Atsushi Saito

Group CEO

The Honorable Mary Jo White

Chair

U.S. Securities and Exchange Commission

100 F Street NE

Washington, DC 20549

Dear Chair White,

First of all, I would like to express my deep admiration of your strong commitment and initiatives toward conducting a holistic review of the US market structure. As CEO of Japan's largest regulated exchange group, I have been encouraged by recent moves by the SEC to address issues related to market fragmentation and its side-effects, and to restore the full-fledged functions of regulated exchange markets and investor confidence in the US.

In connection with this, I am aware of the heightened interest in the US on the topic of optimal tick sizes with the SEC initiating its Tick Size Pilot Program. This prompted me to share our experience in Japan, and how Tokyo Stock Exchange will be changing tick sizes after conducting a similar pilot program.

As you may know, TSE applies a tiered tick size regime where tick sizes vary depending on the quote price. Prior to the pilot program, all issues shared the same tick size table. The TSE pilot sought to analyze and monitor the effects of smaller tick sizes on liquidity and spreads. We introduced a separate finer tick size table to a group of 100 issues with large market cap and high liquidity in January 2014. This shares the same rationale behind the Tick Size Pilot Program in the US, which, in your case, broadened the tick size for small-cap issues.

The analysis paper on how the TSE tick size pilot program affected overall trading activities in these issues is enclosed herein for your reference.

Our analysis revealed a positive correlation between the degree of reduction in an issue's best bid/offer (BBO) spreads and its level of liquidity prior to the introduction of the pilot program. The BBO spread narrowed as a result of introduction of smaller tick sizes, that is, the higher the liquidity, the narrower BBO spreads became. Liquidity was defined in terms of depth in the order book. Meanwhile, we also observed that resultant narrower spreads were accompanied by relative decreases in order book depth. These results indicate that the optimal tick size level varies depending on the liquidity profile. As such, we will fine-tune our tick size table in September 2015 and broaden

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Tokyo 103-8244, Japan
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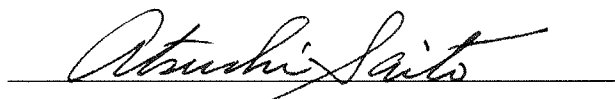
JPX
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Atsushi Saito

Group CEO

back the tick sizes at price ranges at which the spreads were observed to have become wider than the corresponding tick size. I believe that our tiered tick size regime has allowed us to be flexible in responding to the observations from the pilot program.

As I read through the various comments on the SEC's Tick Size Pilot Program submitted in the public comment process, regardless of whether they were in favor of the program, I found high expectations for a long-awaited review of the tick size regime in the US since decimalization was introduced 15 years ago.

Please allow me to take this opportunity to express my appreciation for the SEC's continued efforts as I mention the detailed research report on decimalization published in July 2012. The SEC report provided helpful insight on the subject matter and served as an invaluable reference in our research.

Finally, I hope that our experience will aid you in your efforts to develop a robust tick size regime in the US. Please do not hesitate to contact us for further information.

Sincerely,

Atsushi Saito
Director & Representative Executive Officer, Group CEO
Japan Exchange Group, Inc.

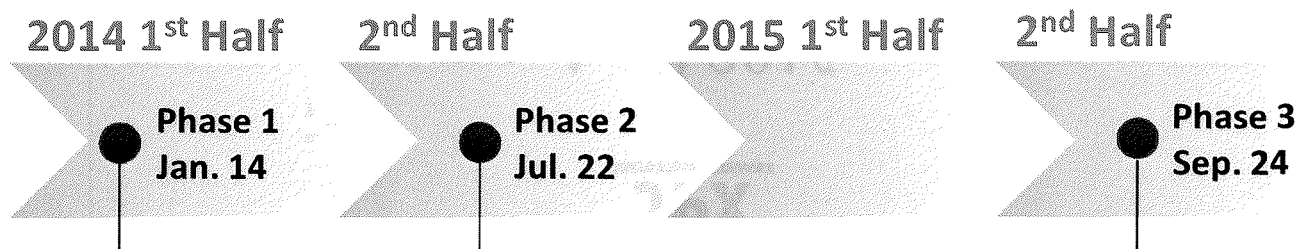Enclosure: "Impact of Tick Size Pilot Program on Trading Costs at Tokyo Stock Exchange"
(http://www.jpx.co.jp/english/corporate/research-study/working-paper/index.html)

Executive Summary

JPX
TOKYO STOCK EXCHANGE

April 2015
Tokyo Stock Exchange

1. Outline

2014 1st Half   2nd Half   2015 1st Half   2nd Half

Phase 1
Jan. 14

Phase 2
Jul. 22

Phase 3
Sep. 24

Tick Size Pilot Program in TSE

- Reduce tick sizes in TOPIX 100 constituents in two phases.
  - ✓ **Phase 1:** Reduce tick sizes for stocks priced above JPY 3,000.
  - ✓ **Phase 2:** Introduce decimal tick sizes (JPY 0.1 or JPY 0.5) for stocks priced under JPY 5,000.

Phase 1

Quote Range (JPY)		Normal Tick Size (JPY)	Phase 1 Tick Size (JPY)
Over	Less Than		
3,000	5,000	5	1
5,000	10,000	10	1
10,000	30,000	10	5

Phase 2

Quote Range (JPY)		Phase 1 Tick Size(JPY)	Phase 2 Tick Size (JPY)
Over	Less Than		
1	1,000	1	0.1
1,000	3,000	1	0.5
3,000	5,000	1	0.5

- ✓ **Phase 3:** Review Phase 1 & 2 impact and finalize new tick size table.
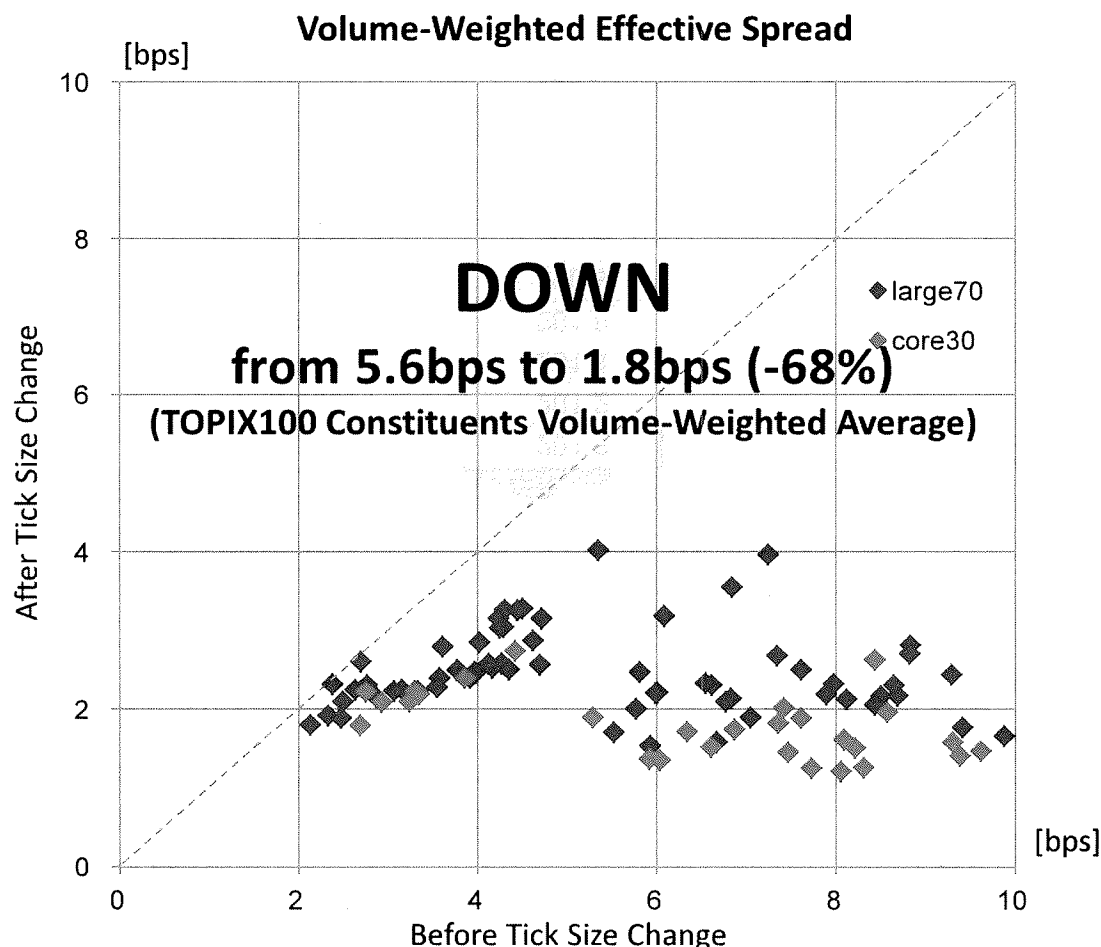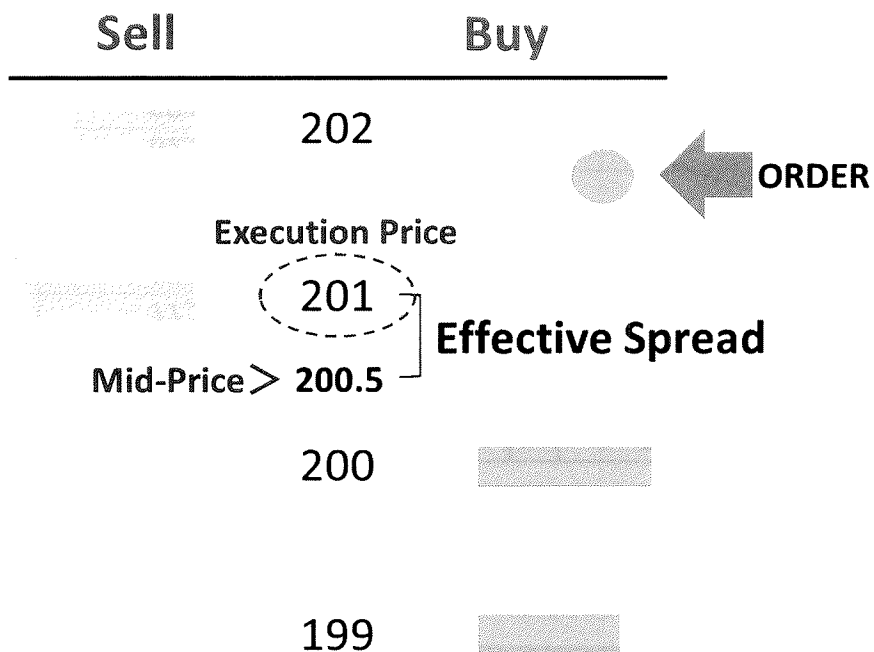
2. Changes in the Order Book

