-2.40	-0.65
No. Observations	199				
R-squared	0.63				
Adj. R-squared	0.61				

*** p < 0.01, ** p < 0.05, * p < 0.10

4.3 Intraday volatility and variance ratio

For intraday volatility (one-minute), we ran a multiple regression analysis of intraday volatility after tick size optimization for each liquidity group, with the results shown from Table 4.8 through Table 4.10. An 80% tick reduction (dummy variable) was significant and negative for all groups, while a 90% tick reduction (dummy variable) was only significant for Group 3. A 50% tick reduction (dummy variable) was not significant for any of the groups, and if the level of reduction in tick size were to have an impact on volatility, it would not be unusual for a 90% tick reduction (dummy variable) to be significant, but that was not the case.

On the other hand, Table 4.11 shows the results of a multiple regression analysis that also adds in interaction terms for low liquidity (dummy variable of 1 if applying to Group 3, and 0 otherwise) and high liquidity (dummy variable of 1 if applying to Group 1, and 0 otherwise) with the level of tick reduction and liquidity dummy variable for the entire sample without separating the sample into groups by liquidity. These results show that a 90% tick reduction (dummy variable) has 5% significance. In addition, not difference in significance occurred with tick a 50% tick reduction (dummy variable) units, and while the interaction term of tick-50%×high liquidity had 10% significance, it was negative. Consequently, it is possible that there could be a reduction in volatility even for tick-50% stocks for high-liquidity stocks. From these results, it is conceivable that the volatility is reduced for stocks with large levels of tick size reduction.

Table 4.8 Results of the multiple regression analysis on 1-minute volatility (Group 1)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
1-minute volatility (pre-change)	0.61***	1.00×10^{-4}***	0.000	0.49	0.72
HFT ratio (pre-change)	1.20×10^{-3}***	5.91×10^{-5}***	0.000	1.00×10^{-3}	2.00×10^{-3}
No. of orders (pre-change)	1.97×10^{-10}	1.65×10^{-5}	0.202	-1.06×10^{-10}	5.00×10^{-10}
Depth_1st (pre-change)	-4.65×10^{-10}	-1.39×10^{-5}	0.173	-1.14×10^{-9}	2.06×10^{-10}
50% tick reduction (dummy variable)	-2.32×10^{-5}	-1.08×10^{-5}	0.405	-7.81×10^{-5}	3.16×10^{-5}
80% tick reduction (dummy variable)	-8.30×10^{-5}**	-2.89×10^{-5}**	0.046	-1.65×10^{-4}	-1.32×10^{-6}
90% tick reduction (dummy variable)	-5.85×10^{-5}	-2.32×10^{-5}	0.159	-1.40×10^{-4}	2.30×10^{-5}
No. Observations	199				
R-squared	0.60				
Adj. R-squared	0.58				

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 4.9 Results of the multiple regression analysis on 1-minute volatility (Group 2)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
1-minute volatility (pre-change)	0.63***	1.00×10^{-4}***	0.000	0.52	0.75
HFT ratio (pre-change)	9.00×10^{-4}***	3.52×10^{-5}***	0.007	8.00×10^{-4}	2.00×10^{-3}
No. of orders(pre-change)	3.21×10^{-10}**	2.65×10^{-5}**	0.041	1.39×10^{-11}	6.29×10^{-10}
Depth_1st (pre-change)	-1.66×10^{-9}***	-3.58×10^{-5}***	0.000	-2.50×10^{-9}	-8.19×10^{-10}
50% tick reduction (dummy variable)	-3.47×10^{-5}	-1.67×10^{-5}	0.256	-9.47×10^{-5}	2.54×10^{-5}
80% tick reduction (dummy variable)	-1.00×10^{-4}***	-4.97×10^{-5}***	0.002	-1.46×10^{-4}	-5.39×10^{-5}
90% tick reduction (dummy variable)	-7.08×10^{-5}	-2.53×10^{-5}	0.119	-1.60×10^{-4}	1.83×10^{-5}
No. Observations	200				
R-squared	0.55				
Adj. R-squared	0.54				

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 4.10 Results of the multiple regression analysis on 1-minute volatility(Group 3)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
1-minute volatility (pre-change)	0.64***	1.00×10^{-4}***	0.000	0.54	0.74
HFT ratio (pre-change)	3.00×10^{-4}	1.28×10^{-5}	0.273	-4.00×10^{-4}	6.00×10^{-3}
No. of orders(pre-change)	2.99×10^{-10}**	2.59×10^{-5}**	0.024	4.03×10^{-11}	5.58×10^{-10}
Depth_1st (pre-change)	-1.27×10^{-9}	-6.32×10^{-6}	0.406	-4.27×10^{-9}	1.73×10^{-9}
50% tick reduction (dummy variable)	-4.04×10^{-5}	-1.94×10^{-5}	0.129	-9.26×10^{-5}	1.19×10^{-5}
80% tick reduction (dummy variable)	-8.89×10^{-5}**	-3.04×10^{-5}**	0.020	-1.64×10^{-4}	-1.41×10^{-5}
90% tick reduction (dummy variable)	-8.24×10^{-5}**	-2.99×10^{-5}**	0.047	-1.64×10^{-4}	-1.14×10^{-6}
No. Observations	199				
R-squared	0.60				
Adj. R-squared	0.58				

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 4.11 Results of the multiple regression analysis on 1-minute volatility (all)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
1-minute volatility (pre-change)	0.61***	1.00×10^{-4}***	0.000	0.54	0.68
HFT ratio (pre-change)	1.00×10^{-3}***	4.36×10^{-5}***	0.000	1.00×10^{-3}	1.00×10^{-3}
No. of orders(pre-change)	3.04×10^{-10}**	1.93×10^{-5}**	0.025	3.86×10^{-11}	5.70×10^{-10}
Depth_1st (pre-change)	-9.32×10^{-10}***	-2.34×10^{-5}***	0.000	-1.42×10^{-9}	-4.48×10^{-10}
50% tick reduction (dummy variable)	-3.17×10^{-5}	-1.58×10^{-5}	0.231	-8.36×10^{-5}	2.02×10^{-5}
80% tick reduction (dummy variable)	-1.00×10^{-4}***	-5.53×10^{-5}***	0.000	-1.28×10^{-4}	-7.24×10^{-5}
90% tick reduction (dummy variable)	-8.78×10^{-5}**	-3.64×10^{-5}**	0.016	-1.59×10^{-4}	-1.65×10^{-5}
low liquidity (dummy variable)	1.80×10^{-5}	8.09×10^{-6}	0.570	-4.43×10^{-5}	8.03×10^{-5}
high liquidity (dummy variable)	8.78×10^{-5}***	3.94×10^{-5}***	0.005	2.63×10^{-5}	1.49×10^{-4}
90% tick reduction×low liquidity	-5.84×10^{-5}	-1.46×10^{-5}	0.180	-1.44×10^{-5}	2.71×10^{-5}
90% tick reduction×high liquidity	-2.04×10^{-5}	-5.68×10^{-5}	0.626	-1.03×10^{-4}	6.20×10^{-5}
50% tick reduction×low liquidity	-4.18×10^{-5}	-1.52×10^{-5}	0.260	-1.15×10^{-4}	-8.36×10^{-5}
50% tick reduction×high liquidity	-6.55×10^{-5}*	-2.23×10^{-5}*	0.080	-1.39×10^{-4}	7.85×10^{-6}
No. Observations	462				
R-squared	0.58				
Adj. R-squared	0.57				

*** p < 0.01, ** p < 0.05, * p < 0.10

For the analysis of the variance ratio, we compared the mean values of the variance ratios for each group and for the level of tick size reduction before and after the optimization (using a paired t-test).

The results are shown in Table 4.12. Before tick size optimization, the average price of the variance ratio was about 0.7 to 0.9, and the variance ratio for a 50% tick reduction is a high price (at close to 1) compared to others. The group for 50% tick reduction is shown in Figure 4.2, and this is because stock prices are in a range of ¥1,000 to ¥3,000[28], tick weight[29] (tick size÷stock prices) is a comparatively low price range, and there were many stocks with appropriate tick size even in terms of STR (described later).

Before tick size optimization, it is possible that smooth stock price fluctuations were prevented due to a too coarse tick size, but the variance ratio increased (asymptotic to 1)[30] after tick size optimization and the difference had statistical significance. In the analysis of ETFs, etc., there was no statistical significance in the difference of the variance ratio before and after tick size optimization for low liquidity groups (Group 3), but for TOPIX Mid 400 constituents, it appears an impact from tick size optimization was detected where there was comparatively high liquidity even for low liquidity groups (Group 3).

Therefore, this tick size optimization of TOPIX Mid 400 constituents is considered to have contributed to the market efficiency for the entire TOPIX Mid 400.

Table 4.12 Change in the variance ratio before and after tick size optimization

	Degree of freedom	Before	After	t-value	p-value
Total sample (Mid 400)					
90% reduction	103	0.73	1.02	-17.84***	0.00
80% reduction	83	0.76	0.99	-15.81***	0.00
50% reduction	208	0.91	0.99	-8.78***	0.00
Group 1					
90% reduction	40	0.74	1.02	-9.71***	0.00
80% reduction	27	0.80	1.01	-6.90***	0.00
50% reduction	62	0.92	0.98	-3.29***	0.00
Group 2					
90% reduction	31	0.73	1.02	-10.97***	0.00
80% reduction	28	0.73	0.97	-9.40***	0.00
50% reduction	71	0.92	0.98	-4.05***	0.00
Group 3					
90% reduction	30	0.72	1.02	-10.55***	0.00
80% reduction	26	0.75	1.01	-12.63***	0.00
50% reduction	73	0.89	1.00	-8.59***	0.00
Large 70					
Unchanged	69	0.93	0.96	-1.60	0.11

*** p < 0.01, ** p < 0.05, * p < 0.10

[28] About 96% of the TOPIX Mid 400 constituents had stock prices below ¥10,000 in the period before tick size optimization, and most stock prices for stocks included in the 50% tick reduction group were in the range of ¥1,000 to ¥3,000.

[29] Tick weights indicate the relative size of tick size at each price level of stocks.

[30] The closer the variance ratio is to 1, the more long-term price movements are an extension of short-term price movements, i.e., stock prices move closer to Brownian motion (market efficiency).

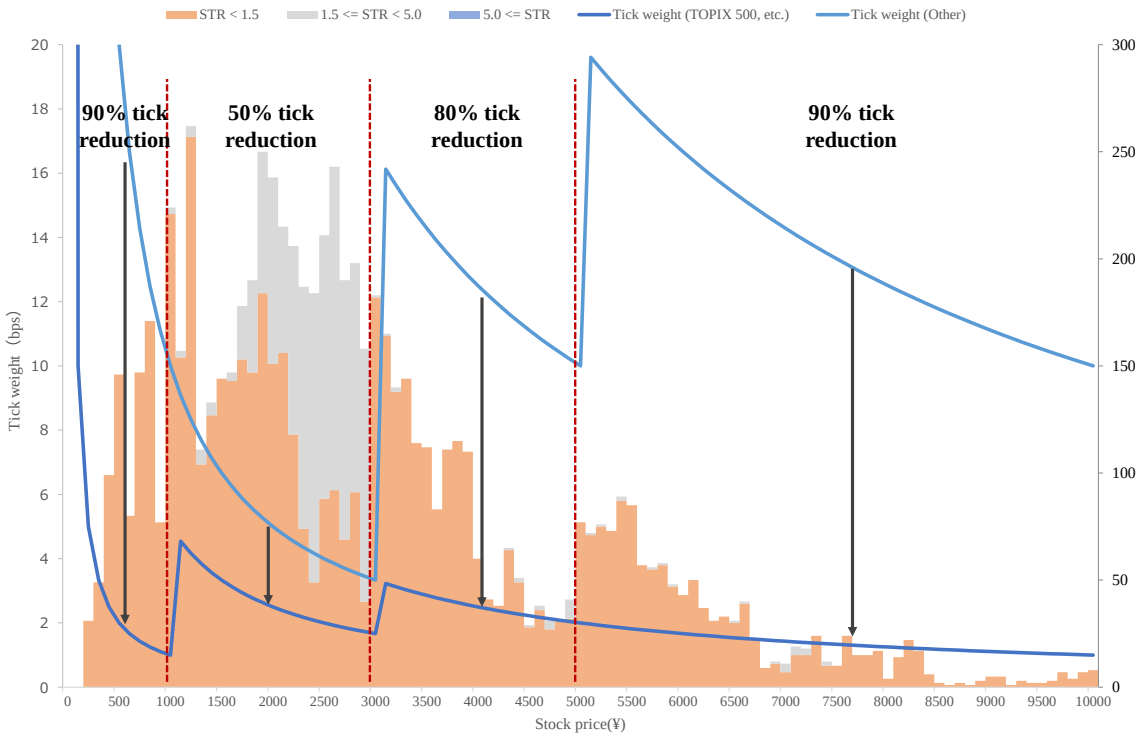

Figure 4.2 Stock price (STR) distribution and tick weight for TOPIX Mid 400 constitutes before tick size optimization

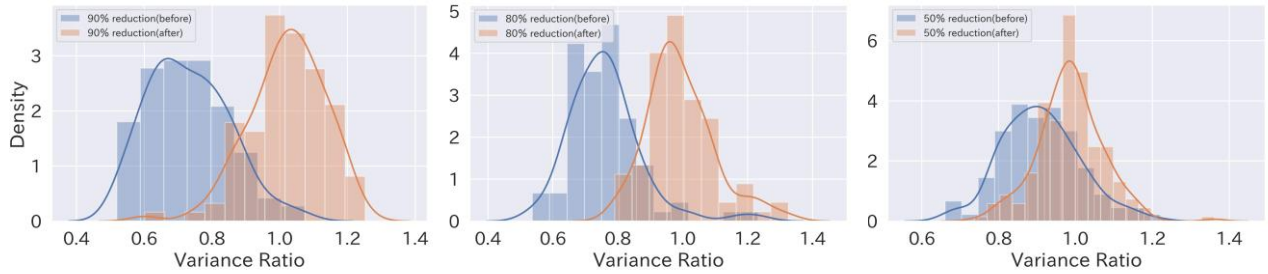

Figure 4.3 Variance ratio before and after by the degree of tick size reduction (Total sample)

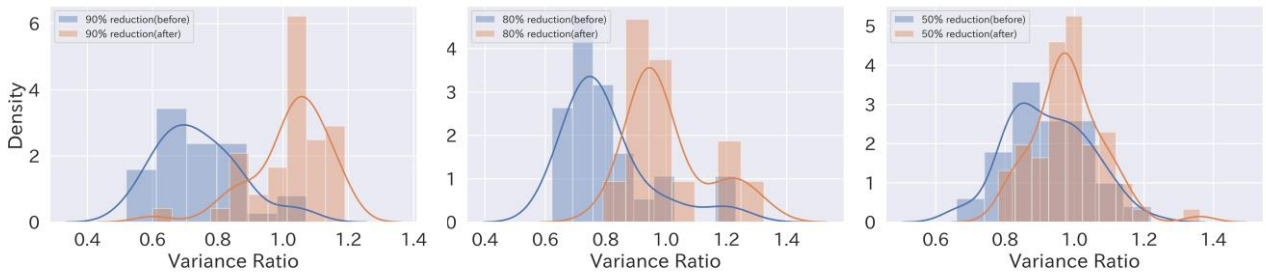

Figure 4.4 Variance ratio before and after by the degree of tick size reduction (Group 1)