✓ Quoted spread narrowed and price improvements observed.
✓ Quotes in the order book are dispersed across a large number of smaller ticks.

Mizuho Financial Group (8411)
2014/07/18 14:50:00

SELL	PRICE	BUY
468,768	▲OVER	
77,264	209.0	
87,374	208.0	
61,026	207.0	
75,884	206.0	
82,326	205.0	
68,000	204.0	
110,868	203.0	
147,046	202.0	
114,048	201.0	
	200.0	425,569
	199.0	245,910
	198.0	234,691
	197.0	85,330
	196.0	63,191
	195.0	70,500
	194.0	27,929
	193.0	20,995
	▼UNDER	58,333

Phase 2

Mizuho Financial Group (8411)
2014/07/22 09:10:00

SELL	PRICE	BUY
839,786	▲OVER	
1,352	201.3	
2,068	201.2	
856	201.1	
19,696	201.0	
3,822	200.9	
4,735	200.8	
3,192	200.7	
2,479	200.6	
	200.5	5,753
	200.4	5,216
	200.3	4,785
	200.2	9,425
	200.1	22,599
	200.0	162,614
	199.9	1,332
	199.8	1,282
	199.7	1,758
	▼UNDER	413,805

*Order volumes per trading unit (1 trading unit: 100 shares)

3. Effective Spread Reduction and Price Improvement

✓ Effective spread, or spread cost actually borne by investors, has decreased significantly.
✓ The total spread cost in TOPIX 100 constituents has dropped by 3.8bps. (JPY 99.2 billion on an annual basis.)

Definition of Effective Spread

Sell   **Buy**

202

◀ ORDER

Execution Price

(201)   ⎤ **Effective Spread**

Mid-Price > 200.5 ⎦

200

199

Volume-Weighted Effective Spread

[bps]

DOWN
from 5.6bps to 1.8bps (-68%)
(TOPIX100 Constituents Volume-Weighted Average)

◆ large70
● core30

After Tick Size Change

Before Tick Size Change

[bps]

- "Volume-Weighted Effective Spread" is the spread between the execution price and BBO mid-price (immediately prior to execution) averaged by the volume weight of the number of executed shares. Denominator of the spread calculation is the mid-price. All executions during continuous auction are included in the calculation.
- For orders executed at more than one price, the volume-weighted price is used as the execution price.
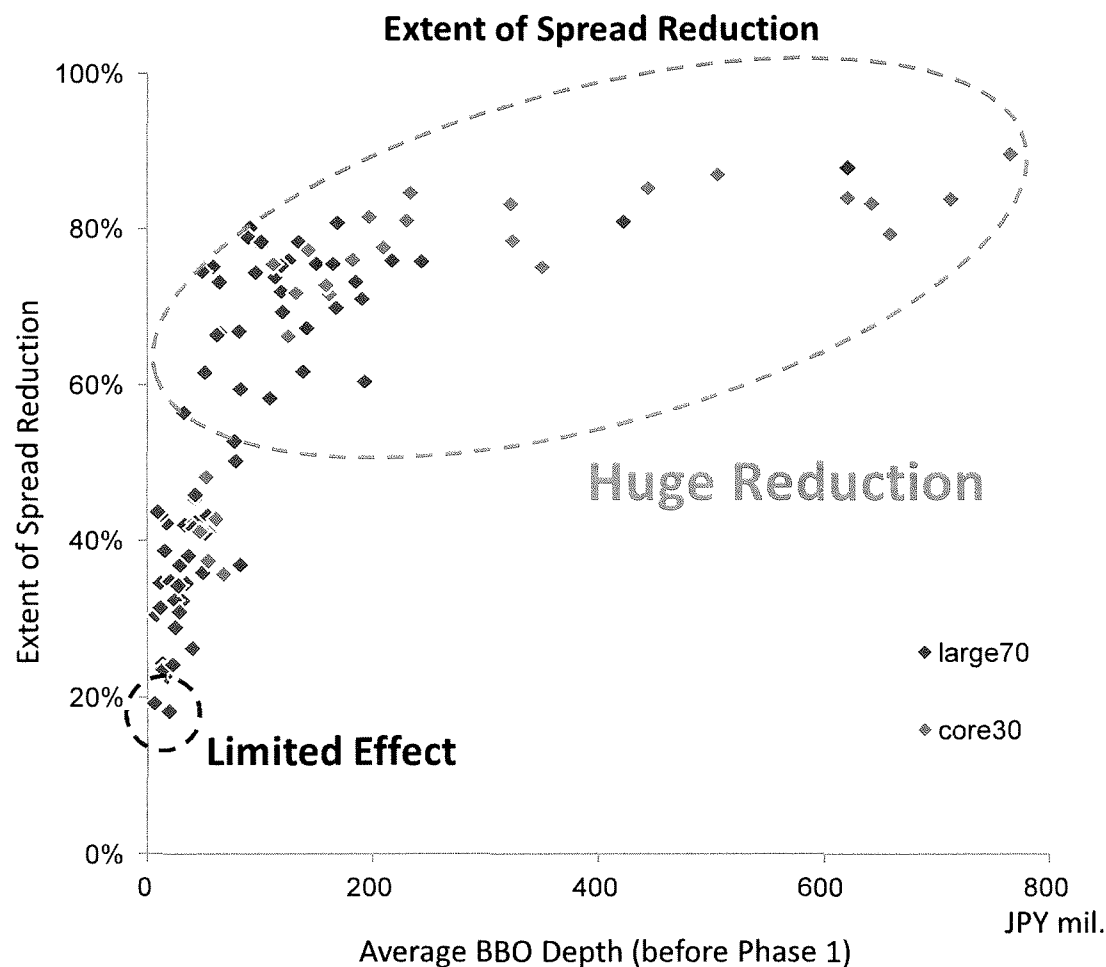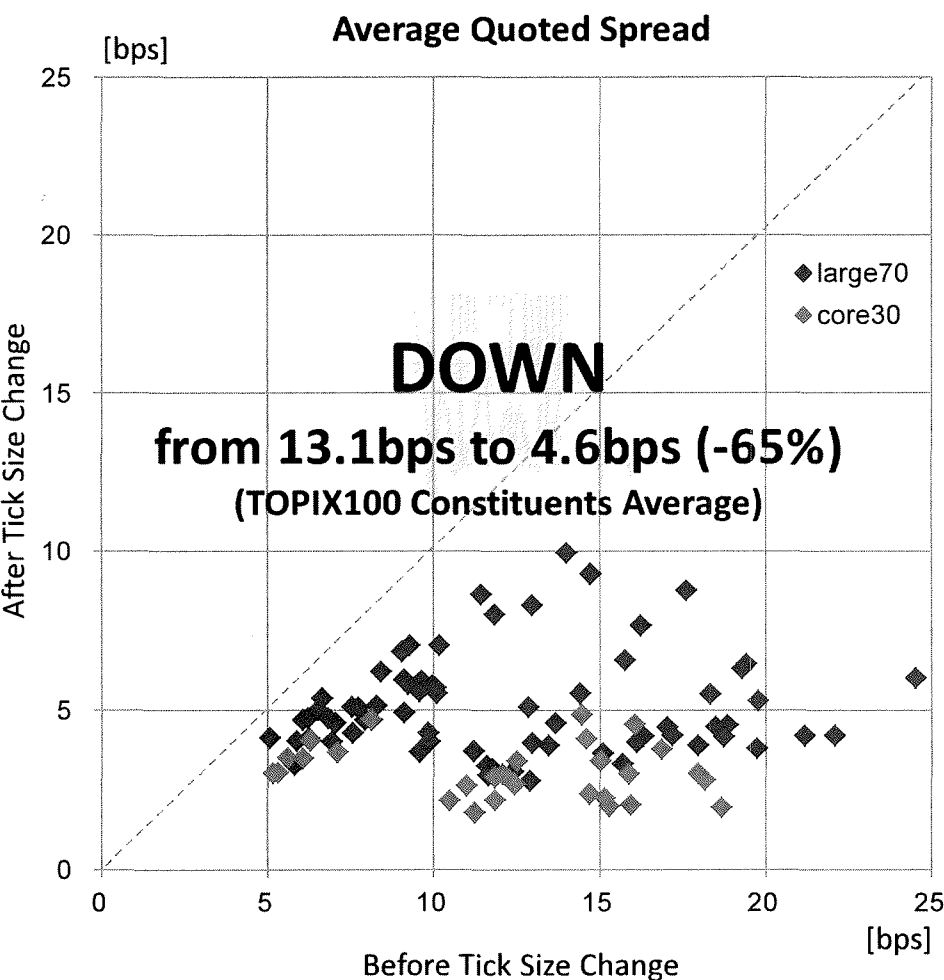
4. Transition of Trading Value