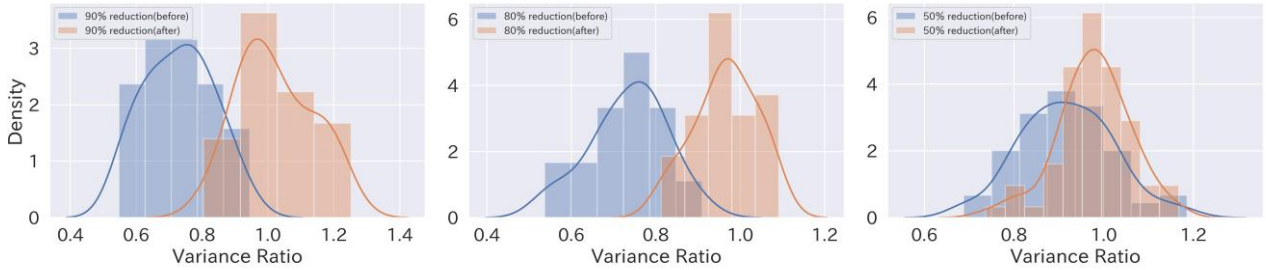

Figure 4.5 Variance ratio before and after by the degree of tick size reduction (Group 2)

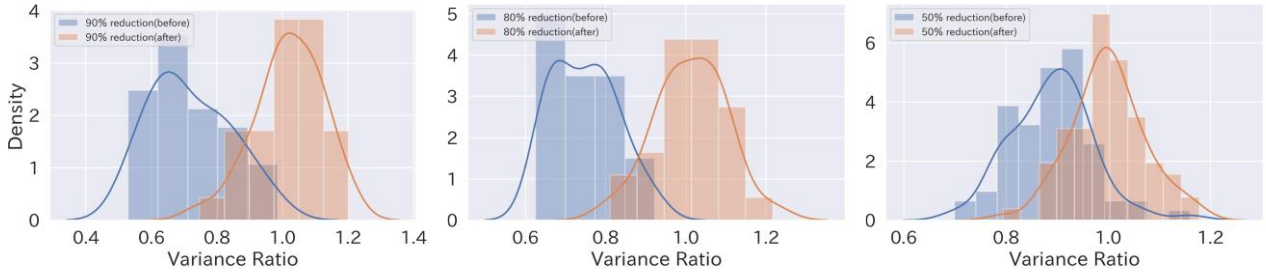

Figure 4.6 Variance ratio before and after by the degree of tick size reduction (Group 3)

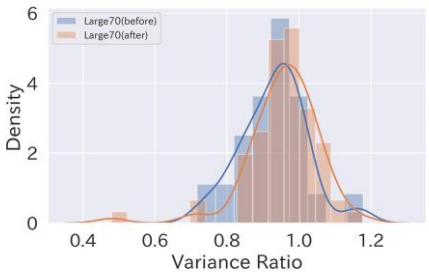

Figure 4.7 Variance ratio before and after tick size optimization (TOPIX Large 70 constituents)

4.4 STR(Spread to Tick Ratio)

STR[31] was too low (tick size was too coarse) before the tick size optimization of TOPIX Mid 400 constituents, and this is also clear from the STR distribution shown in Figure 4.8. STR of less than 1.5 is taken to mean the tick size is coarse[32], and before tick size optimization, almost all stocks have STR of less than 1.5. More than 80% of the STR after tick size optimization are distributed in the range of 1.5 to 5.0, which suggests the tick size is generally within an optimal range. The tick size after tick size optimization has generally been within an optimal range overall, which suggests that tick size optimization had an impact even for low liquid stock groups (Group 3).

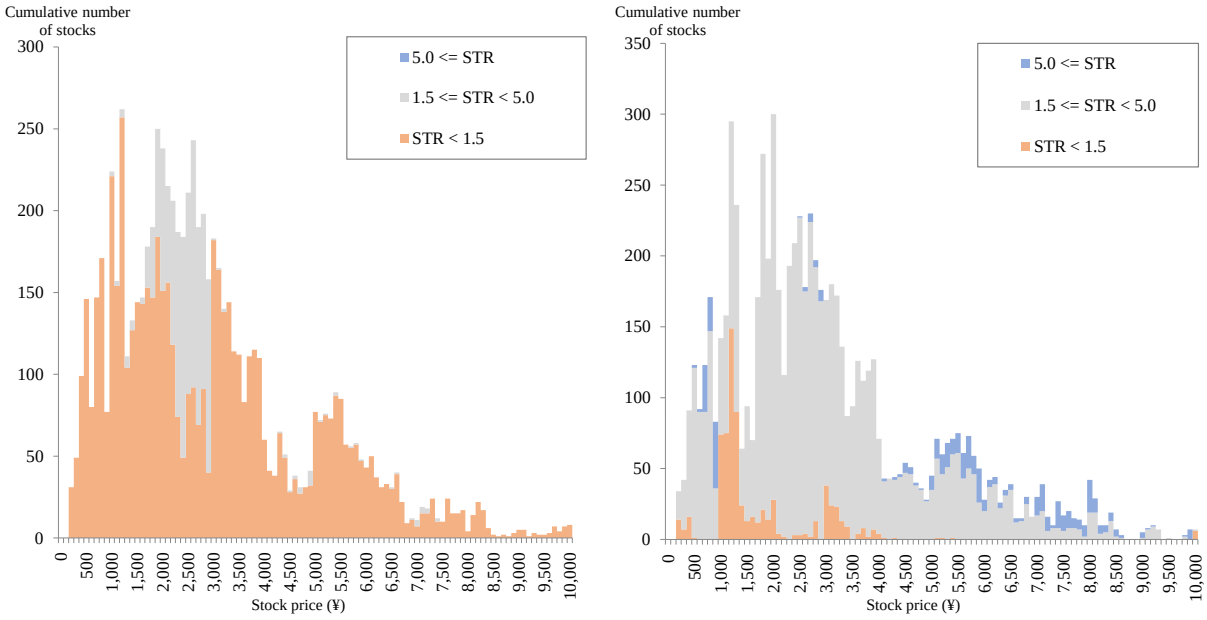

Figure 4.8 STR distribution of TOPIX Mid 400 constituents
(Left:before tick size optimization, Right:after tick size optimization)

Confirming the results of the multiple regression analysis undertaken as for the STR after tick size optimization, the tick size dummy variable was significant for all groups and that coefficient is also inversely proportional to the rate of reduction in tick size. i.e., the greater the reduction in tick size, the greater the impact of increasing the STR. In addition, the greater the reduction in the liquidity of the stock, the stronger the impact of the change in tick size on STR, which is evident from comparison with the non-standardized coefficient of each analysis.

[31] Comparison of the time weighted average spread of a stock for one day (bid-ask spread) and tick size (time weighted average spread÷tick size) for each stock.
[32] Referring to Huang et.al (2017), STR of 1.5 or less is considered to be an excessive tick size and STR of 1.5 to 5.0 is an appropriate range, and the same idea is used in this paper.

Table 4.13 Results of the multiple regression analysis of STR (Group 1)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
STR (pre-change)	1.30***	0.55***	0.000	1.04	1.56
HFT ratio (pre-change)	-1.70	-0.08	0.142	-3.98	0.57
Order volume/No. of orders (pre-change)	-2.00×10^{-4}***	-0.45***	0.000	-2.69×10^{-4}	-1.31×10^{-4}
1-minute volatility (pre-change)	-48.20*	-0.08*	0.083	-102.81	6.42
Trading volume (pre-change)	1.43×10^{-4}*	0.14*	0.069	-1.10×10^{-9}	2.97×10^{-8}
50% tick reduction (dummy variable)	0.64***	0.30***	0.000	0.38	0.90
80% tick reduction (dummy variable)	1.06***	0.37***	0.000	0.69	1.43
90% tick reduction (dummy variable)	2.93***	1.18***	0.000	2.58	3.28
No. Observations	202				
R-squared	0.68				
Adj. R-squared	0.67				

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 4.14 Results of the multiple regression analysis of STR (Group 2)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
STR (pre-change)	1.40***	0.60***	0.000	1.13	1.68
HFT ratio (pre-change)	-6.67***	-0.27***	0.000	-10.18	-3.17
Order volume/No. of orders (pre-change)	-3.00×10^{-4}***	-0.47***	0.000	-3.83×10^{-4}	-2.17×10^{-4}
1-minute volatility (pre-change)	382.48	0.07	0.188	-188.59	953.56
Trading volume (pre-change)	2.91×10^{-8}***	0.19**	0.012	6.37×10^{-9}	5.18×10^{-8}
50% tick reduction (dummy variable)	0.92***	0.44***	0.000	0.60	1.25
80% tick reduction (dummy variable)	1.62***	0.57***	0.000	1.14	2.11
90% tick reduction (dummy variable)	4.13***	1.51***	0.000	3.63	4.64
No. Observations	203				
R-squared	0.73				
Adj. R-squared	0.71				

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 4.15 Results of the multiple regression analysis of STR (Group 3)

				95% confidence interval for non-standardized	
	Non-standardized	Standardized	p-value	Minimum	Maximum
STR (pre-change)	1.57***	0.70***	0.000	1.30	1.85
HFT ratio (pre-change)	-7.20***	-0.28***	0.001	-11.39	-3.01
Order volume/No. of orders (pre-change)	-4.00×10^{-4}***	-0.39***	0.000	-5.40×10^{-4}	-2.60×10^{-4}
1-minute volatility (pre-change)	-89.33	-0.02	0.765	-677.08	498.42
Trading volume (pre-change)	4.84×10^{-8}***	0.33***	0.000	2.40×10^{-8}	7.28×10^{-8}
50% tick reduction (dummy variable)	1.19***	0.57***	0.000	0.85	1.53
80% tick reduction (dummy variable)	2.44***	0.83***	0.000	1.93	2.95
90% tick reduction (dummy variable)	5.04***	1.82***	0.000	4.48	5.60
No. Observations	202				
R-squared	0.77				
Adj. R-squared	0.76				

*** p < 0.01, ** p < 0.05, * p < 0.10

4.5 Depth

Since the distribution of orders for each price differs according to the level of tick size reduction, the impact of a tick size reduction on depth will differ and Figure 4.9 shows the volume of change (the volume of change from before tick size optimization (%), median) in depth from 1 to 10. There was no major change in in the trend from Group 1 through 3, and the biggest level of reduction in depth was for where there was a 90% reduction in tick size, an approximate 90% reduction for depths 1 to 6. The level of reduction in depth gradually declines from depth 7. A similar trend is found where there was an 80% reduction in tick size. On the other hand, where there was a 50% reduction in tick size, the trend was -60% to -55% for depths 1 to 10, and we could not verify a trend for a decline in the absolute value of the level of reduction in depth.

In the analysis of ETFs, etc., where tick size was reduced by 50% or 80% or more, the approximate level of reduction in depth was about 0% for Depth 5, and this point was different from the current analysis. The reasons can be considered to include (1) a market-making scheme has been developed for ETFs, etc., and market makers provide substantial orders (liquidity) at prices, etc. that are a few ticks away from the best quoted price, and(2) the tick size of TOPIX Mid 400 constituents are relatively coarse compared to their liquidity, and orders at each price have been dispersed evenly after tick size optimization.

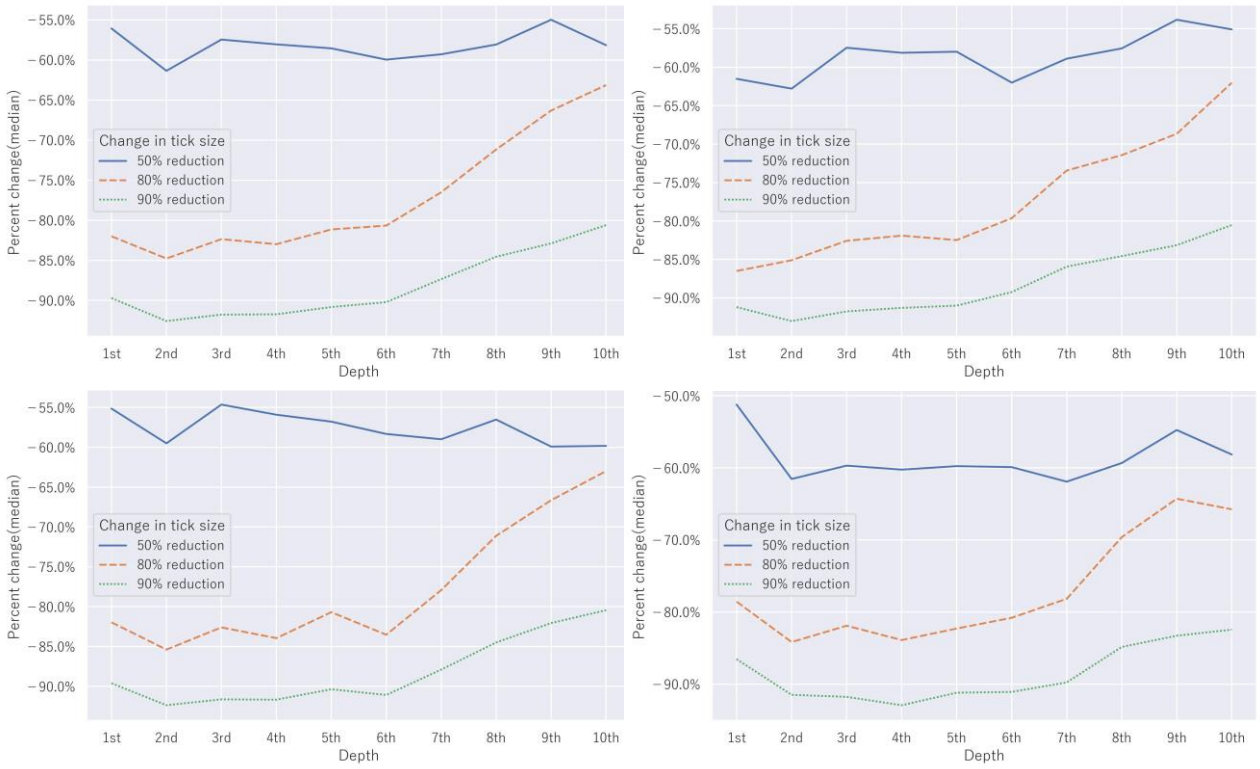

Figure 4.9 Change in the depth (median) after optimization of the tick size
(Upper left: All, Upper right: Group 1, Lower left: Group 2, Lower right: Group 3)

From the previous results, we confirmed that the level of reduction in depth also grows larger the larger the level of tick size reduction. However, if the cumulative value of depth has reduced after tick size optimization, this could mean an increase in execution costs for investors, etc.[33]. Therefore, it is important to confirm how the cumulative value of depth changed before and after the optimization of tick size.

Figure 4.10 - Figure 4.13 show the findings for the Nth quoted price (the Nth ask price and the Nth bid price), the distance (bps)[34] standardized at the median for the best quoted price, and the changes in cumulative depth (median) up until the Nth for each. There appears to have been virtually no change in cumulative depth since before tick size optimization when looking at the results by liquidity and by the level of tick size reduction. However, cumulative depth also appears to have fallen after tick size optimization for near 1st cumulative depth before tick size optimization.

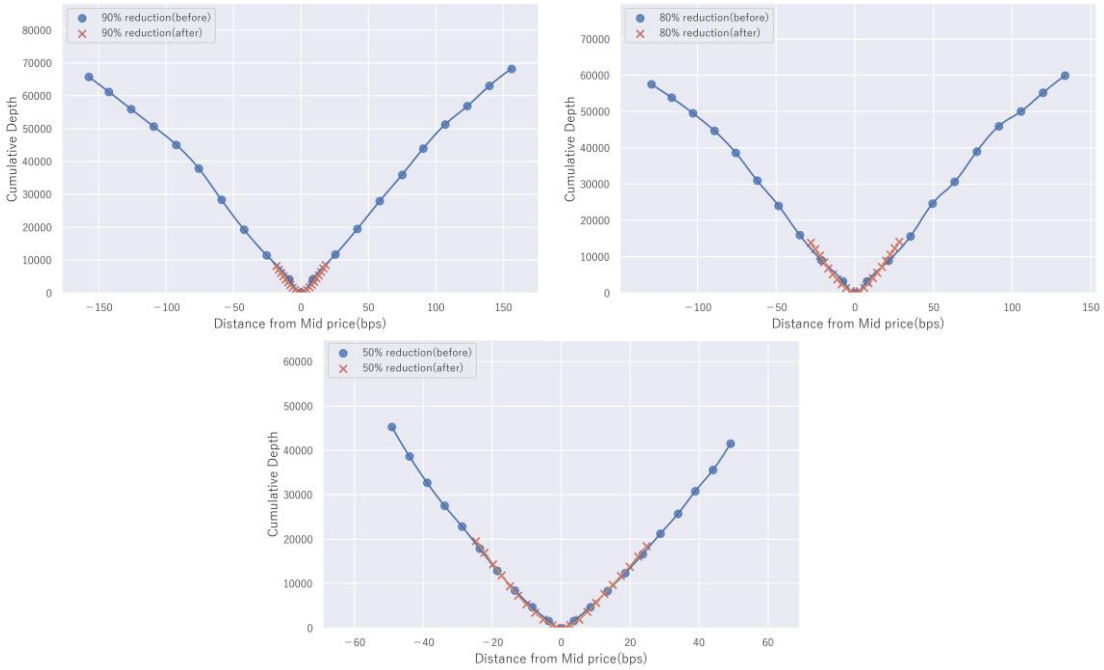

Figure 4.10 Distance and cumulative depth from the midpoint of the best quoted price for Bids (1-10) and Asks (1-10) (All(Upper left: 90% reduction in tick size, Upper right: 80% reduction in tick size, Lower: 50% reduction in tick size))

[33] For example, for 50% reduction in tick size, the distance between the price and BBO median of 1st depth has halved, (we can hypothesize that the distance has similarly halved for 2nd and 3rd), and the 1st depth is 1/8 the level before tick size optimization, 2nd depth is 1/8 the level before tick size optimization, and 3rd depth is ¾ the level before tick size optimization. In this case, taking the distance between the 1st depth and the BBO median before tick size optimization as 10bps, and the 1st depth before tick size optimization as 100,000 stock (1,000 units), the execution costs for an order of 100,000 stocks would be 10bps. Similarly, in the event of ordering 100,000 stocks after tick size optimization, this would be (5bps x 12,500 stocks + 10bps x 12,500 stocks + 15bps x 75,000 stocks)/100,000 stocks, with execution costs of 13.125bps and a higher execution cost after tick size optimization (In this case, if the order volume at the best quoted price after optimization < the order volume a the 3rd quoted price after optimization, the execution cost after optimization would be increased).

[34] Calculated from (The Nth bid price - the Nth ask price) ÷ 2 ÷ the median for the best quoted price.

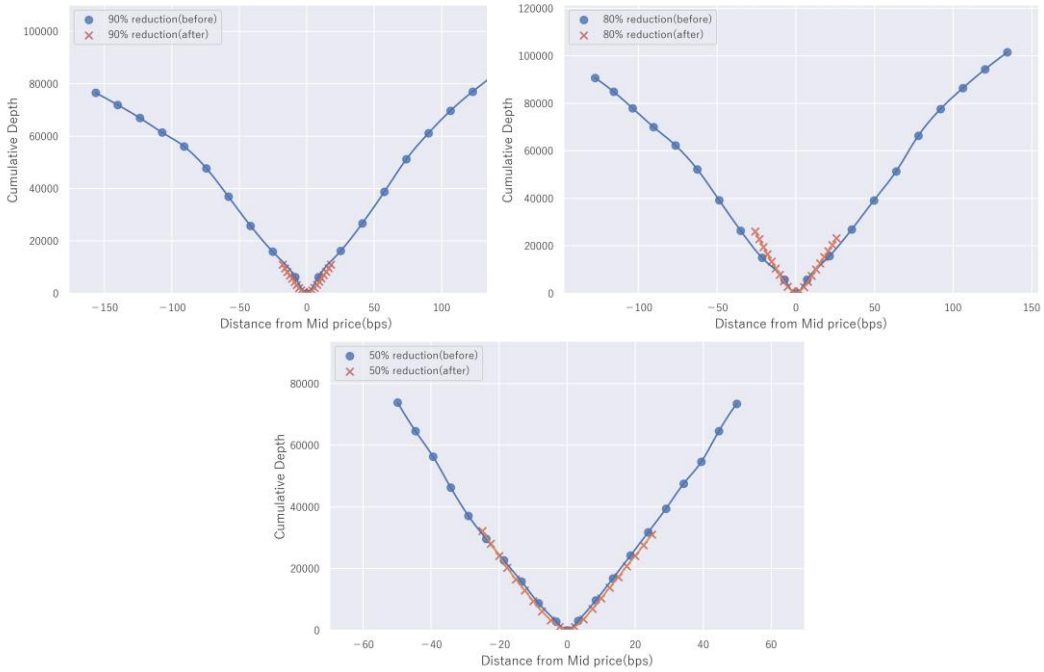

Figure 4.11 Distance and cumulative depth from the midpoint of the best quoted price for Bids (1-10) and Asks (1-10) (Group 1(Upper left: 90% reduction in tick size, Upper right: 80% reduction in tick size, Lower: 50% reduction in tick size))

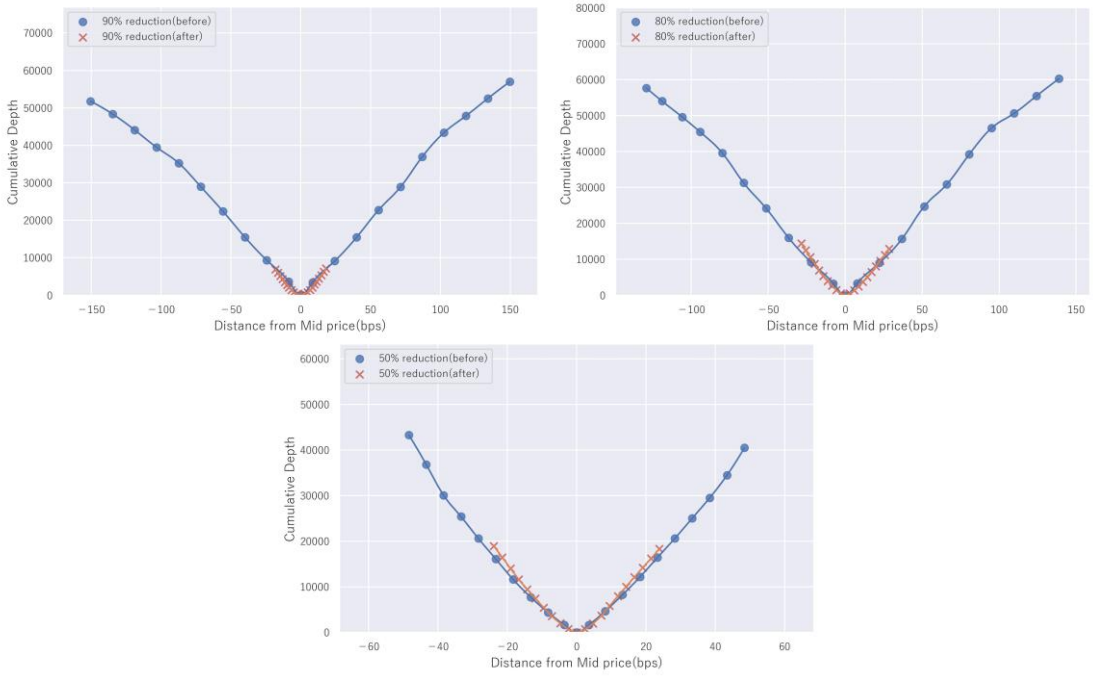

Figure 4.12 Distance and cumulative depth from the midpoint of the best quoted price for Bids (1-10) and Asks (1-10) (Group 2(Upper left: 90% reduction in tick size, Upper right: 80% reduction in tick size, Lower: 50% reduction in tick size))

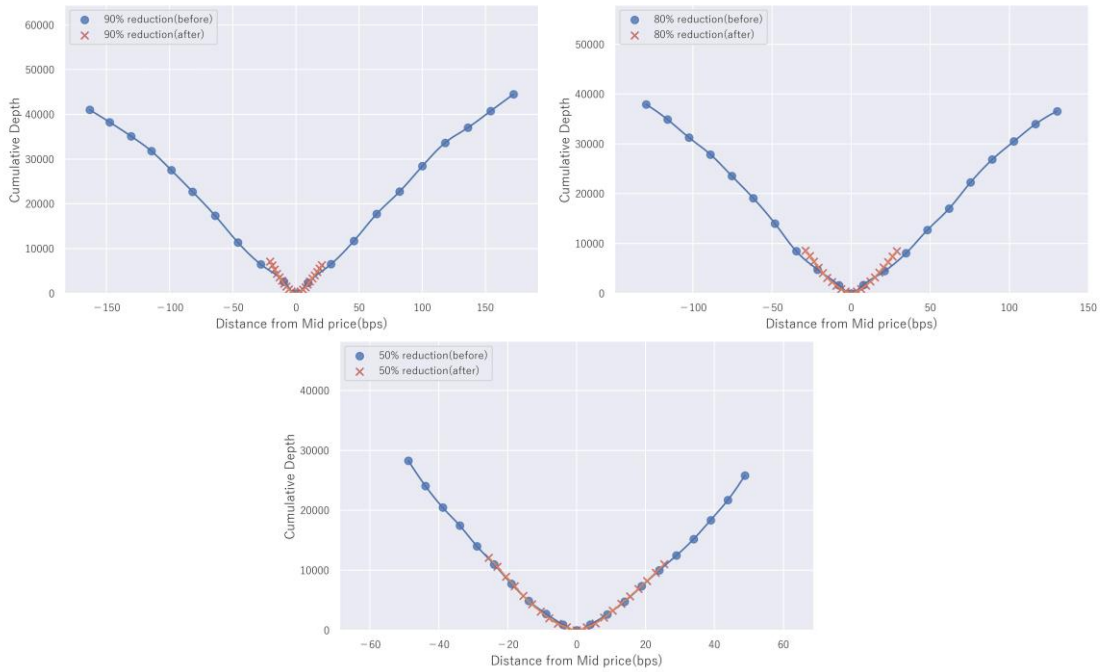

Figure 4.13 Distance and cumulative depth from the midpoint of the best quoted price for Bids (1-10) and Asks (1-10) (Group 3(Upper left: 90% reduction in tick size, Upper right: 80% reduction in tick size, Lower: 50% reduction in tick size))

4.5.1 The method of estimating cumulative depth after optimization standardized to the distance from the midpoint of the best quoted price before tick size optimization

There does not appear to be much change in cumulative depth before and after tick size optimization from Figure 4.10 through Figure 4.13, so we quantitatively analyze whether or not there was an actual difference, etc. When undertaking the analysis, the distance from the midpoint of the best quoted price for each N differs before and after tick size optimization, so this needs to be adjusted.

We take t1 to be before tick size optimization and t2 to be after tick size optimization, with the distance from the midpoint (Mid) of the best quoted price for number n in t1 taken to be $d_{t1,n}$ and ($1 \leqq n \leqq 10$). We estimate the cumulative depth for t2 and distance $d_{t1,n}$ and where there is cumulative depth sandwiching $d_{t1,n}$ ($d_{t2,m} < d_{t1,n} < d_{t2,m+1}$($1 \leqq n \leqq 10$, $1 \leqq m \leqq 9$), we calculate the cumulative depth for $d_{t1,n}$ after tick size optimization from a linear interpolation of $d_{t2,m}$and $d_{t2,m+1}$ (See Figure 4.14Left). In addition, where $d_{t2,10} < d_{t1,n}$ and it is not possible to sandwich $d_{t1,n}$ and $d_{t2,10}$ is somewhat close to $d_{t1,n}$ (when it becomes $\frac{d_{t1,n-1}+d_{t1,n}}{2} < d_{t2,10}$), we calculate the gradient between $d_{t2,9}$ and $d_{t2,10}$, and calculate the cumulative depth in $d_{t1,n}$ after tick size optimization (See Figure 4.14Right).

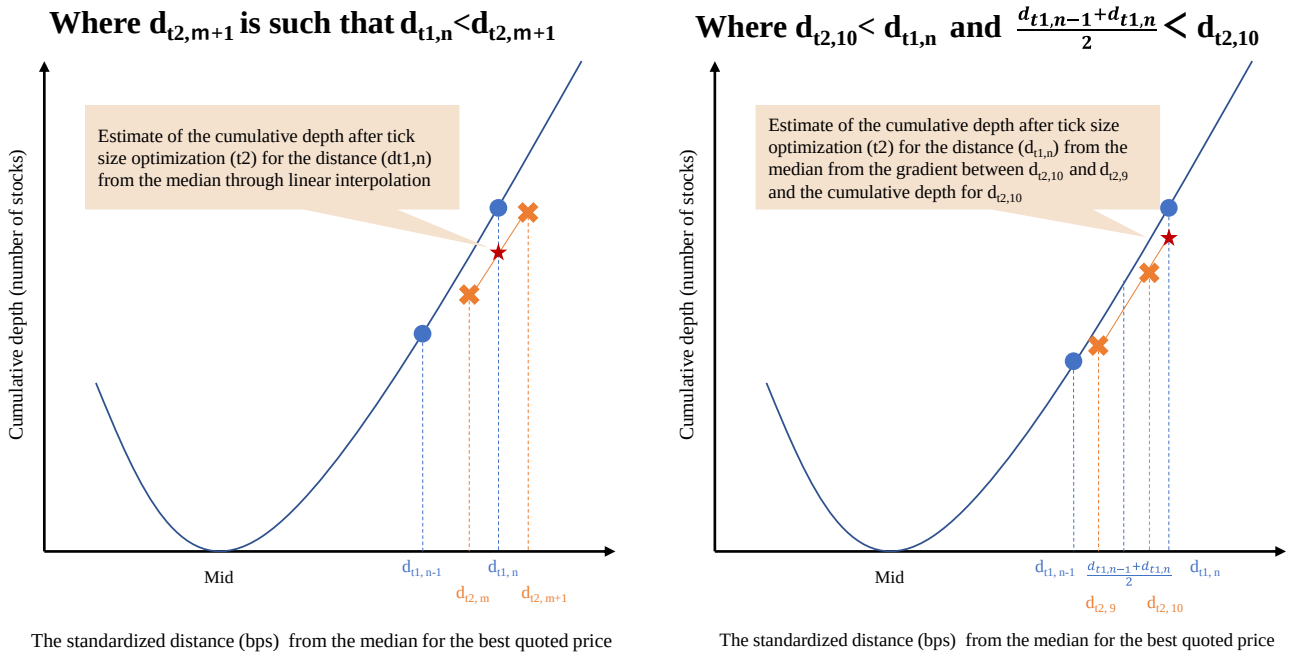

Figure 4.14 Image of the method of estimating cumulative depth of $d_{t1,n}$ after tick size optimization

4.5.2 Test the difference in cumulative depth before and after tick size optimization

Conduct a test[35] to see if there is a difference before and after tick size optimization for the cumulative depth (cumulative depth for bid/ask from 1 to 5[36]) after tick size optimization estimated from method 0 standardized to the cumulative depth before tick size optimization.