- ✓ No significant change in share of TOPIX100 trading value near the start of both Phases 1 and 2.
- ✓ Trading cost reductions were achieved with high liquidity.
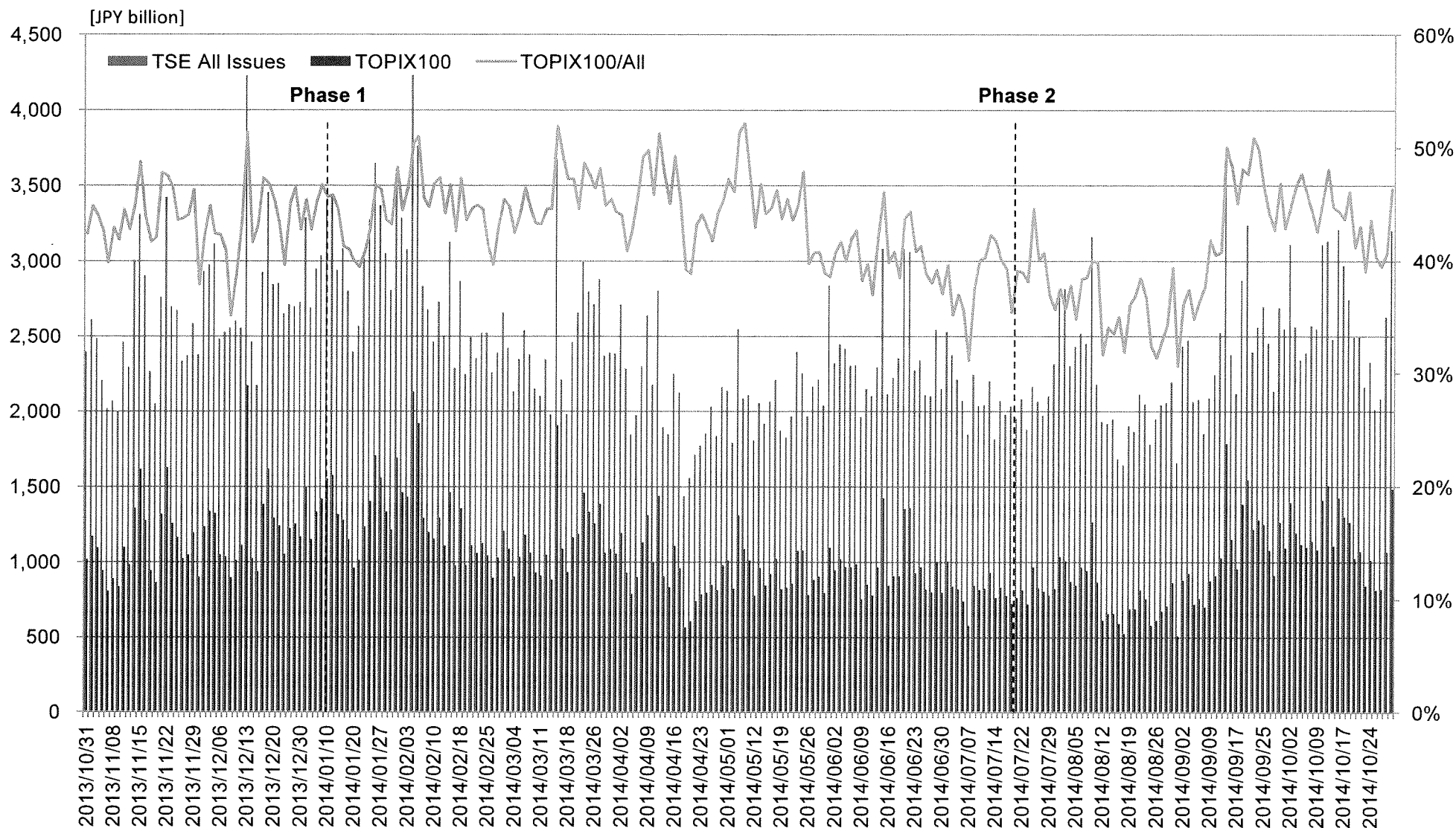
6. Quoted Spread at Price Band with Sub-yen Tick Sizes

- ✓ Quoted spreads fell below JPY 1 for all issues priced under JPY 1,000.
- ✓ Only a few issues priced between JPY 3,000 and JPY 5,000 saw the same effect.

Average Quoted Spread [JPY] (After Phase 2)
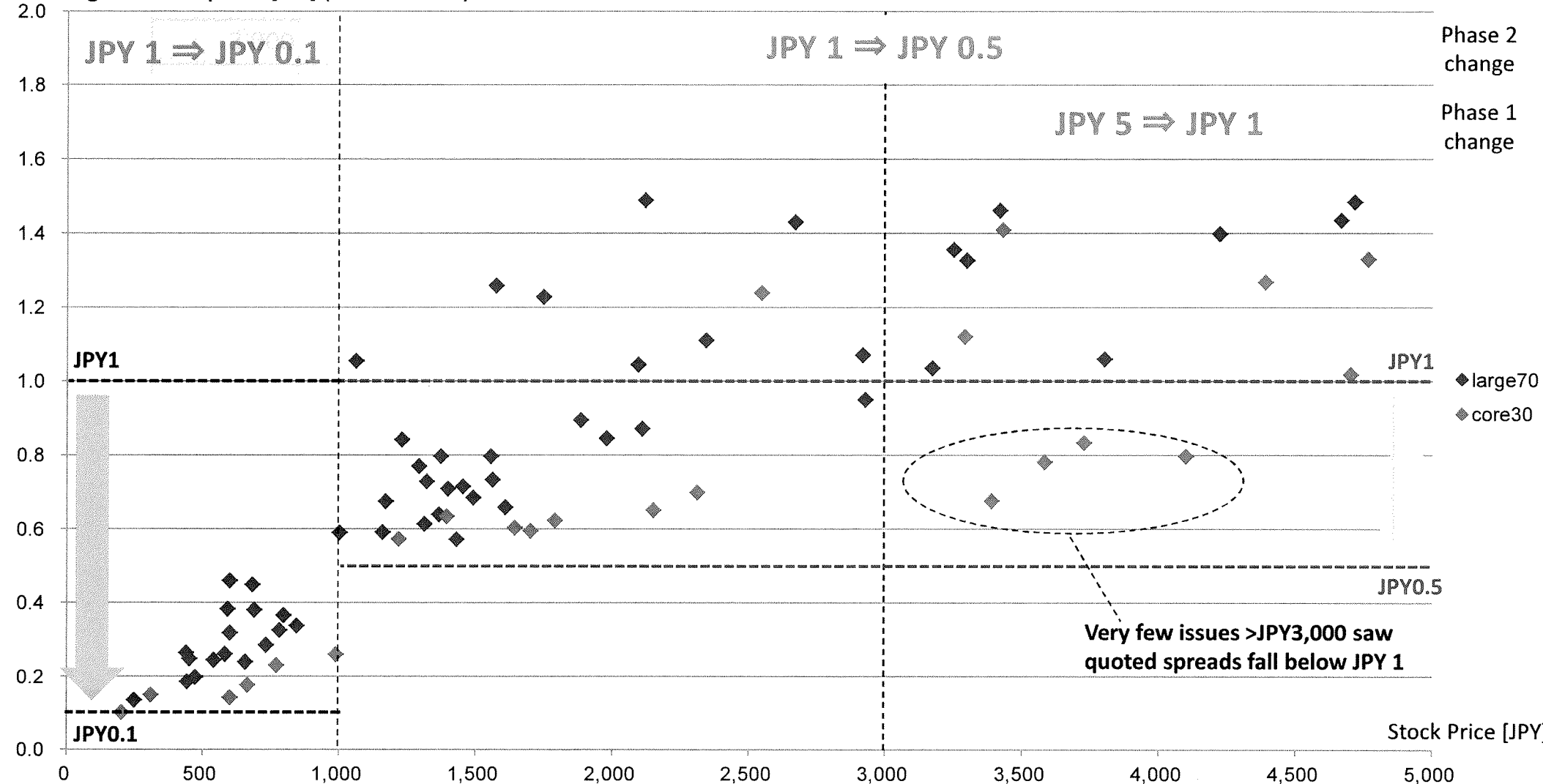
7. Proposed Plan for Phase 3

\<Phase 3 Plan\>

Phase 3 Issues	As is the case with Phases 1 and 2, the small tick sizes will only be applied to TOPIX100 constituents.
Tick Size Revision	The tick size for prices above JPY 3,000 but JPY 5,000 or less will be changed to JPY 1 (currently, JPY 0.5). (Tick sizes for price bands at tenfold increments (e.g., above JPY 30,000 but JPY 50,000 or less) will be similarly revised to the next larger tick size.)

\<Tick Size\>

Price(JPY)		Other Issues	TOPIX100 Constituents Phase 1	TOPIX100 Constituents Phase 2	TOPIX100 Constituents Phase 3
More than	Up to				
	1,000	1	1	0.1	0.1
1,000	3,000	1	1	0.5	0.5
3,000	5,000	5	1	0.5	1
5,000	10,000	10	1	1	1
10,000	30,000	10	5	5	5
30,000	50,000	50	5	5	10
50,000	100,000	100	10	10	10

... Core30
... Large70

No.	Code	Name	Price	No.	Code	Name	Price	No.	Code	Name	Price	No.	Code	Name	Price
1	8411	Mizuho FG	204.3	26	8053	SUMITOMO	1,260.5	51	5411	JFE Holdings	2,588.0	76	8316	Sumitomo Mitsui FG	4,477.5
2	9202	ANA HOLDINGS	303.8	27	7752	RICOH	1,279.5	52	9064	YAMATO HOLDINGS	2,588.0	77	4502	Takeda	5,015
3	5401	Nippon Steel & Sumitomo Metal	308.4	28	8001	ITOCHU	1,370.5	53	6758	SONY	2,640.0	78	6902	DENSO	5,683
4	5020	JX Holdings	437.1	29	9502	Chubu Electric Power	1,416.0	54	8802	Mitsubishi Estate	2,685.0	79	9021	JR West	5,712
5	9532	OSAKA GAS	455.9	30	6503	Mitsubishi Electric	1,438.5	55	8113	UNICHARM	2,762.0	80	6971	KYOCERA	5,824
6	8309	Sumitomo Mitsui Trust	494.0	31	8795	T&D Holdings	1,458.0	56	6301	KOMATSU	2,789.0	81	9432	NTT	6,230
7	6502	TOSHIBA	531.0	32	7202	ISUZU MOTORS	1,528.5	57	8725	MS&AD Insurance Group	2,830.0	82	6988	NITTO DENKO	6,272
8	4188	Mitsubishi Chemical	626.8	33	2503	Kirin Holdings	1,542.5	58	8630	NKSJ Holdings	3,027.5	83	9735	SECOM	6,873
9	8308	Resona Holdings	639.3	34	6752	Panasonic	1,554.0	59	7261	Mazda	3,147.0	84	7203	TOYOTA	7,429
10	9531	TOKYO GAS	649.7	35	8591	ORIX	1,565.5	60	8801	Mitsui Fudosan	3,430.0	85	9433	KDDI	7,544
11	8332	The Bank of Yokohama	669.3	36	5802	Sumitomo Electric Industries	1,579.0	61	7267	HONDA	3,595.5	86	6594	NIDEC	7,949
12	6702	FUJITSU	684.8	37	1928	Sekisui House	1,606.0	62	2502	Asahi Group	3,739.0	87	9984	SoftBank	7,966
13	8306	Mitsubishi UFJ FG	690.0	38	8031	MITSUI & CO.,	1,612.0	63	4578	Otsuka	3,785.5	88	6367	DAIKIN	8,090
14	7011	Mitsubishi Heavy Industries	695.1	39	4755	Rakuten	1,634.5	64	2914	JAPAN TOBACCO	3,798.0	89	4063	Shin-Etsu	8,118
15	8604	Nomura Holdings	718.8	40	4503	Astellas Pharma	1,713.5	65	7269	SUZUKI MOTOR	3,853.0	90	8035	Tokyo Electron	8,294
16	8002	Marubeni	745.7	41	5713	Sumitomo Metal Mining	1,739.5	66	7751	CANON	3,906.0	91	9020	JR East	8,954
17	6501	Hitachi	920.1	42	8750	The Dai-ichi Life Insurance	1,744.0	67	8766	Tokio Marine	3,970.5	92	6981	MURATA	12,980
18	3402	TORAY INDUSTRIES	933.0	43	4911	Shiseido	1,764.5	68	4901	FUJIFILM Holdings	3,980.5	93	1878	DAITO TRUST	13,600
19	8601	Daiwa Securities	959.3	44	4568	DAIICHI SANKYO	1,780.5	69	5108	BRIDGESTONE	4,122.0	94	7974	Nintendo	14,130
20	3407	ASAHI KASEI	1,038.5	45	9437	NTT DOCOMO	1,866.0	70	8830	Sumitomo R&D	4,156.5	95	9022	JR Central	17,515
21	7912	Dai Nippon Printing	1,055.0	46	6326	KUBOTA	1,874.0	71	4523	Eisai	4,282.0	96	6954	FANUC	20,260
22	7201	NISSAN MOTOR	1,105.0	47	8058	Mitsubishi	2,222.0	72	7741	HOYA	4,293.0	97	4661	ORIENTAL LAND	26,190
23	8267	AEON CO.,	1,200.0	48	2802	Ajinomoto Co.,	2,232.5	73	7270	Fuji Heavy Industries	4,381.0	98	6273	SMC CORP	32,610
24	9503	The Kansai Electric Power	1,209.5	49	1925	DAIWA HOUSE	2,282.5	74	4452	Kao Corp	4,440.0	99	9983	FAST RETAILING	43,425
25	1605	INPEX	1,219.0	50	1963	JGC	2,555.0	75	3382	Seven & I HD	4,456.0	100	6861	KEYENCE	55,520

[Note] Prices are base prices on Dec. 1, 2014.

JPX
WORKING
PAPER

Impact of Tick Size Pilot Program on Trading Costs at Tokyo Stock Exchange

JPX
TOKYO STOCK EXCHANGE

January 2015
Tokyo Stock Exchange, Inc.
Masafumi Kondo*

* Equities Department, Tokyo Stock Exchange, Inc. & Corporate Strategy Department, Japan Exchange Group, Inc. (m-kondo@jpx.co.jp)

1. Background

✓ Changed tick sizes for TOPIX100 constituents in January and July 2014 in Phases 1 and phase 2 of a pilot program, with Phase 3 scheduled for September 2015.
✓ First attempt at TSE on decimal pricing and changing tick sizes for only a certain group of issues.
✓ Narrower tick sizes were expected to lower trading costs for high-liquidity issues.

History of Tick Size Revisions at Tokyo Stock Exchange

Price (JPY)	1985/12/02	1998/04/13	2000/07/17	2008/07/22	2010/01/04	2014/01/14*	2014/07/22*
Above — Up to 1,000	1						0.1
1,000 ~ 2,000		1	1	1	1		
2,000 ~ 3,000		5	5	5		1	0.5
3,000 ~ 5,000	10				5		
5,000 ~ 10,000		10	10	10	10		1
10,000 ~ 30,000						5	5
30,000 ~ 50,000	100	50	50	50	50		
50,000 ~ 100,000		100	100			10	10
100,000 ~ 300,000				100	100	50	50
300,000 ~ 500,000	1,000	1,000	1,000		500		
500,000 ~ 1 million				1,000		100	100
1 million ~ 3 million					1,000	500	500
3 million ~ 5 million					5,000		
5 million ~ 10 million			10,000	10,000		1,000	1,000
10 million ~ 20 million	10,000	10,000			10,000		
20 million ~ 30 million			50,000	50,000		5,000	5,000
30 million ~ 50 million					50,000		
50 million ~			100,000	100,000	100,000	10,000	10,000

Note: Only TOPIX100 constituents

2.1 Outline of Analysis

- ✓ Analyzed trading cost of TOPIX100 constituents after tick size change based on Implementation Shortfall.
- ✓ Grouped TOPIX100 constituents by price bands based on tick size changes.
- ✓ Divided issues into test groups A, C, and D, and control groups B and E for the two phases.
- ✓ Compared changes in trading cost benchmarks of the groups during the one-month periods (20 business days) before and after the tick size changes based on FLEX Full market data.