Table 4.16 shows the results of the test. In terms of the 1st cumulative depth, cumulative depth after optimization has declined for each group (1 through 3) as well as for all Mid 400, and the difference is significant. In terms of 2nd and subsequent cumulative depths, overall cumulative depth after optimization exceeds cumulative depth before optimization, but for Group 1, the group with a 50% tick reduction, the cumulative depth after optimization is below the level before optimization, and the difference is significant.

On the other hand, in terms of TOPIX Large 70 group that did not have a change in tick size, overall the cumulative depth in the period after tick size optimization has been below the level before optimization, and as a result of the impact of the market environment, it is also possible that the cumulative depth after tick size optimization for TOPIX Mid 400 constituents had declined.

[35] We tested the median cumulative depth by liquidity group. Since we cannot assume the distribution of cumulative depth to be a normal distribution, we tested using the Wilcoxon signed-rank test.

[36] It is considered that for stocks with the highest liquidity that the distance from the midpoint of the best quoted price for each N after tick size optimization becomes shorter to a certain extent in accordance with the ratio of change in tick size. Theoretically, the distance from the midpoint of the best quoted price to the 10th quoted price for stocks that had a 50% reduction in tick size is thought likely to be close to the distance to the 5th quoted price before tick size optimization, we analyzed up until the quoted price before tick size optimization.

Table 4.16 Test (Wilcoxon signed-rank test) for the difference before and after tick size optimization for cumulative depth (median)

			Ask					Bid				
			1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
All Mid 400	90% reduction	Before change	4,081	8,018				4,013	8,019			
		After the change	2,507***	8,784***				2,768***	8,537			
		p-value	0.00	0.00				0.00	0.66			
		Number of samples	102	69				102	69			
	80% reduction	Before change	3,203	8,892	9,842			3,215	9,042	10,542		
		After the change	2,166***	9,878***	12,838***			2,241***	10,032***	13,508***		
		p-value	0.00	0.00	0.00			0.00	0.00	0.00		
		Number of samples	84	84	23			84	84	30		
	50% reduction	Before change	1,619	4,721	8,352	12,362	16,653	1,587	4,697	8,475	12,874	17,699
		After the change	697***	4,669***	9,045	13,507	18,203	1,230***	4,574***	8,749***	13,378***	18,315***
		p-value	0.00	0.00	0.11	0.39	0.37	0.00	0.00	0.01	0.01	0.00
		Number of samples	206	209	209	209	207	209	209	209	209	208
Group 1	90% reduction	Before change	6,174	9,486				6,135	10,219			
		After the change	3,588***	11,056**				3,567***	9,737			
		p-value	0.00	0.05				0.00	0.32			
		Number of samples	39	22				39	22			
	80% reduction	Before change	5,756	15,711	25,243			5,712	14,979	25,562		
		After the change	4,071***	17,257	31,396*			4,633***	18,895	37,501**		
		p-value	0.00	0.43	0.06			0.00	0.37	0.02		
		Number of samples	28	28	5			28	28	7		
	50% reduction	Before change	2,992	9,619	16,767	24,225	31,872	2,790	8,734	15,784	22,657	29,550
		After the change	1,061***	8,198***	15,992***	23,161***	30,129***	1,865***	7,556***	14,325***	21,587***	29,177***
		p-value	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
		Number of samples	63	63	63	63	62	63	63	63	63	62
Group 2	90% reduction	Before change	3,465	6,320				3,616	6,369			
		After the change	2,717***	7,571				2,649***	7,293			
		p-value	0.00	0.15				0.00	0.81			
		Number of samples	32	20				32	20			
	80% reduction	Before change	3,298	9,015	13,083			3,235	9,203	15,098		
		After the change	2,165***	9,620**	13,961**			2,410***	10,595***	16,968**		
		p-value	0.00	0.04	0.02			0.00	0.01	0.04		
		Number of samples	29	29	7			29	29	8		
	50% reduction	Before change	1,581	4,612	8,229	12,174	16,640	1,566	4,345	7,690	11,581	16,082
		After the change	703***	4,895***	9,223	13,626	18,203	1,274***	4,660***	8,803	13,283	18,164
		p-value	0.00	0.00	0.30	0.14	0.11	0.00	0.01	0.83	0.73	0.78
		Number of samples	71	72	72	72	71	72	72	72	72	72
Group 3	90% reduction	Before change	2,364	5,878				2,590	6,204			
		After the change	1,785***	7,460***				1,920***	7,372			
		p-value	0.00	0.00				0.00	0.19			
		Number of samples	31	27				31	27			
	80% reduction	Before change	1,675	4,458	7,521			1,617	4,748	8,445		
		After the change	1,087***	5,919***	9,808***			1,163***	6,016***	11,255***		
		p-value	0.00	0.00	0.01			0.00	0.00	0.00		
		Number of samples	27	27	11			27	27	15		
	50% reduction	Before change	956	2,613	4,760	7,346	9,995	927	2,712	4,878	7,720	10,977
		After the change	483***	2,723***	5,157	7,799	10,617	759***	2,523***	5,035	8,081	11,401
		p-value	0.00	0.00	0.61	0.98	0.74	0.00	0.00	0.99	0.63	0.16
		Number of samples	72	74	74	74	74	74	74	74	74	74
Large70	Unchanged	Before change	1,512	4,901	8,952	13,337	17,892	1,530	4,551	8,515	12,666	16,717
		After the change	1,077***	3,885***	7,555***	11,669***	15,960***	1,056***	3,680***	6,977***	10,609***	14,307***
		p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Number of samples	70	70	70	70	70	70	70	70	70	70

*** p < 0.01, ** p < 0.05, * p < 0.10

4.5.3 Multiple regression analysis for cumulative depth

To exclude the impact of the market environment, etc. on after tick size optimization, we add data for TOPIX Large 70 as the control group to each group (1 – 3) and conduct a multiple regression analysis taking log(cumulative depth_after change) as the explained variable, log(cumulative depth_before change) as the explanatory variable and a 50% tick reduction (dummy variable), an 80% tick reduction (dummy variable), and a 90% tick reduction (dummy variable).

Analytical results are as follows. For all analytical results, a 90% tick reduction (dummy variable) was significant and negative for the Bid and Ask log(cumulative depth 1st_after the change), and for stocks with a 90% reduction in tick size, we found that the cumulative depth for the distance from the midpoint of the best quoted price before tick size optimization to the 1st quoted price (the best

quoted price) declined (-13% to -10% reduction[37] compared to before tick size optimization from the analytical results for All Mid 400). In addition, we found that cumulative depth for 2nd and beyond was significant and positive for all groups. A roughly similar trend was found when considered in terms of groups by liquidity, with a 50% tick reduction (dummy variable) for Group 1 (high liquidity) log(cumulative depth 1st_after the change) having 5% significance and negative.

Table 4.17 Results of the multiple regression analysis of cumulative depth (All Mid 400)

	Ask					Bid				
	log(cumulative depth 1st_after the change)	log(cumulative depth 2nd_after the change)	log(cumulative depth 3rd_after the change)	log(cumulative depth 4th_after the change)	log(cumulative depth 5th_after the change)	log(cumulative depth 1st_after the change)	log(cumulative depth 2nd_after the change)	log(cumulative depth 3rd_after the change)	log(cumulative depth 4th_after the change)	log(cumulative depth 5th_after the change)
log(cumulative depth 1st_before change)	0.952***	-	-	-	-	0.935***	-	-	-	-
log(cumulative depth 2nd_before change)	-	0.980***	-	-	-	-	0.950***	-	-	-
log(cumulative depth 3rd_before change)	-	-	1.009***	-	-	-	-	0.969***	-	-
log(cumulative depth 4th_before change)	-	-	-	1.004***	-	-	-	-	0.959***	-
log(cumulative depth 5th_before change)	-	-	-	-	1.004***	-	-	-	-	0.962***
50% tick reduction (dummy variable)	-0.033	0.104***	0.130***	0.116***	0.104***	-0.024	0.116***	0.141***	0.121***	0.102***
80% tick reduction (dummy variable)	-0.080**	0.276***	0.340***	-	-	-0.031	0.356***	0.416***	-	-
90% tick reduction (dummy variable)	-0.140***	0.322***	-	-	-	-0.098***	0.284***	-	-	-
No. Observations	465	432	302	279	277	465	432	309	279	278
R-squared	0.958	0.965	0.969	0.971	0.974	0.956	0.963	0.966	0.969	0.972
Adj. R-squared	0.958	0.965	0.969	0.971	0.974	0.956	0.962	0.966	0.968	0.972

*** p < 0.01, ** p < 0.05, * p < 0.10

[37] Since we take the logarithm in relation to the explained variable, the impact of the 90% tick reduction (dummy variable) on the cumulative depth after tick size optimization is multiplied by $e^{-0.140} \sim e^{-0.098}$.

Table 4.18 Results of the multiple regression analysis of cumulative depth (Group 1)

	Ask					Bid				
	log(cumulative depth 1st_after the change)	log(cumulative depth 2nd_after the change)	log(cumulative depth 3rd_after the change)	log(cumulative depth 4th_after the change)	log(cumulative depth 5th_after the change)	log(cumulative depth 1st_after the change)	log(cumulative depth 2nd_after the change)	log(cumulative depth 3rd_after the change)	log(cumulative depth 4th_after the change)	log(cumulative depth 5th_after the change)
log(cumulative depth 1st_before change)	0.970***	-	-	-	-	0.951***	-	-	-	-
log(cumulative depth 2nd_before change)	-	0.996***	-	-	-	-	0.966***	-	-	-
log(cumulative depth 3rd_before change)	-	-	1.028***	-	-	-	-	0.977***	-	-
log(cumulative depth 4th_before change)	-	-	-	1.026***	-	-	-	-	0.970***	-
log(cumulative depth 5th_before change)	-	-	-	-	1.026***	-	-	-	-	0.967***
50% tick reduction (dummy variable)	-0.091**	0.066**	0.076***	0.067**	0.061**	-0.088**	0.061*	0.076**	0.070**	0.064**
80% tick reduction (dummy variable)	-0.086	0.208***	0.304***	-	-	-0.016	0.299***	0.491***	-	-
90% tick reduction (dummy variable)	-0.206***	0.257***	-	-	-	-0.132**	0.242***	-	-	-
No. Observations	200	183	138	133	132	200	183	140	133	132
R-squared	0.964	0.976	0.979	0.979	0.981	0.964	0.972	0.974	0.974	0.976
Adj. R-squared	0.963	0.976	0.979	0.979	0.980	0.963	0.972	0.973	0.974	0.975

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 4.19 Results of the multiple regression analysis of cumulative depth (Group 2)

	Ask					Bid				
	log(cumulative depth 1st_after the change)	log(cumulative depth 2nd_after the change)	log(cumulative depth 3rd_after the change)	log(cumulative depth 4th_after the change)	log(cumulative depth 5th_after the change)	log(cumulative depth 1st_after the change)	log(cumulative depth 2nd_after the change)	log(cumulative depth 3rd_after the change)	log(cumulative depth 4th_after the change)	log(cumulative depth 5th_after the change)
log(cumulative depth 1st_before change)	0.992***	-	-	-	-	0.976***	-	-	-	-
log(cumulative depth 2nd_before change)	-	1.037***	-	-	-	-	1.006***	-	-	-
log(cumulative depth 3rd_before change)	-	-	1.042***	-	-	-	-	1.006***	-	-
log(cumulative depth 4th_before change)	-	-	-	1.036***	-	-	-	-	0.999***	-
log(cumulative depth 5th_before change)	-	-	-	-	1.032***	-	-	-	-	0.996***
50% tick reduction (dummy variable)	-0.013	0.143***	0.168***	0.153***	0.140***	0.002	0.161***	0.183***	0.162***	0.144***
80% tick reduction (dummy variable)	-0.114**	0.233***	0.319***	-	-	-0.062	0.315***	0.366***	-	-
90% tick reduction (dummy variable)	-0.208***	0.257***	-	-	-	-0.141***	0.239***	-	-	-
No. Observations	203	191	149	142	141	203	191	150	142	142
R-squared	0.949	0.960	0.967	0.970	0.972	0.953	0.962	0.966	0.969	0.972
Adj. R-squared	0.948	0.960	0.967	0.969	0.972	0.952	0.961	0.965	0.968	0.972

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 4.20 Results of the multiple regression analysis of cumulative depth (Group 3)

	Ask					Bid				
	log(cumulative depth 1st_after the change)	log(cumulative depth 2nd_after the change)	log(cumulative depth 3rd_after the change)	log(cumulative depth 4th_after the change)	log(cumulative depth 5th_after the change)	log(cumulative depth 1st_after the change)	log(cumulative depth 2nd_after the change)	log(cumulative depth 3rd_after the change)	log(cumulative depth 4th_after the change)	log(cumulative depth 5th_after the change)
log(cumulative depth 1st_before change)	1.026***	-	-	-	-	0.983***	-	-	-	-
log(cumulative depth 2nd_before change)	-	1.046***	-	-	-	-	1.004***	-	-	-
log(cumulative depth 3rd_before change)	-	-	1.060***	-	-	-	-	1.025***	-	-
log(cumulative depth 4th_before change)	-	-	-	1.047***	-	-	-	-	1.005***	-
log(cumulative depth 5th_before change)	-	-	-	-	1.043***	-	-	-	-	1.005***
50% tick reduction (dummy variable)	0.021	0.129***	0.160***	0.135***	0.115***	0.016	0.139***	0.181***	0.138***	0.105***
80% tick reduction (dummy variable)	-0.093*	0.344***	0.369***	-	-	-0.063	0.405***	0.400***	-	-
90% tick reduction (dummy variable)	-0.137***	0.367***	-	-	-	-0.136***	0.293***	-	-	-
No. Observations	202	198	155	144	144	202	198	159	144	144
R-squared	0.947	0.963	0.970	0.974	0.976	0.934	0.957	0.969	0.972	0.975
Adj. R-squared	0.946	0.963	0.970	0.974	0.976	0.932	0.956	0.968	0.972	0.975

*** p < 0.01, ** p < 0.05, * p < 0.10

4.6 Change in investment behavior of investors, etc.

From the analytical results, etc. to date, we have found that the nominal spread and effective spread narrow after tick size optimization, while depth also declines according to the change in tick size. Next, we verify how investor behavior has changed before and after tick size optimization.

4.6.1 No. of orders[38]

There is an increase in prices at which orders can be made due to tick size optimization and depth declines due to the distribution of orders. As a result, since the circumstances are more likely to result in stock price fluctuations (1 tick movement in stock price), there has likely been a particular increase in the number of orders by HFT (High Frequency Trading) traders[39], etc., who conduct trading through algorithms.

Table 4.21 summarizes the number of orders before and after tick size optimization. This highlights how the number of orders increases depending on the level of tick size reduction and liquidity. In addition, most of the increase in the number of orders is attributed to HFT traders.

[38] No. of orders includes new orders, change orders, and cancellation orders.

[39] HFT traders here refer to firms registered as high-speed traders that engage in high-speed trading activities and as defined in the Financial Instruments and Exchange Law.

Table 4.21 No. of orders/business days and stocks for each group in the period before and after tick size optimization

	No. of orders			No. of orders (HFT)			No. of orders (non-HFT)		
	Before change	After the change	After/before	Before change	After the change	After/before	Before change	After the change	After/before
Total sample									
90% reduction	30,816	109,582	3.6	20,219	90,230	4.5	10,598	19,352	1.8
80% reduction	28,485	69,756	2.4	20,090	57,121	2.8	8,395	12,636	1.5
50% reduction	52,246	77,852	1.5	39,003	62,100	1.6	13,243	15,752	1.2
Group 1									
90% reduction	41,056	164,017	4.0	26,066	137,145	5.3	14,990	26,872	1.8
80% reduction	42,421	118,009	2.8	28,416	96,558	3.4	14,005	21,452	1.5
50% reduction	78,853	124,156	1.6	57,215	98,794	1.7	21,638	25,362	1.2
Group 2									
90% reduction	28,768	91,523	3.2	18,782	73,580	3.9	9,986	17,943	1.8
80% reduction	25,997	55,902	2.2	18,892	45,706	2.4	7,104	10,196	1.4
50% reduction	49,715	72,616	1.5	37,535	58,036	1.5	12,180	14,580	1.2
Group 3									
90% reduction	19,388	56,229	2.9	13,967	45,368	3.2	5,420	10,861	2.0
80% reduction	16,706	34,597	2.1	12,741	28,484	2.2	3,964	6,114	1.5
50% reduction	32,057	43,526	1.4	24,927	34,814	1.4	7,130	8,712	1.2
Large 70									
No change in tick size	157,167	201,869	1.3	116,042	156,929	1.4	41,125	44,940	1.1

In addition, Table 4.22 shows the aggregates by new orders, change orders and cancellation orders for the number of orders. There is an overall increase in the number, but this highlights the particularly pronounced increase in the number of cancellation orders.

Table 4.22 Number of new orders, change orders, cancellation orders/business days and stocks for each group during the period before and after tick size optimization

	No. of new orders			No. of change orders			No. of cancellation orders		
	Before change	After the change	After/before	Before change	After the change	After/before	Before change	After the change	After/before
Total sample									
90% reduction	18,179	57,113	3.1	1,621	6,229	3.8	11,016	46,240	4.2
80% reduction	16,482	36,852	2.2	1,347	3,326	2.5	10,656	29,579	2.8
50% reduction	28,970	41,532	1.4	2,508	3,916	1.6	20,767	32,404	1.6
Group 1									
90% reduction	24,366	85,975	3.5	2,320	8,215	3.5	14,370	69,827	4.9
80% reduction	24,854	63,187	2.5	2,273	4,637	2.0	15,295	50,185	3.3
50% reduction	44,312	67,060	1.5	4,006	5,472	1.4	30,534	51,624	1.7
Group 2									
90% reduction	16,996	47,734	2.8	1,485	5,554	3.7	10,288	38,234	3.7
80% reduction	14,903	29,252	2.0	1,129	2,873	2.5	9,965	23,777	2.4
50% reduction	27,353	38,461	1.4	2,290	3,736	1.6	20,073	30,418	1.5
Group 3									
90% reduction	11,218	28,623	2.6	839	4,299	5.1	7,331	23,307	3.2
80% reduction	9,497	17,704	1.9	621	2,451	3.9	6,588	14,442	2.2
50% reduction	17,483	22,787	1.3	1,446	2,767	1.9	13,128	17,973	1.4
Large 70									
No change in tick size	86,359	108,962	1.3	9,305	10,460	1.1	61,504	82,447	1.3

Next we confirm how the proportion of the total number of orders has changed in regard to change and cancellation orders, for which the number of orders has increased. Figure 4.15 shows what we have confirmed for each group taking the ratio of change orders to be the number of change orders/ number of orders and the ratio of cancellation orders to be the number of cancellation orders /number of orders.

The ratio of change orders after tick size optimization was comparatively high for Group 3, and the ratio of change orders tends to increase the larger the absolute value of the tick size reduction. Undertaking a multiple regression analysis taking the actual ratio of change orders after tick size

optimization as the explained variable shows that the coefficient of the tick size change (dummy variable) was positive with a significant difference. In addition, the absolute value of the 50% tick reduction (dummy variable) coefficient<the absolute value of the 80% tick reduction (dummy variable) coefficient< absolute value of the 90% tick reduction (dummy variable) coefficient, and there is a tendency for the impact to differ according to the level of tick size reduction. In addition, in setting the dummy variable for the low-liquidity stock group (Group 3) and the high-liquidity stock group (Group 1), the dummy variable for the low-liquidity stock group was significant and positive, whereas the dummy variable for the high-liquidity stock group was significant and negative. Therefore, we verified that the ratio of change orders tended to increase after tick size optimization for the low-liquidity stock group.

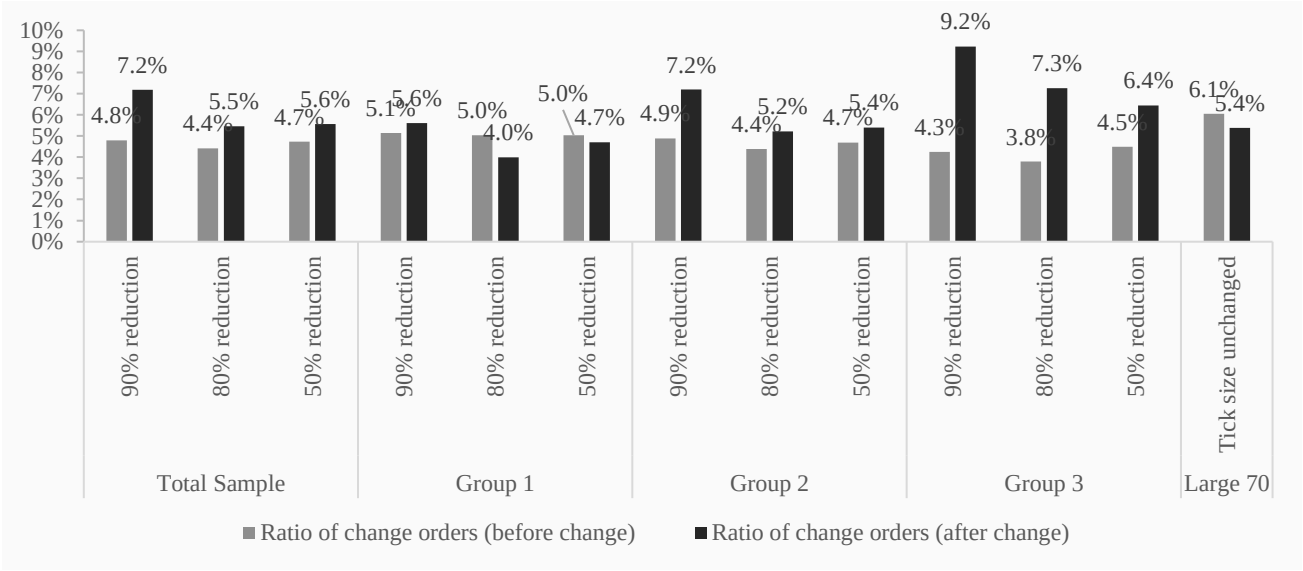

Figure 4.15 Change in the ratio of change orders

On the other hand, the ratio of cancellation orders was generally in a range of 40.6% to 42.7% after tick size optimization, and there was not a large impact from the level of tick size reduction. On conducting a multiple regression analysis of the ratio of cancellation orders after tick size optimization in the same way as for the ratio of change orders, the coefficients for an 80% tick reduction (dummy variable) and a 90% tick reduction (dummy variable) were positive and significant. In addition, in contrast to the liquidity dummy for change orders, the dummy variable for the low-liquidity stock group was significant and negative, while the dummy variable for the high-liquidity stock group was significant and positive.

Therefore, investors (here, considered mainly to be investors that trade through HFT and programs, placing orders mechanically) tend to reissue new orders after cancelling existing orders for high-liquidity stocks, placing more cancellation orders than change orders, while tending to respond with change orders for low-liquidity stocks.

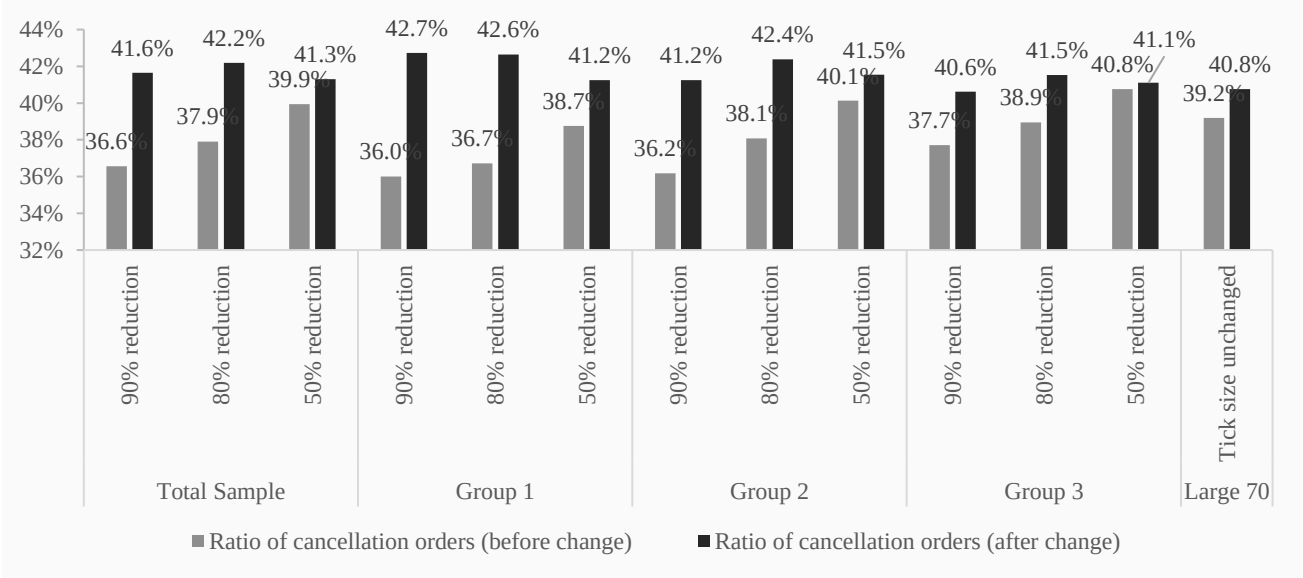

Figure 4.16 Change in the ratio of cancellation order

4.6.2 Order volume per order

We were able to confirm that the depth for each tick declines due to tick size optimization, and since this is likely to result in investors changing their order volume per order, we confirm the change in order volume per order before and after tick size optimization. In addition, we also confirm the change in the orders for which there is higher intent (new market orders, orders that triggered the execution during trading hours (Take Orders)).

The results are shown in below. We found that the levels of decline in the order volume/No. of orders (all) and the order volume/No. of orders (Take) differ according to the level of tick size reduction. In addition, we found there was virtually no change[40] in order volume/No. of orders (new market orders). Since there is virtually no use of market orders by HFT traders and institutional investors, etc., these are mainly considered to be orders placed by individual investors, and it is possible that there has been no change in the order volume, etc. for individual investors.

[40] We conducted a t-test of the difference before and after optimization for order volume/No. of orders (new market orders) in relation to all groups. We confirmed a difference with 5% significance for Group 1 (90% reduction), Group 3 (80% reduction), and Group 3 (50% reduction), but there was no significance for other groups.

Table 4.23 Order volume per order by group during the period before and after tick size optimization

	Order volume/No. of orders (all)			Order volume/No. of orders (new market orders)			Order volume/No. of orders (Take)		
	Before change	After the change	After/before	Before change	After the change	After/before	Before change	After the change	After/before
Total sample									
90% reduction	2,893	1,198	0.41	1,027	943	0.92	1,080	563	0.52
80% reduction	1,290	803	0.62	598	630	1.05	540	358	0.66
50% reduction	1,469	1,067	0.73	795	808	1.02	593	468	0.79
Group 1									
90% reduction	3,214	1,105	0.34	1,288	1,040	0.81	1,337	618	0.46
80% reduction	1,706	943	0.55	846	865	1.02	761	476	0.63
50% reduction	1,815	1,270	0.70	1,110	1,078	0.97	810	618	0.76
Group 2									
90% reduction	3,194	1,385	0.43	1,006	1,035	1.03	1,123	586	0.52
80% reduction	1,216	807	0.66	564	594	1.05	499	344	0.69
50% reduction	1,461	1,058	0.72	796	813	1.02	566	443	0.78
Group 3									
90% reduction	2,156	1,126	0.52	705	719	1.02	697	466	0.67
80% reduction	937	655	0.70	376	423	1.13	354	250	0.71
50% reduction	1,181	902	0.76	525	572	1.09	435	366	0.84
Large 70									
No change in tick size	1,470	1,323	0.90	1,327	1,350	1.02	759	704	0.93

4.6.3 Relationship between order volume per order and depth

The following plots the relationship between order volume per order and the ratio of depth (1st) before and after tick size optimization (after the change/before the change) This shows that such relationship is clear for groups where the level of tick size reduction was -80% and -90%, while order volume per order also declined proportionally to the decline in depth 1st (with a similar trend for Take Orders).

On conducting a similar multiple regression analysis taking order volume per order after tick size optimization as the explained variable, we found that the 50% tick reduction (dummy variable), 80% tick reduction (dummy variable), and 90% tick reduction (dummy variable) were all significant and negative, while there was no significance for the liquidity dummy variables (dummy variable for low-liquidity stock group, dummy variable for high-liquidity stock group). In addition, the significance was negative in relation to depth (1st), with the results showing that the larger the depth before tick size optimization the greater the decline in order volume per order after tick size optimization. Therefore, this suggests that order volume per order is not much influenced by liquidity (trading volume), but more determined by the size of depth and the impact from the change in tick size.