Groups and Tick Sizes

Price (JPY)		Other Issues	TOPIX100 Constituents Phase 1 (2014/01/14)		TOPIX100 Constituents Phase 2 (2014/07/22)	
Above	Up to 1,000	1	1	Group B (62)	0.1	Group C (24)
1,000 ~	3,000					
3,000 ~	5,000	5	1	Group A (38)	0.5	Group D (56)
5,000 ~	10,000	10				
10,000 ~	30,000		5		1	
30,000 ~	50,000	50			5	Group E (20)
50,000 ~		100	10		10	

Note: Figures in parentheses indicate number of issues.

Implementation Shortfall Transaction Costs

Brokerage Costs	Fees, Commissions
Investment Costs	Delay Costs, Taxes
Trading Costs	Spread Costs Timing Costs Market Impact Costs
Other Costs	Opportunity Costs

Sugihara (2011) based on Kissell (2006)

✓ Measured spread costs using quoted spread and effective half spread.

✓ Compared $\overline{qs}$, the average quoted spread qs^t, for each issue during each period. Quoted spread qs^t is defined as the difference between the best ask price P_{ba}^t and best bid price P_{bb}^t divided by the midpoint of BBO P_{mid}^t at each one-minute interval t.

✓ Calculated the volume weighted effective half spread es^d using execution volume Q_{exec}^i on each business day d, and compared $\overline{es}$, the average es^d, for each issue during each period. Effective half spread es^i is defined as the difference between the execution price P_{exec}^i and the midpoint of BBO just before execution P_{mid}^i divided by P_{mid}^i for each execution i in continuous trading.

Sell	Buy	
	202	← Buy Order
	Execution Price	
	(201)	] Effective Half Spread
Midpoint of BBO → (200.5)		
	200	Quoted Spread
	199	
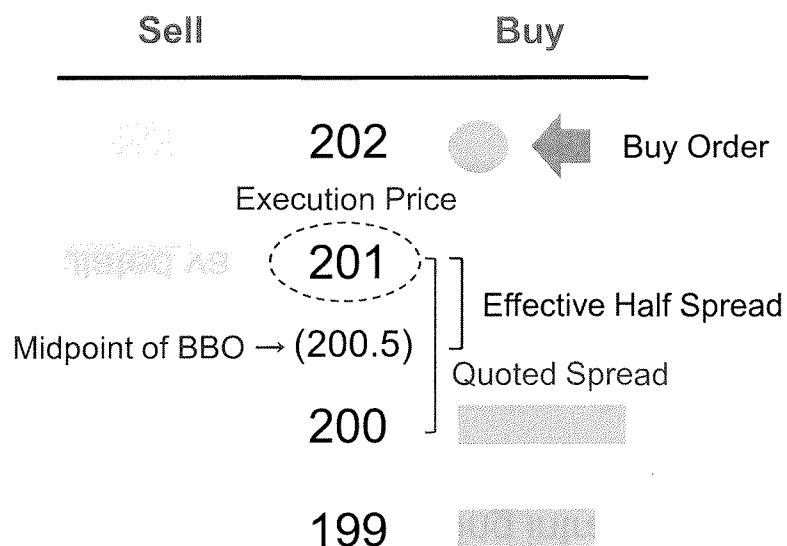
$$qs^t = \frac{P_{ba}^t - P_{bb}^t}{P_{mid}^t}$$

$$es^i = \frac{|P_{exec}^i - P_{mid}^i|}{P_{mid}^i}$$

$$es^d = \frac{\sum_{i=1}^{n}(es^i \times Q_{exec}^i)}{\sum_{i=1}^{n} Q_{exec}^i}$$

Note: In the calculation of es^i, execution i is defined as all simultaneous executions due to a single order. For executions striding more than a single price level, volume weighted execution price is used for P_{exec}^i and total execution volume (sum of execution volumes at each price level) is used for Q_{exec}^i.

✓ Measured timing costs using intraday volatility σ^d, defined as the standard deviation of the natural logarithm of the fluctuation rate of the midpoint of BBO at each one- and ten-minute time interval t on each business day d.

✓ Calculated σ_1^d and σ_{10}^d at one- and ten-minute intervals respectively, and compared $\overline{\sigma_1}$ and $\overline{\sigma_{10}}$, the respective averages of σ_1^d and σ_{10}^d, for each issue during each period.

✓ Calculated variance ratio vr^d using σ_1^d and σ_{10}^d, and compared $\overline{vr}$, the average vr^d, for each issue during each period.
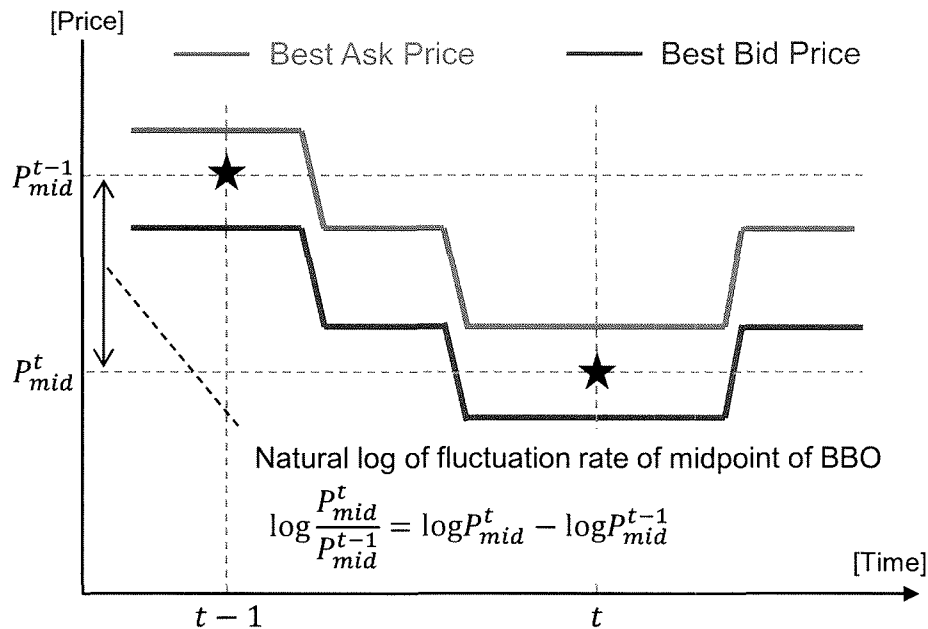
$$\mu = \frac{1}{N}\sum_{t=1}^{N}(\log P_{mid}^t - \log P_{mid}^{t-1})$$

$$(\sigma^d)^2 = \frac{1}{N}\sum_{t=1}^{N}\left(\log P_{mid}^t - \log P_{mid}^{t-1} - \mu\right)^2$$

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

[Price]

Best Ask Price ——— Best Bid Price

P_{mid}^{t-1}

P_{mid}^t

Natural log of fluctuation rate of midpoint of BBO

$$\log \frac{P_{mid}^t}{P_{mid}^{t-1}} = \log P_{mid}^t - \log P_{mid}^{t-1}$$

[Time]

$t-1$ t

Note: Based on TSE's five-hour trading day (i.e., 300 minutes), for σ_1^d , t=300 and for σ_{10}^d, t=30.

✓ Measured market impact using the virtual effective half spread cost to compare changes in trading cost for executing equal volume orders before and after tick size change.

✓ Calculated the effective half spread es_{50}^t, the virtual effective half spread caused by immediate execution of market orders at Q_{50}, the 50th percentile of execution volume for each issue in continuous trading during the period before tick size change, based on order book information, at one-minute intervals.

✓ Compared $\overline{es}_{50}$, the average of es_{50}^t, for each issue during each period. Similarly for $\overline{es}_{90}$ and $\overline{es}_{99}$.