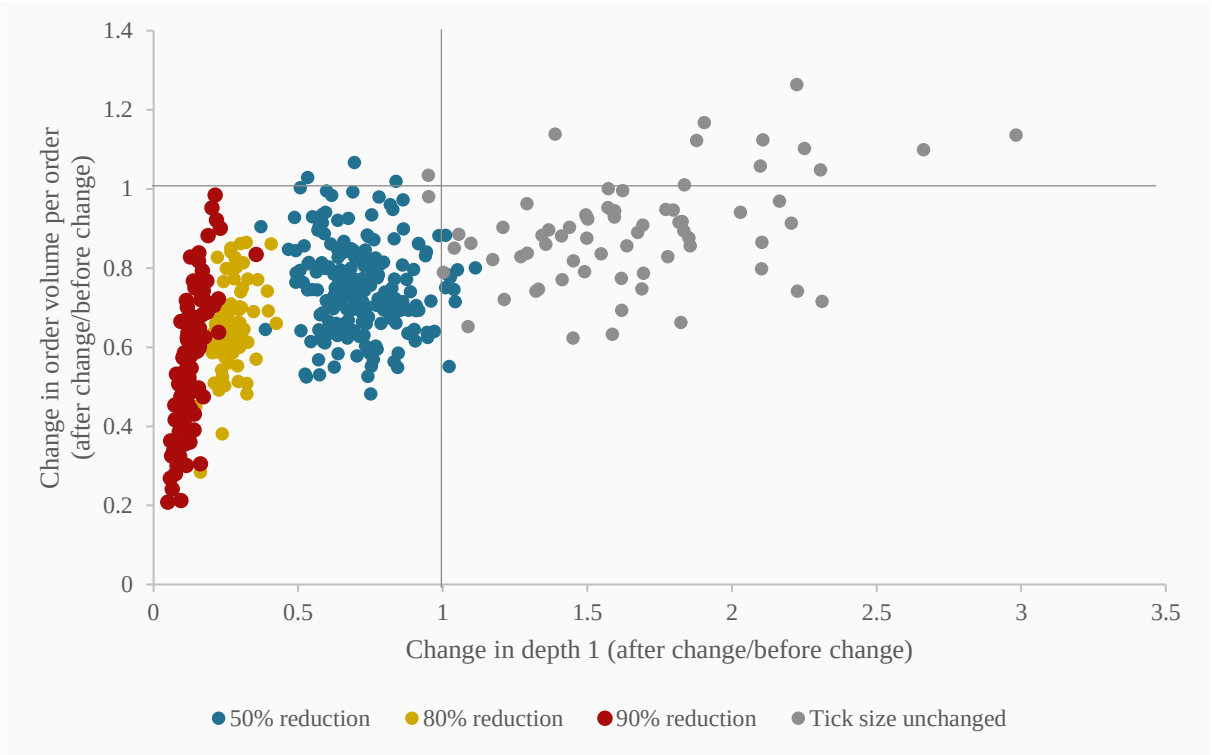

Figure 4.17 Relationship with order volume per order and change in Depth 1st

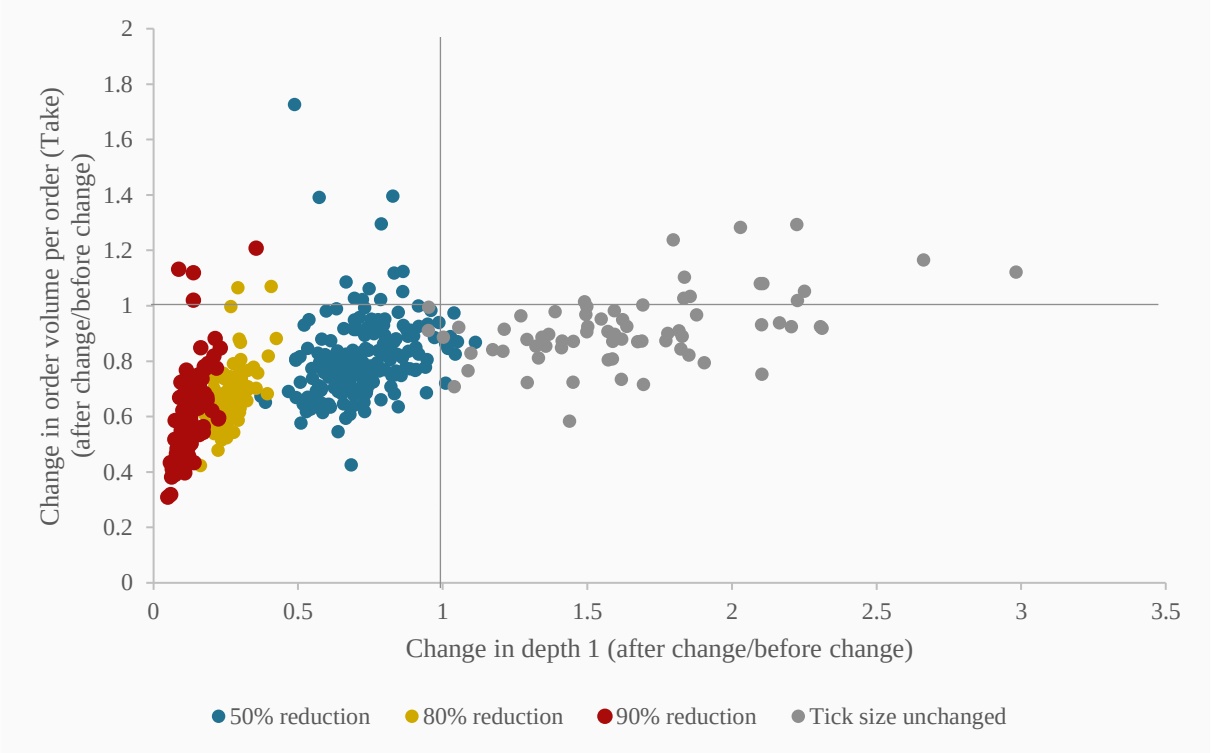

Figure 4.18 Relationship with order volume per order (Take) and change in Depth 1st

4.6.4 Order volume per order (Take) and cumulative depth

We were able to confirm that depth after tick size optimization declines due to the dispersal of orders attributed to tick size optimization, which consequently resulted in a decline in order volume per order. From the analytical results to date (4.5.3), we are able to confirm that the cumulative depth after tick size optimization up until the distance of depth (1st) before tick size optimization declined for Groups 1 to 3 (80% tick reduction and 90% tick reduction) and this confirms the relationship between the cumulative depth that declined after tick size optimization and the order volume per order for Take Orders for which there is high order intent. Specifically, even in the case of order volume per order before tick size optimization, we confirm whether or not the depth of the order book after tick size optimization is sufficient to absorb the impact.

Order volume per order (Take) after tick size optimization declined due to a reduction in depth, but Figure 4.19 to Figure 4.21 confirm through a comparison of order volume per order (Take) before tick size optimization and cumulative depth after tick size optimization confirms that the order book had sufficient depth (cumulative depth[41]) even for the order volume before tick size optimization. The 50th percentile (median) and 99th percentile[42] relative to the period before optimization of stocks included in the respective samples are indicated for order volume per order (Take).

The 50th percentile of the order volume per order (Take) before tick size optimization is roughly about the same level as depth (1st) after tick size optimization, which confirms that Take Orders benefit from a reduction in execution costs due to tick size optimization. In addition, there were large deviations at the 50th percentile and 90th percentile for order volume per order (Take) for stock groups with a tick size reduction of -90% for all groups. Even when calculating the cumulative depth after tick size optimization for the 99th percentile, the execution costs (Effective spread) declined[43].

[41] Here, we use the average cumulative depth of bid and ask for cumulative depth.

[42] **The 50th percentile and 99th percentile for the average price during the period** for stocks included in the sample. Note that this is not the 50th percentile and 99th percentile of the order volume per order (Take) during the analysis period for each sample (stocks) (the distribution of the average price during the period declined(1/n times)).

[43] For example, in the case of a 90% reduction in tick for Group 1, and assuming an order placed at the 99th percentile (7,450 stocks) for order volume (Take) before tick size optimization, the effective spread before tick size optimization would be 1.16bps and the effective spread after tick size optimization would be 8.85bps (-21%).

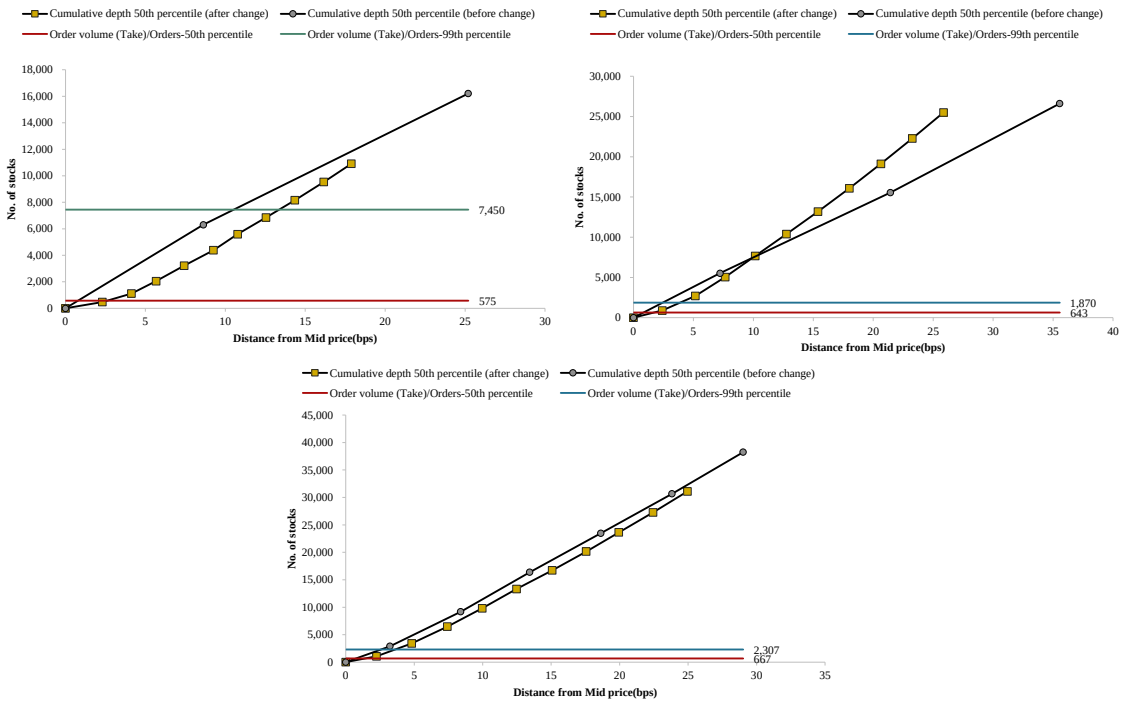

Figure 4.19 Cumulative depth and order volume per order (Take) before tick size optimization (Group 1(Upper left: 90% reduction in tick size, Upper right: 80% reduction in tick size, Lower: 50% reduction in tick size))

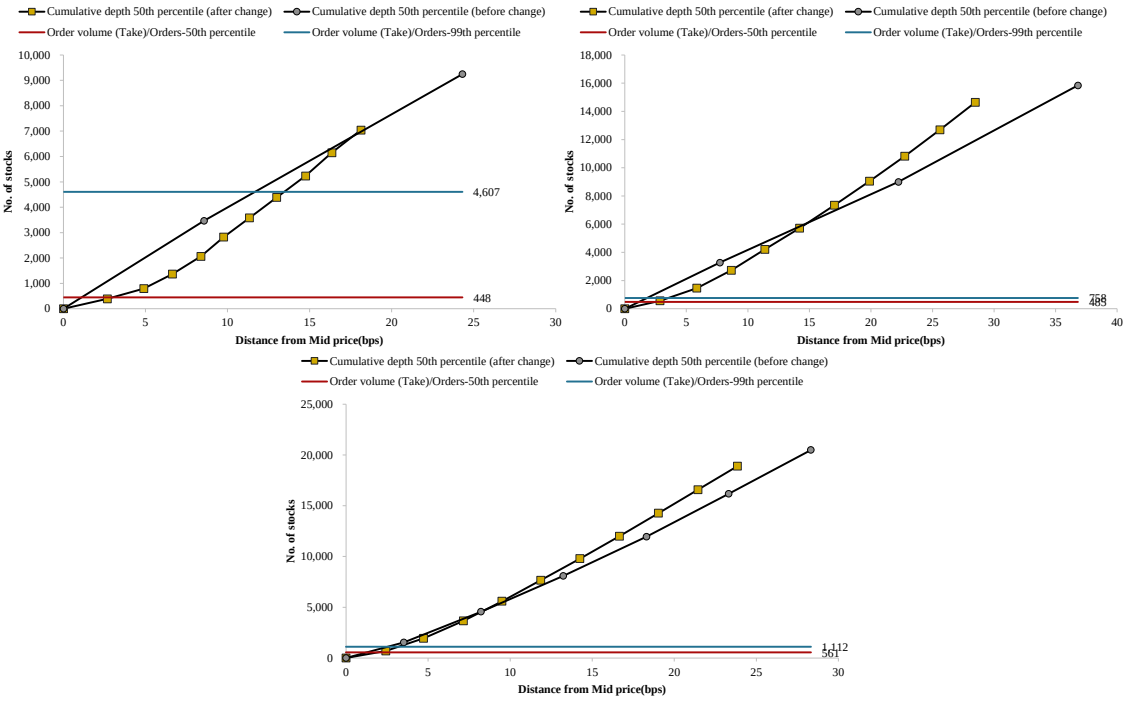

Figure 4.20 Cumulative depth and order volume per order (Take) before tick size optimization (Group 2(Upper left: 90% reduction in tick size, Upper right: 80% reduction in tick size, Lower: 50% reduction in tick size))

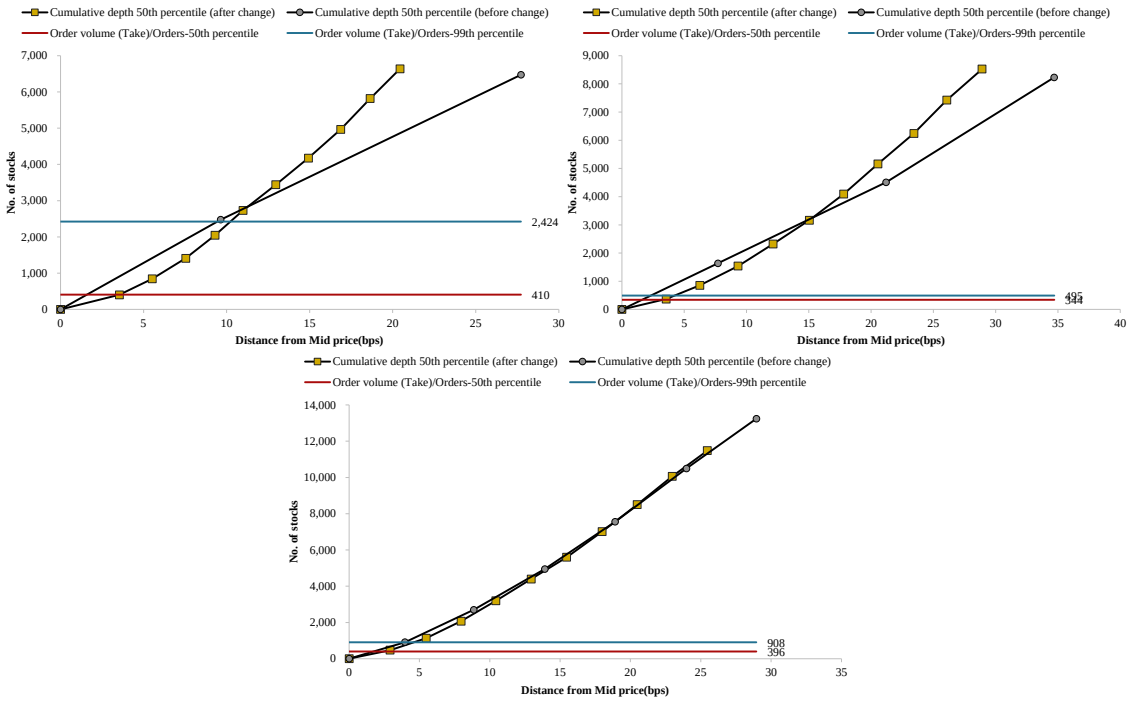

Figure 4.21 Cumulative depth and order volume per order (Take) before tick size optimization (Group 3(Upper left: 90% reduction in tick size, Upper right: 80% reduction in tick size, Lower: 50% reduction in tick size))

5 Assessment of the impact forecasts using data for ETFs, etc.

Wakamatsu (2022) forecasted the impact of ick size optimization on TOPIX Mid 400 constituents. At the time we forecast using the models (multiple regression analysis model and neural network model (NN model)) created from data for ETFs, etc. (top group in terms of trading value), and we assess using these two models. Specifically, we enter the data for TOPIX Mid 400 constituents before tick size optimization into both models and obtain the estimates for effective spread and STR after tick size optimization and compare with the actual values.

5.1 Effective spread

The variables used in the model created with the ETFs, etc. data are “Effective spread (pre-change), Depth (1st), trading volume per order, 50% tick reduction (dummy variable), 80% or more tick reduction (dummy variable).” These variables are calculated using the data for TOPIX Mid 400 constituents before tick size optimization, with the forecast values obtained by insertion into the models.

Table 5.1 shows the results. The forecast effective spread after tick size optimization is close to the real data under the multiple regression analysis model. On the other hand, the forecast effective spread was much larger than the real data for all models, which may not have been able to fully reflect the features of the TOPIX Mid 400 constituents.

Table 5.1 Forecast effective spread after tick size optimization for each model

	Effective spread (Average before the period) (bps)	**Forecast** effective spread (Average after the period) (bps)	After vs. before (bps)	**Forecast** change in effective spread (One business day average, Units:¥)
Multiple regression analysis model	6.59[44]	3.80	-2.79	-324,147,085
NN model		4.77	-1.82	-211,976,053
	Effective spread (Average before the period) (bps)	Effective spread (Average after the period) (bps)	After vs. before (bps)	Change in effective spread (One business day average, Units:¥)
Real data	6.59[44]	3.15[44]	-3.44	-401,019,794[44]

[44] To eliminate the impact from tick size change on stocks, etc. that transition to a stock price range with a changed tick size, the data is calculated by excluding data, etc. following transition to a different stock price range.

In addition, Table 5.2 shows the results of the model performance evaluation. Better results were obtained for the root mean squared error[45]and mean absolute error[46] with the multiple regression analysis model, while better results for the coefficient of determination[47] were obtained with the NN model.

Figure 5.1 is a graph that plots the forecast value from both models and the actual value. In terms of deviation from the regression line, we found there was a smaller deviation with the NN model, but there was a small deviation from the actual value with the multiple regression analysis model.

Table 5.2 Model performance evaluation (Effective spread)

	Root mean squared error	Mean absolute error	Coefficient of determination(R^2)
Multiple regression analysis model	1.23	0.97	0.12
NN model	2.70	1.92	0.32

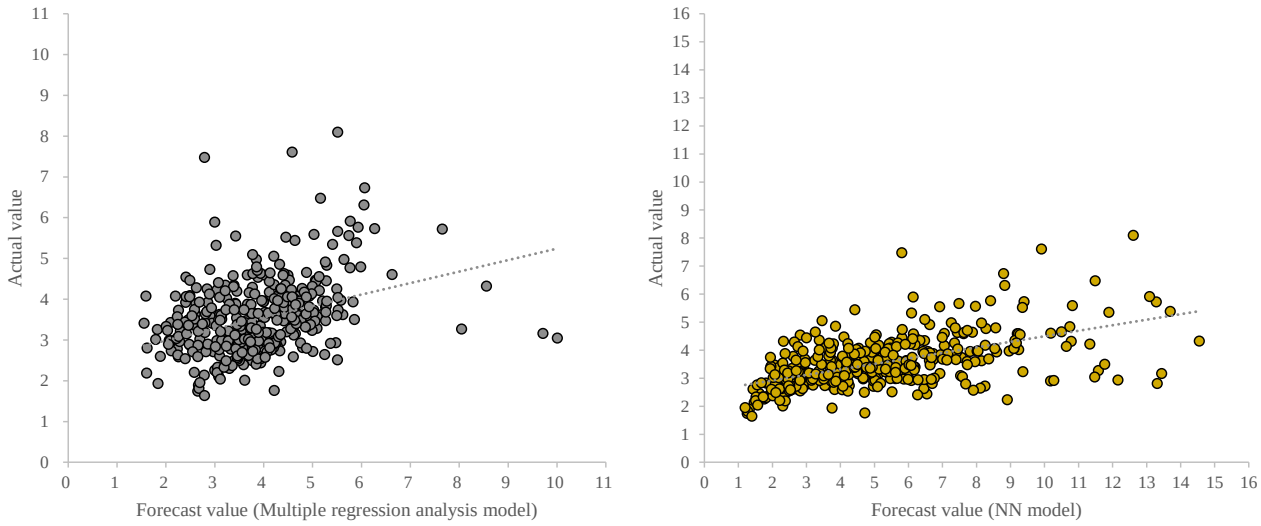

Figure 5.1 Forecast value and actual value for the effective spread according to the model (Left: Multiple regression analysis model, Right: NN model)

[45] This is also referred to as Root Mean Square Error (RMSE). Calculated with $RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$ taking y_i: actual value for sample i, $\hat{y}_i$: forecast value for sample i, and n: total sample number. This indicates that the model performs better the smaller the values. If the sample includes many outliers, there is a tendency for RMSE to also become much larger.

[46] This is referred to as Mean Absolute Error (MAE). Calculated with $MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$ taking y_i: actual value for sample i, $\hat{y}_i$: forecast value for sample i, and n: total sample number. This indicates that the model performs better the smaller the values.

[47] Coefficient of determination(R^2) is calculated with $R^2 = 1 - \sum_{i=1}^{n}\frac{(y_i-\hat{y}_i)^2}{(y_i-\bar{y})^2}$ taking y_i: actual value of sample i, $\hat{y}_i$: forecast value of sample i, and $\bar{y}$: average price of actual value. The performance of a model is indicated as good when it is close to 1 where 1 is the assessment of the ability to forecast all coefficients of determination.

5.2 STR

The variables used in the STR forecast model created with the ETFs, etc. data are "STR (pre-change), Depth (1st), 50% tick reduction (dummy variable), 80% or more tick reduction (dummy variable)." We extract the STR forecast value after tick size optimization using these variables for TOPIX Mid 400 constituents and compare the models as we did for effective spread.

Table 5.3 shows the results. The forecast STR from both models is larger than the actual STR, but the forecast STR from the NN model is closer to the actual STR.

Table 5.3 Forecast STR after tick optimization for each model

	STR (Average before the period)	**Forecast STR** (Average after the period)	After vs. before
Multiple regression analysis model	1.26	5.92	4.66
NN model		3.57	2.31
	STR (Average before the period)	STR (Average after the period)	After vs. before
Real data	1.26	2.65	1.39

Table 5.4 shows the result of the assessment of the model as we did for effective spread. Although the NN model is smaller and superior for root mean square error and mean absolute error, the coefficient of determination is virtually 0, and it does not have meaning as a model.

Confirming the data that largely deviated from the actual value under the NN model, there were stocks where STR before tick size optimization was extremely low (close to 1) and depth (1st) was extremely large. Since this model has learned from ETFs, etc. data comprised of many comparatively low-liquidity stocks, it has not been able to sufficiently learn from that type of data and consequently been unable to forecast very well.

In addition, for the multiple regression analysis model, as shown in Figure 5.2, although there is not such a large deviation from the regression line, the forecast minimum STR is close to 4, which can confirm a large deviation of the minimum value from the actual value. This is considered to be largely affected by the dummy variable for the level of reduction in the tick size. This is considered likely to be the result of ETFs, etc. having low liquidity compared to TOPIX Mid 400 constituents[48], and the increase in the regression coefficient for the dummy variable in the model as a result of the strong impact from the level of reduction in tick size, leading to an overestimation of the impact.

[48] In the analysis of ETFs, etc. (2022 (Wakamatsu)) the median trading value of the high-liquidity group was ¥170 million/day, while this time, the median trading value of the high-liquidity group of the TOPIX Mid 400 constituents is ¥4.27 billion/day and the median trading value for the low-liquidity group is ¥700 million/day. In terms of liquidity, TOPIX Mid 400 constituents is higher.

Table 5.4 Model performance evaluation (STR)

	Root mean squared error	Mean absolute error	Coefficient of determination (R2)
Multiple regression analysis model	3.46	3.35	0.36
NN model	2.74	1.55	0.00

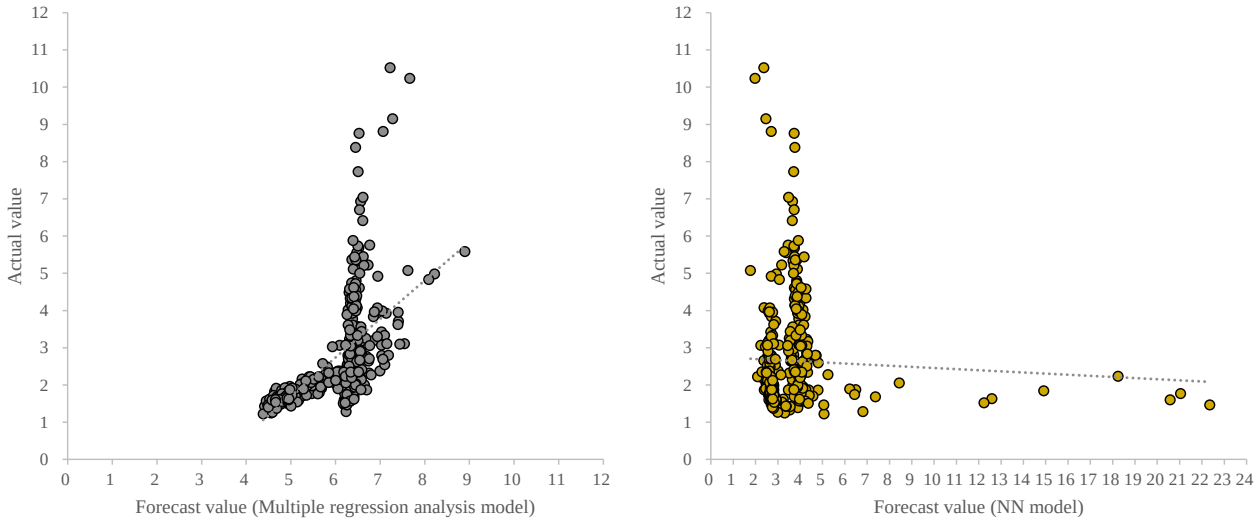

Figure 5.2 Forecast value and actual value for the STR according to the model
(Left: Multiple regression analysis model, Right: NN model)

6 Conclusion

We conducted analysis of the impact on investor execution costs and the market from the application of a tick table with smaller tick size for TOPIX Mid 400 constituents from June 5, 2023, and assessed that these measures reduced investor execution costs (estimated cost cutting of about ¥120 billion per year).

In regard to the impact of tick size optimization for TOPIX Mid 400 constituents, there are many stocks of about 400 also include stocks with comparatively low liquidity, so learning from the analytical results related to tick size optimization for ETFs, etc. conducted on November 29, 2021, it is possible that the impact differs by liquidity. The results of analysis by liquidity group, show similar trends in the analysis of the low-liquidity group as well as the high-liquidity group, with the impact of tick size on TOPIX Mid 400 constituents as a whole, and not just high-liquidity stocks. One reason for the impact of tick size optimization on TOPIX Mid 400 constituents as a whole is considered to be the excessive coarseness of tick size for the TOPIX Mid 400 constituents before tick size optimization. As is clear from the graph on the left in Figure 4.8, more than 80% of the TOPIX Mid 400 constituents had STR below 1.5 before tick size optimization.

In regard to the quoted spread for individual analytical results, there was negative significance for stock groups other than those with a 50% tick size reduction and for the effective spread there was negative significance for all levels of tick size reduction. Therefore, investor execution costs are considered to have been reduced even for trading of low-liquidity stock groups among TOPIX Mid 400 constituents.

In regard to intraday volatility, a significant and negative impact was verified for stock groups with large levels of tick size reduction (-80% and -90%), and volatility was reduced for stocks with large levels of tick size reduction. In addition, all groups had variance ratios of volatility approaching 1, and market efficiency is also considered to have improved.

As described above, the circumstances for STR before tick size optimization had contracted to generally within an optimal range for STR after optimization, and the tick size has not become excessively small after optimization.

In regard to depth, order have been dispersed, so the depth for each tick has declined according to the level of tick size reduction. In regard to cumulative depth, we found having confirmed the cumulative depth after optimization in conjunction with the 1st depth before tick optimization (the distance from the midpoint of the best quoted price) that there has been a decline of about 10 to 13%.

In regard to investor behavior, there has been an increase in orders from investors who mainly conduct trading based on programs, etc., and verified a comparative increase in the ratio of cancellation orders for high-liquidity stock groups and a trend for comparative increase in the ratio of change orders for low-liquidity stock groups. In addition, investor order volume per order (including order volume per order for Take Orders) has been largely affected by the depth of the best quoted price and reduction in tick size. On the other hand, looking at cumulative depth, the level was sufficient to be absorbed even with the order volume per order before tick size optimization, and there was no major

adverse effect on execution costs.

In the analysis related to tick size optimization for ETFs, etc. (Wakamatsu (2022)), the impact forecast from applying the TOPIX 100 tick table to TOPIX Mid 400 constituents was conducted with two models (Multiple regression, NN model), and the analysis this time compared the forecast value and the actual value with such models. The results found that while there were no major outliers in the forecast values using both models, overall, the level of decline in the effective spread was small and there was a large increase in the STR. The data used in the forecast was for ETFs, etc., and as described in this paper, liquidity and other metrics are low compared to TOPIX Mid 400 constituents, and it is possible that the forecast of high-liquidity stocks could not be appropriately achieved. The results of the forecast from the two models have advantages and disadvantages. It is considered useful to have a model ensemble often used in machine learning as one method to improve the forecast accuracy.

As described above, investor execution costs were cut through tick size optimization, and this analysis did not establish that there was a negative impact on stocks with comparatively low liquidity in the TOPIX Mid 400 constituents, which had been a concern. From the results of this analysis, etc., we consider that investor convenience and market efficiency can be improved by setting tick size according to the liquidity of each stock. Tick size is an important and vital component of price formation and investor execution costs, and in overseas countries, appropriate tick sizes between markets are uniformly regulated through laws and ordinances. Therefore, it will be necessary to look at setting appropriate tick sizes according to liquidity as is done overseas while also considering the ease of understanding and operational complexities for market participants, etc.