[Price] Sell Order

— Best Ask Price
— Best Bid Price

P_{mid}^t

½ of Quoted Spread

Market Impact Cost

Effective Half Spread

◆ ... Simultaneous executions due to single order

[Time]

Volume Weighted Execution Price
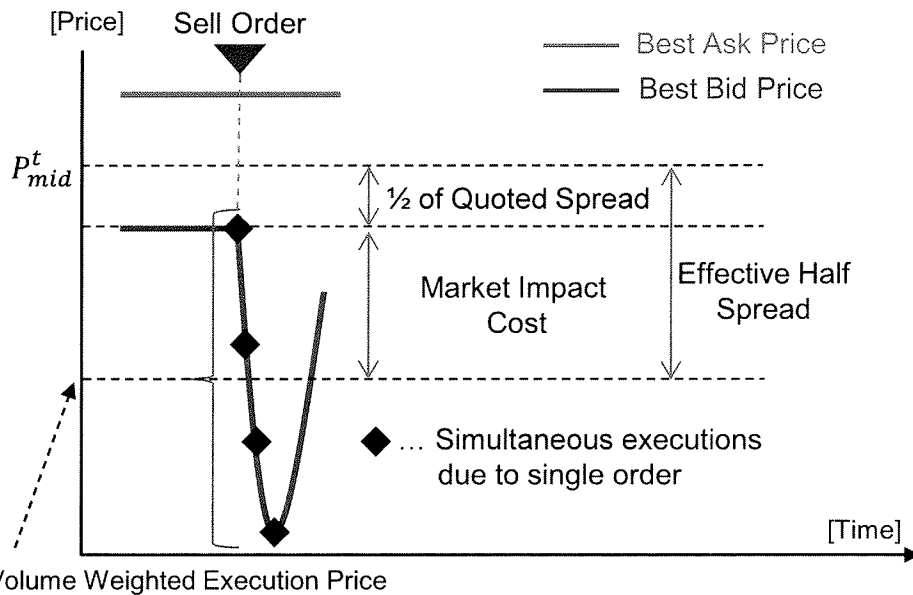
$$Q_{50} = \sum_{x=1}^{k} Q_{ask,x}^t + \alpha^t = \sum_{y=1}^{l} Q_{bid,y}^t + \beta^t$$

$$(Q_{ask,k+1}^t > \alpha^t \geq 0, \ Q_{bid,l+1}^t > \beta^t \geq 0)$$

$$es_{50}^t = \frac{1}{2}(es_{50,buy}^t + es_{50,sell}^t)$$

$$= \frac{1}{2}\left(\frac{\{\sum_{x=1}^{k}(P_{ask,x}^t \times Q_{ask,x}^t) + P_{ask,k+1}^t \times \alpha^t\}/Q_{50} - P_{mid}^t}{P_{mid}^t}\right.$$

$$\left. + \frac{P_{mid}^t - \{\sum_{y=1}^{l}(P_{bid,y}^t \times Q_{bid,y}^t) + P_{bid,l+1}^t \times \beta^t\}/Q_{50}}{P_{mid}^t}\right)$$

Note1: In the calculation of percentile volumes, simultaneous executions at multiple price levels due to a single order are regarded as one execution and the sum of the execution volumes at each price level is used.

Note2: es_{50}^t is the average of $es_{50,buy}^t$ and $es_{50,sell}^t$, respectively the virtual effective half spreads for market buy and sell orders.

Note3: $(P_{ask,1}^t, Q_{ask,1}^t), (P_{ask,2}^t, Q_{ask,2}^t), (P_{ask,3}^t, Q_{ask,3}^t)$... are quoted ask prices and volumes from the midpoint of BBO at t, $(P_{bid,1}^t, Q_{bid,1}^t), (P_{bid,2}^t, Q_{bid,2}^t), (P_{bid,3}^t, Q_{bid,3}^t)$... are for bids.

3.1 Result 1 – Spread Costs

✓ Both quoted spread and effective half spread decreased in the test groups.
✓ No significant change in quoted spread for some Group D issues (see bottom right chart on P14).
✓ Effective half spread in test groups were roughly ½ of the quoted spread even after tick size change, that is, market impact costs of actual executions in test groups did not increase.

Changes in Quoted Spread and Effective Half Spread

	Before	After	% Change	t-statistic
Panel A: Quoted Spread ($\overline{qs}$) (bps)				
Phase 1				
Group A (changed)	14.48	5.96	-56.52%	16.412***
Group B (unchanged)	12.52	12.50	+0.09%	–
Phase 2 90% reduction				
Group C (changed from 1 to 0.1)	19.27	4.80	-71.94%	25.758*** → more effective
Group D (changed from 1 to 0.5)	6.44	4.90	-22.67%	9.423***
Group E (unchanged) 50% reduction	5.25	5.07	-1.37%	–
Panel B: Effective Half Spread ($\overline{es}$) (bps)				
Phase 1				
Group A (changed)	7.06	2.71	-58.26%	17.765***
Group B (unchanged)	6.19	6.21	+0.76%	–
Phase 2	approx. ½ of quoted spread			
Group C (changed from 1 to 0.1)	9.74	2.27	-73.94%	28.603***
Group D (changed from 1 to 0.5)	3.12	2.28	-24.68%	10.036***
Group E (unchanged)	2.28	2.27	+1.53%	–

closer to reduction rate

Note1: Figures indicate the average of the results for each issue in each group.
Note2: t-statistics are obtained using a two-tailed t-test symmetric about zero of the difference in % change between test groups and control groups.
*, ** and *** indicate 10%, 5% and 1% significance levels respectively.

✓ Value-based effective half spread, or the difference between the actual execution value and the virtual execution value using the midpoint of BBO as the execution price, means the spread cost actually borne by investors.

✓ Total spread cost reduction since Phase 1 was JPY 556 million, and total value-based effective half spread decreased by 3.76bps, which is equal to JPY 397 million on a daily basis (JPY 99.2 billion on an annual basis) based on ADV of TOPIX100 constituents.

Changes in Value-Based Effective Half Spread

	Effective Half Spread (JPY 100 mil.)			Ratio to Trading Value (bps)		
	Before	After	Change	Before	After	Change
Phase 1						
All TOPIX100 constituents	7.04	5.85	-1.20	5.55	4.17	-1.38
Group A (changed)	3.53	1.46	-2.07	5.37	2.08	-3.29
Group B (unchanged)	3.52	4.39	+0.87	5.73	6.25	+0.52
Phase 2		JPY 556 mil. decrease			3.76bps decrease	
All TOPIX100 constituents	2.93	1.48	-1.45	3.54	1.79	-1.75
Group C (changed from 1 to 0.1)	1.62	0.37	-1.25	8.31	1.91	-6.39
Group D (changed from 1 to 0.5)	0.95	0.72	-0.24	2.37	1.82	-0.54
Group E (unchanged)	0.35	0.39	+0.04	1.53	1.63	+0.10

(Note) Includes the impact of changes in market conditions in the periods subject to analysis

Note1: Value-based effective half spread is calculated by multiplying execution volume by the difference between the execution price and the midpoint of BBO.
Note2: ADV of TOPIX100 constituents from 2013/10/31 to 2014/10/30 is calculated to be JPY 1,057 billion.
Note3: Figures are daily averages of total value-based effective half spread in each group.
Note4: Ratio for trading value is calculated by dividing total value-based effective half spread by total trading value in each group.

3.2 Result 2 – Timing Costs

✓ One-minute volatility decreased at 1% significance level for Groups A and C, but ten-minute volatility decreased at 5% significance level only for Group A.
✓ Narrowing tick sizes seems to reduce shorter term intraday volatility.
✓ No significant change for Group D, possibly due to relatively less significant tick size reduction.

Changes in Intraday Volatility

	Before	After	% Change	t-statistic
Panel A: One-Minute Volatility ($\overline{\sigma_1}$) (bps)				
Phase 1				
Group A (changed)	6.64	7.63	+15.41%	6.420***
Group B (unchanged)	6.32	8.63	+37.78%	–
Phase 2				
Group C (changed from 1 to 0.1)	5.86	5.55	-5.14%	4.259***
Group D (changed from 1 to 0.5)	5.08	5.25	+4.56%	1.023
Group E (unchanged)	4.86	5.21	+7.38%	–
Panel B: Ten-Minute Volatility ($\overline{\sigma_{10}}$) (bps)				
Phase 1				
Group A (changed)	17.33	22.04	+27.15%	2.179**
Group B (unchanged)	17.17	23.00	+35.97%	–
Phase 2				
Group C (changed from 1 to 0.1)	14.68	15.98	+10.07%	0.399
Group D (changed from 1 to 0.5)	13.45	14.69	+10.65%	0.345
Group E (unchanged)	13.31	14.84	+11.85%	–

The market was highly volatile after Phase 1, resulting in increased volatility for both groups. However, it was smaller for Group A.

Note1: Figures indicate the average of the results for each issue in each group.
Note2: t-statistics are obtained using a two-tailed t-test, symmetric about zero, of the difference in % change between test groups and control groups.
    *, ** and *** indicate 10%, 5% and 1% significance levels respectively.

✓ Reduced intraday volatility in shorter time frames after tick size change due to BBO price moving at smaller tick sizes.

✓ For test groups, variance ratio approached one with large reductions in short-term intraday volatility.