(Reference) Descriptive statistics

Descriptive statistics for three groups classified in tertiles of trading value and for TOPIX Large 70, which has been added as a control group.

Table 6.1 Top group in terms of trading value (Group 1)

	Before				After			
	Mean	Median	Std.	Count	Mean	Median	Std.	Count
No. of orders	59,385	48,128	36,372	132	135,233	112,192	81,015	132
Order volume (stocks)	48,215,882	30,120,254	55,934,629	132	69,739,739	43,174,107	89,934,458	132
Trading volume (stocks)	5,573,669	2,851,679	10,399,785	132	5,404,474	2,664,375	9,737,208	132
Number executed	8,684	7,211	6,308	132	12,109	9,469	11,053	132
Trading value (¥ million)	6,277	4,234	7,509	132	6,652	4,086	10,398	132
Number of transaction units per contract	516	382	455	132	348	295	187	132
HFT ratio	37.6%	37.8%	5.1%	132	35.6%	35.2%	3.6%	132
Ratio of cancellation orders	37.5%	38.2%	3.5%	132	42.0%	42.5%	2.4%	132
Ratio of change orders	5.1%	4.9%	1.3%	132	4.8%	4.5%	1.5%	132
Order volume/No. of orders (all)	2,227	1,470	2,637	132	1,149	871	818	132
Order volume/No. of orders (new market orders)	1,110	893	901	132	1,021	868	665	132
Order volume/No. of orders (Take)	963	639	1,062	132	588	417	472	132
Quoted spread (bps)	5.8	5.8	2.5	132	2.4	2.3	0.7	132
Effective spread (bps)	7.3	7.1	4.5	132	3.4	3.4	0.8	132
1-minute volatility	1.0×10^{-3}	7.9×10^{-4}	2.0×10^{-3}	132	7.7×10^{-4}	7.2×10^{-4}	2.1×10^{-4}	132
10-minute volatility	3.0×10^{-3}	2.2×10^{-3}	6.1×10^{-3}	132	2.4×10^{-3}	2.3×10^{-3}	6.7×10^{-4}	132
STR	1.1	1.1	0.2	132	2.3	1.8	1.2	132
variance ratio	0.84	0.83	0.15	132	1.00	0.99	0.12	132
Depth (1st)	14,639	4,496	38,327	132	1,531	892	2,219	132
Depth (2nd)	23,240	7,956	55,037	132	3,079	1,740	4,318	132
Depth (3rd)	24,531	9,032	55,325	132	3,872	2,282	5,169	132
Depth (4th)	25,519	10,580	55,072	132	4,222	2,541	5,470	132
Depth (5th)	26,225	11,143	55,215	132	4,501	2,716	6,097	132
Depth (6th)	24,637	10,650	48,266	132	4,624	2,681	6,523	132
Depth (7th)	22,049	8,828	42,698	132	4,821	2,748	6,850	132
Depth (8th)	20,206	8,116	39,946	132	4,981	2,841	7,290	132
Depth (9th)	19,158	8,313	38,856	132	5,193	2,946	7,750	132
Depth (10th)	18,964	7,755	45,634	132	5,224	2,984	7,378	132
50% tick reduction (dummy variable)	0.48	0.00	0.50	132				
80% tick reduction (dummy variable)	0.21	0.00	0.41	132				
90% tick reduction (dummy variable)	0.31	0.00	0.46	132				

Table 6.2 Middle group in terms of trading value (Group 2)

	Before				After			
	Mean	Median	Std.	Count	Mean	Median	Std.	Count
No. of orders	39,504	39,778	16,614	133	73,520	63,509	34,384	133
Order volume (stocks)	26,813,955	21,203,970	22,216,444	133	35,553,016	24,240,100	35,389,767	133
Trading volume (stocks)	2,026,044	1,369,830	2,299,289	133	1,950,471	1,280,430	1,974,420	133
Number executed	4,683	4,569	1,911	133	5,932	5,051	3,177	133
Trading value (¥ million)	1,832	1,765	398	133	1,899	1,832	650	133
Number of transaction units per contract	379	298	274	133	285	249	124	133
HFT ratio	37.5%	37.8%	3.7%	133	36.4%	36.4%	3.0%	133
Ratio of cancellation orders	38.7%	39.5%	3.3%	133	41.7%	41.8%	1.8%	133
Ratio of change orders	4.7%	4.4%	1.1%	133	5.8%	5.1%	2.2%	133
Order volume/No. of orders (all)	1,825	1,196	1,913	133	1,082	877	695	133
Order volume/No. of orders (new market orders)	796	639	501	133	819	670	532	133
Order volume/No. of orders (Take)	686	512	631	133	456	379	254	133
Quoted spread (bps)	5.9	5.0	2.9	133	2.8	2.7	0.9	133
Effective spread (bps)	6.9	6.5	2.8	133	3.8	3.7	0.8	133
1-minute volatility	8.0×10^{-4}	7.7×10^{-4}	1.8×10^{-4}	133	7.0×10^{-4}	6.9×10^{-4}	1.8×10^{-4}	133
10-minute volatility	2.3×10^{-3}	2.2×10^{-3}	6.1×10^{-4}	133	2.2×10^{-3}	2.1×10^{-3}	5.9×10^{-4}	133
STR	1.3	1.1	0.3	133	2.6	2.0	1.4	133
variance ratio	0.83	0.84	0.14	133	0.99	0.98	0.09	133
Depth (1st)	8,047	2,440	28,581	133	887	638	869	133
Depth (2nd)	13,095	4,101	42,410	133	1,587	989	2,012	133
Depth (3rd)	13,899	5,073	40,271	133	2,109	1,364	2,610	133
Depth (4th)	14,549	5,893	37,019	133	2,370	1,571	2,900	133
Depth (5th)	14,859	5,712	39,181	133	2,541	1,671	3,153	133
Depth (6th)	14,786	6,580	30,082	133	2,645	1,729	3,355	133
Depth (7th)	13,010	5,515	23,862	133	2,784	1,817	3,582	133
Depth (8th)	10,677	4,693	19,059	133	2,838	1,837	3,623	133
Depth (9th)	10,199	4,998	18,306	133	2,911	1,888	3,569	133
Depth (10th)	9,082	5,063	15,566	133	3,019	1,881	3,830	133
50% tick reduction (dummy variable)	0.54	1.00	0.50	133				
80% tick reduction (dummy variable)	0.22	0.00	0.41	133				
90% tick reduction (dummy variable)	0.24	0.00	0.43	133				

Table 6.3 Bottom group in terms of trading value (Group 3)

	Before				After			
	Mean	Median	Std.	Count	Mean	Median	Std.	Count
No. of orders	25,941	25,524	11,198	132	44,683	40,817	18,327	132
Order volume (stocks)	14,125,390	11,036,850	10,479,272	132	18,233,183	13,147,605	15,913,191	132
Trading volume (stocks)	797,965	548,730	673,911	132	836,433	590,640	694,761	132
Number executed	2,578	2,357	1,189	132	3,244	2,795	1,648	132
Trading value (¥ million)	711	700	264	132	784	738	346	132
Number of transaction units per contract	280	231	153	132	231	204	74	132
HFT ratio	37.6%	37.0%	3.2%	132	36.3%	36.5%	2.5%	132
Ratio of cancellation orders	39.7%	40.2%	2.5%	132	41.1%	41.4%	1.7%	132
Ratio of change orders	4.3%	4.1%	0.9%	132	7.3%	6.8%	2.9%	132
Order volume/No. of orders (all)	1,360	963	1,025	132	904	745	406	132
Order volume/No. of orders (new market orders)	537	447	299	132	576	484	305	132
Order volume/No. of orders (Take)	480	374	322	132	366	290	215	132
Quoted spread (bps)	6.2	5.4	2.7	132	3.4	3.1	1.1	132
Effective spread (bps)	7.2	6.8	2.8	132	4.4	4.2	1.1	132
1-minute volatility	7.2×10^{-4}	7.0×10^{-4}	1.9×10^{-4}	132	6.3×10^{-4}	6.1×10^{-4}	1.4×10^{-4}	132
10-minute volatility	2.1×10^{-3}	2.0×10^{-3}	6.1×10^{-4}	132	2.0×10^{-3}	1.9×10^{-3}	4.7×10^{-4}	132
STR	1.4	1.2	0.4	132	3.1	2.6	1.5	132
variance ratio	0.82	0.84	0.12	132	1.01	1.00	0.08	132
Depth (1st)	2,629	1,474	5,583	132	542	409	365	132
Depth (2nd)	4,727	2,734	9,028	132	800	539	750	132
Depth (3rd)	5,772	3,469	10,086	132	1,099	771	1,040	132
Depth (4th)	7,023	4,308	10,352	132	1,298	903	1,214	132
Depth (5th)	6,998	4,250	10,377	132	1,442	1,014	1,350	132
Depth (6th)	7,537	4,410	9,804	132	1,532	1,071	1,427	132
Depth (7th)	7,530	4,138	9,206	132	1,606	1,154	1,452	132
Depth (8th)	5,945	3,375	6,469	132	1,636	1,238	1,408	132
Depth (9th)	5,490	3,384	6,300	132	1,729	1,304	1,488	132
Depth (10th)	5,310	3,292	5,702	132	1,784	1,270	1,625	132
50% tick reduction (dummy variable)	0.56	1.00	0.50	132				
80% tick reduction (dummy variable)	0.20	0.00	0.40	132				
90% tick reduction (dummy variable)	0.23	0.00	0.43	132				

Table 6.4 TOPIX Large 70 constituents

	Before				After			
	Mean	Median	Std.	Count	Mean	Median	Std.	Count
No. of orders	157,167	124,893	107,642	70	201,869	167,659	138,302	70
Order volume (stocks)	90,120,710	53,844,538	92,202,940	70	105,120,831	65,736,993	105,654,887	70
Trading volume (stocks)	9,251,781	4,888,860	9,222,833	70	9,529,180	4,792,530	10,149,346	70
Number executed	20,160	15,596	18,154	70	21,386	15,237	20,231	70
Trading value (¥ million)	15,195	9,693	29,104	70	15,621	9,923	27,613	70
Number of transaction units per contract	419	379	219	70	405	340	234	70
HFT ratio	32.6%	32.3%	2.5%	70	34.6%	34.3%	2.5%	70
Ratio of cancellation orders	39.2%	39.7%	2.5%	70	40.8%	41.2%	2.7%	70
Ratio of change orders	6.1%	6.1%	1.1%	70	5.4%	5.3%	1.2%	70
Order volume/No. of orders (all)	1,470	1,130	1,227	70	1,323	993	1,158	70
Order volume/No. of orders (new market orders)	1,327	1,153	789	70	1,350	1,162	805	70
Order volume/No. of orders (Take)	759	545	583	70	704	482	582	70
Quoted spread (bps)	1.6	1.5	0.4	70	1.7	1.6	0.5	70
Effective spread (bps)	3.3	2.9	1.6	70	2.8	2.6	0.8	70
1-minute volatility	6.6×10^{-4}	6.1×10^{-4}	1.9×10^{-4}	70	6.7×10^{-4}	6.6×10^{-4}	1.7×10^{-4}	70
10-minute volatility	2.1×10^{-3}	1.9×10^{-3}	7.1×10^{-4}	70	2.1×10^{-3}	2.1×10^{-3}	5.5×10^{-4}	70
STR	1.6	1.5	0.6	70	1.8	1.6	0.7	70
variance ratio	0.93	0.94	0.09	70	0.96	0.97	0.10	70
Depth (1st)	2,772	1,521	3,507	70	2,326	1,146	3,356	70
Depth (2nd)	5,863	3,127	7,600	70	5,162	2,513	7,340	70
Depth (3rd)	6,770	3,881	8,268	70	6,209	3,189	8,420	70
Depth (4th)	7,155	4,138	8,560	70	6,656	3,500	8,846	70
Depth (5th)	7,281	4,353	8,570	70	6,839	3,712	9,012	70
Depth (6th)	7,205	4,266	8,513	70	6,742	3,521	8,942	70
Depth (7th)	7,244	4,224	8,506	70	6,825	3,528	9,063	70
Depth (8th)	7,274	4,162	8,502	70	6,882	3,580	9,290	70
Depth (9th)	7,390	4,253	8,663	70	6,970	3,672	9,424	70
Depth (10th)	7,275	4,248	8,443	70	6,934	3,696	9,245	70

References

Bessembinder K. (2003). "Trade Execution Costs and Market Quality after Decimalization. " JOURNAL OF FINANCIAL AND QUANTITATIVE ANALYSIS, vol. 38, (No. 4).

Borkovec M. and H. G. Heidle (2010). "Building and Evaluating a Transaction Cost Model: A Primer. " The Journal of Trading, 5, (2), 57 - 77.

Chakravarty S., Panchapagesan V., Wood R.A. (2005). "Did decimalization hurt institutional investors? " Journal of Financial Markets, 8, (4), 400 – 420.

Charles M. Jones, Marc L. Lipson (2001). "Sixteenths: direct evidence on institutional execution costs. " Journal of Financial Economics, 59, 253 - 278.

Chung, K., Chuwonganant,C. (2004). "Tick Size, Order Handling Rules, and Trading Costs. " Financial Management, vol. 33, (No. 1 (Spring, 2004)), 47 - 62.

Chung, K., Robert A. Van Ness (2001). "Order handling rules, tick size, and the intraday pattern of bid-ask spreads for Nasdaq stocks. " Journal of Financial Markets, 4, 143 - 161.

Craig H. Furfine (2003). "Decimalization and market liquidity. " Economic Perspectives, vol. 27 (4th, No.4), 2 - 12.

Dayri, K., and Rosenbaum M. (2015). "Large tick assets: implicit spread and optimal tick size. " Market Microstructure and Liquidity, vol. 01 (No. 01).

European Securities and Markets Authority (2015). "Cost Benefit Analysis – Annex II. ", 280 - 319.

Hiroaki Wakamatsu (2022). "How Changes in Tick Sizes Affect Investors' Execution Costs. " JPX Working Paper, vol.40.

Hu E., Hughes P., Ritter J., Vegella P., and Zhang H. (2018). "Tick Size Pilot Plan and Market Quality. " U.S. Securities and Exchange Commission, White Papers.

Huang W., Lehalle C-A, Rosenbaum M. (2017). "How to Predict the Consequences of a Tick Value Change? Evidence from the Tokyo Stock Exchange Pilot Program. " Market Microstructure and Liquidity, Vol. 2 (Nos. 3&4).

Kondo, M. (2015). "The Impact of the Tick Size Pilot Program on Trading Costs at the Tokyo Stock Exchange. " JPX Working Paper, vol.07.

Securities and Exchange Commission (2005). Final rules and amendments to joint industry plans. Release No. 34-51808; File No. S7-10-04.

Uno, J, and M. Shibata (2012). "The Impact of High-Speed Trades on Liquidity: The Case of the TSE’s arrowhead. " Gendai Finance, 31, 87-107 (in Japanese).

Verousis T., Perotti P., and Sermpinis G. (2017). "One size fits all? High frequency trading, tick size changes and the implications for exchanges: market quality and market structure considerations." Review of Quantitative Finance and Accounting, 50, 353-392.