Example of Changes in Intraday BBO Price Movement
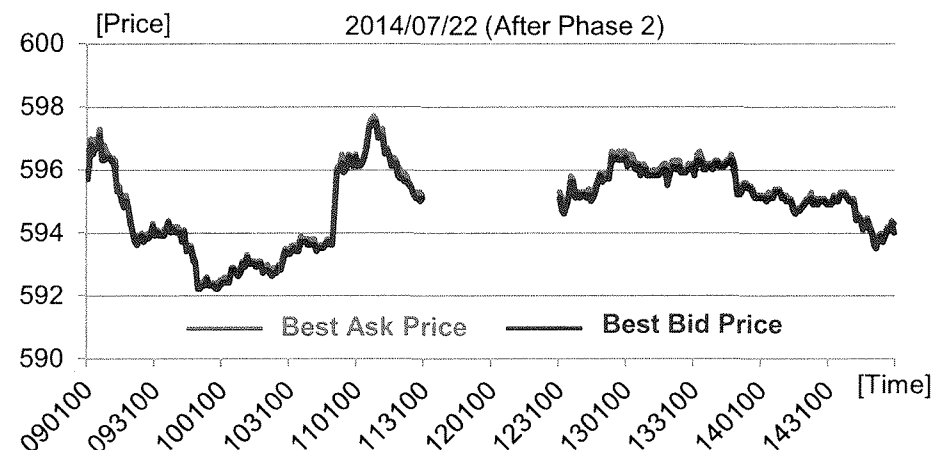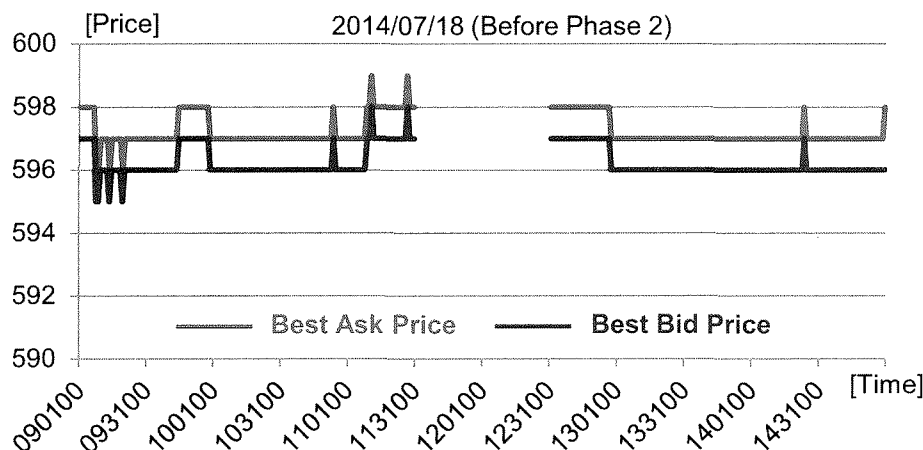
Note1: BBO price movement every minute in Mitsubishi UFJ Financial Group (code: 8306).
Note2: Time indicated in HHMMSS.

Changes in Variance Ratio

	Variance Ratio $\overline{vr}$		$|1 - vr|$	
	Before	After	Before	After
Phase 1				
Group A (changed)	0.82	0.91	0.21	0.15
Group B (unchanged)	0.86	0.84	0.18	0.20
Phase 2				
Group C (changed from 1 to 0.1)	0.79	0.91	0.22	0.17
Group D (changed from 1 to 0.5)	0.83	0.88	0.20	0.18
Group E (unchanged)	0.87	0.89	0.18	0.17

Variance ratio in test groups approached one.
→ Price movement is closer to random walk.

Note1: Figures indicate the average of the results for each issue in each group.
Note2: $|1 - vr|$ is the average of the absolute value of difference between vr^d and one.

3.3 Result 3 – Market Impact Costs

✓ Execution size, or volume of each execution, decreased with larger executed order size.
✓ This may have been due to order slicing to reduce market impact after tick size change.

Changes in Execution Size

	Before	After	% Change	t-statistic
Panel A: Execution size: 50th percentile (shares)				
Phase 1		Analysis on the next page was conducted using these figures for each issue.		
Group A (changed)	264	227	-17.33%	5.816***
Group B (unchanged)	908	898	-1.82%	–
Phase 2				
Group C (changed from 1 to 0.1)	1,426	1,130	-20.19%	3.648***
Group D (changed from 1 to 0.5)	405	364	-12.60%	6.908***
Group E (unchanged)	123	127	+2.89%	–
Panel B: Execution size: 90th percentile (shares)				
Phase 1				
Group A (changed)	1,905	995	-45.54%	16.086***
Group B (unchanged)	7,108	7,826	3.45%	–
Phase 2				
Group C (changed from 1 to 0.1)	13,073	7,029	-47.03%	5.967***
Group D (changed from 1 to 0.5)	2,331	1,776	-23.82%	12.183***
Group E (unchanged)	563	585	+4.00%	–
Panel C: Execution size: 99th percentile (shares)				
Phase 1				
Group A (changed)	8,891	3,172	-57.19%	15.509***
Group B (unchanged)	42,547	48,682	+0.16%	–
Phase 2				
Group C (changed from 1 to 0.1)	90,883	31,470	-68.07%	16.609***
Group D (changed from 1 to 0.5)	9,025	6,227	-27.03%	10.050***
Group E (unchanged)	1,876	2,005	+7.59%	–

small reduction

large reduction

Note1: In the calculation of percentile of execution size, simultaneous executions at multiple price levels due to a single order are regarded as one execution and the total of the execution volumes at each price level is used.
Note2: Figures indicate the average of the results for each issue in each group.
Note3: t-statistics are obtained using a two-tailed t-test, symmetric about zero, of the difference in % change between test groups and control groups.
   *, ** and *** indicate 10%, 5% and 1% significance levels respectively.

✓ $\overline{es}_{50}$ and $\overline{es}_{90}$ decreased at the 1% significance level in test groups, reducing trading costs.

✓ No significant change in $\overline{es}_{99}$, with increased market impact cost offsetting narrower quoted spread.

Changes in Virtual Effective Half Spread

	Before	After	% Change	t-statistic
Panel A: Effective half spread at 50th percentile of execution size before tick size change ($\overline{es}_{50}$) (bps)				
Phase 1				
Group A (changed)	7.24	3.05	-55.66%	16.398***
Group B (unchanged)	6.27	6.27	+0.21%	–
Phase 2				
Group C (changed from 1 to 0.1)	9.64	2.47	-71.02%	24.917***
Group D (changed from 1 to 0.5)	3.23	2.49	-21.53%	8.890***
Group E (unchanged)	2.63	2.54	-1.35%	
Panel B: Effective half spread at 90th percentile of execution size before tick size change ($\overline{es}_{90}$) (bps)				
Phase 1				
Group A (changed)	7.60	4.62	-37.89%	13.139***
Group B (unchanged)	6.69	6.81	+2.60%	–
Phase 2				
Group C (changed from 1 to 0.1)	9.82	3.68	-57.35%	15.677***
Group D (changed from 1 to 0.5)	3.61	3.15	-11.39%	4.067***
Group E (unchanged)	3.11	2.98	-2.57%	–
Panel C: Effective half spread at 99th percentile of execution size before tick size change ($\overline{es}_{99}$) (bps)				
Phase 1				
Group A (changed)	9.34	9.77	+4.00%	1.554
Group B (unchanged)	8.55	9.17	+8.57%	
Phase 2				
Group C (changed from 1 to 0.1)	11.12	8.61	-15.96%	2.053**
Group D (changed from 1 to 0.5)	5.27	5.22	-0.20%	-2.751***
Group E (unchanged)	4.65	4.35	-5.73%	–

significant reduction
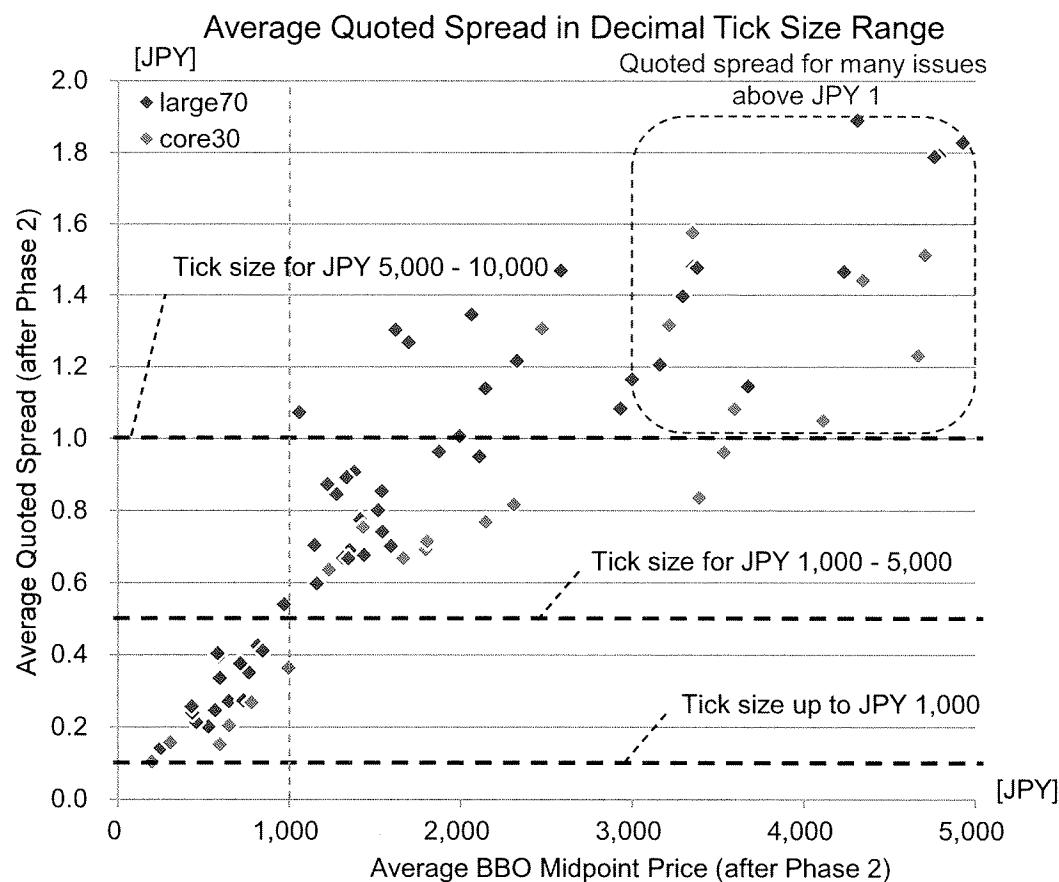
no significant change

Note1: Figures indicate the average of the results for each issue in each group.
Note2: t-statistics are obtained using a two-tailed t-test, symmetric about zero, of the difference in % change between test groups and control groups.
   *, ** and *** indicate 10%, 5% and 1% significance levels respectively.

✓ Larger quoted Spread reduction effect with greater BBO quoted depth.
✓ Average quoted spread for issues in the JPY 3,000-5,000 price band was generally above JPY 1, the next larger tick size.

Quoted Spread Reduction and
Average BBO Quoted Depth before Tick Size Change

- Group A
- Group C
- Group D

Y-axis: Quoted Spread Reduction (0% to 100%)
X-axis: Average BBO Quoted Depth (before Phase 1, shown in JPY) [JPY mil.] (0 to 1,000)

Average Quoted Spread in Decimal Tick Size Range
[JPY]
Quoted spread for many issues above JPY 1

- large70
- core30

Tick size for JPY 5,000 - 10,000
Tick size for JPY 1,000 - 5,000
Tick size up to JPY 1,000

Y-axis: Average Quoted Spread (after Phase 2) (0.0 to 2.0)
X-axis: Average BBO Midpoint Price (after Phase 2) [JPY] (0 to 5,000)

Note1: Average BBO quoted depth is the average value calculated by multiplying the total amount of quoted shares in BBO by the BBO midpoint price every minute.
Note2: Average BBO midpoint price is calculated based on BBO midpoint prices observed every minute.

✓ Issues with large BBO quoted depth reductions showed significant decrease in quoted spread, leading to concerns that increased market impact would negatively impact trading cost.
✓ However, such negative impact was not observed since the effective spread also decreased significantly for such issues.

Comparison of Quoted Spread Reduction and BBO Quoted Depth Reduction
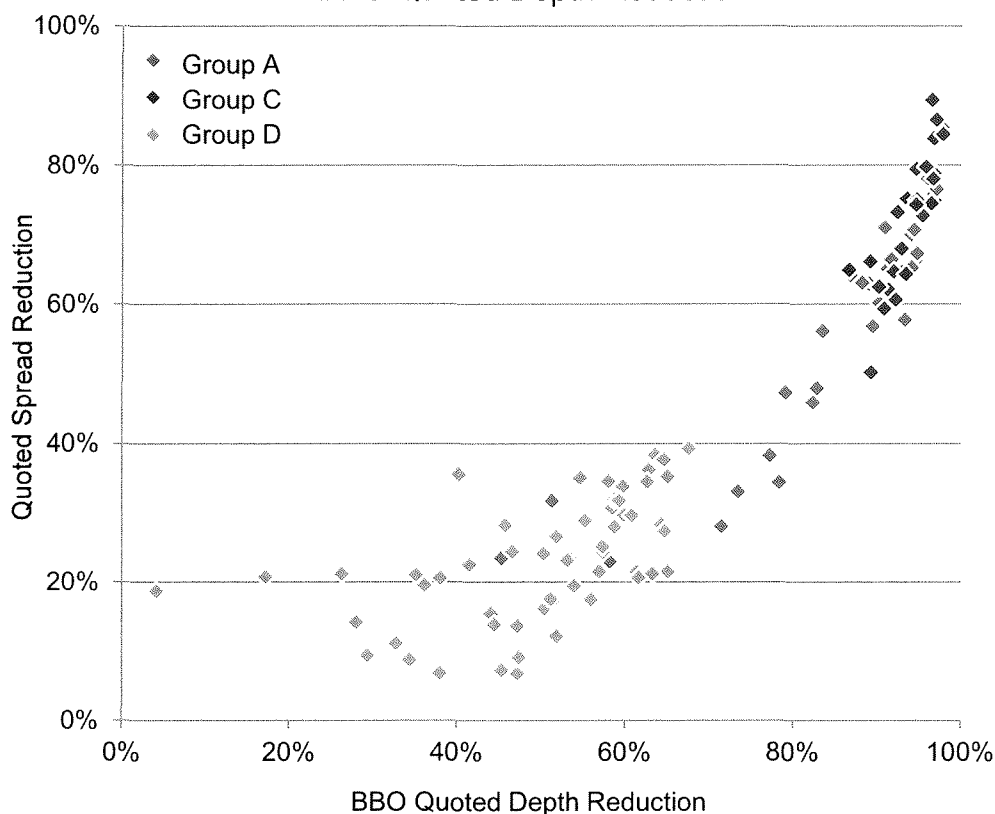
Comparison of Effective Spread Reduction and BBO Quoted Depth Reduction
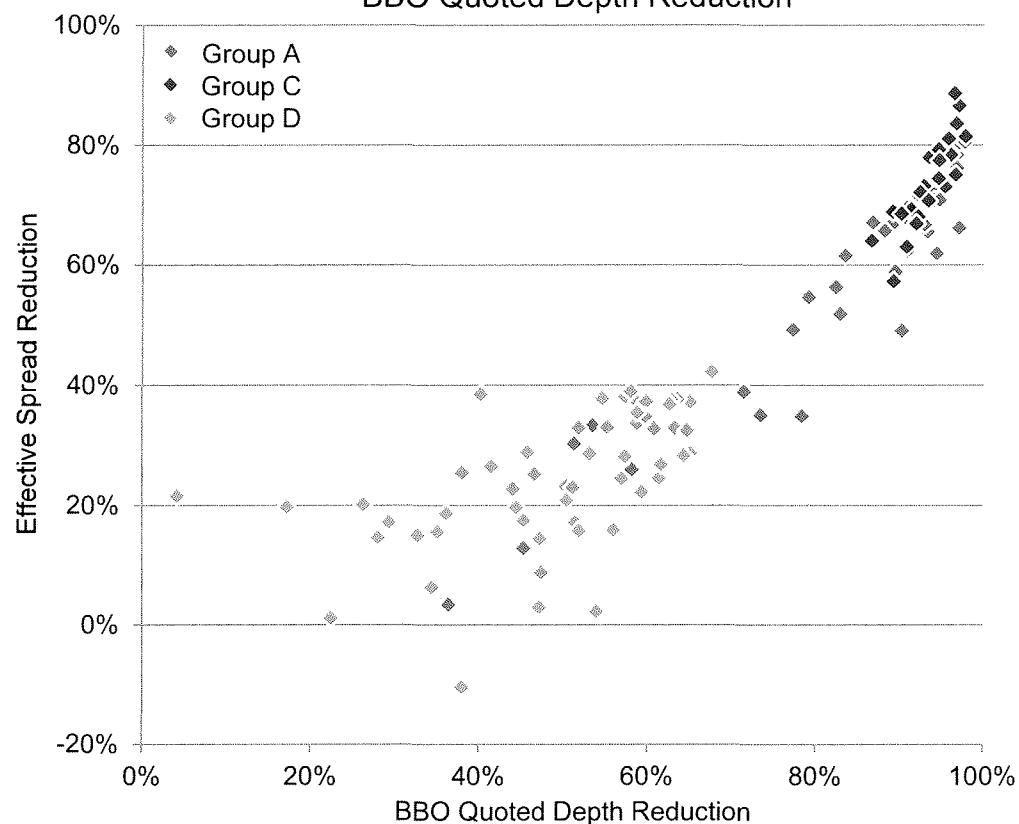
4. Conclusion

✓ Both quoted spread and effective spread decreased, and total value-based effective half spread in all TOPIX100 constituents was reduced by 3.76bps, which is equal to JPY 397 million on a daily basis.

✓ Reduction in intraday volatility at one-minute intervals was statistically significant.

✓ Increased market impact cost did not negatively impact effective spread even for extremely large-sized orders.

The results show that trading cost in TOPIX100 constituents decreased.

Findings

● Since a correlation was observed between the quoted spread reductions and BBO quoted depth before tick size change, smaller tick size is not expected to reduce quoted spread for issues that do not have sufficient liquidity.

● Based on the BBO quoted depth reductions in TOPIX100 constituents from Phases 1 and 2, narrowing the tick sizes further is not likely to result in further reductions in trading cost.

● With regard to the optimal tick size, considerations should be made to broaden the tick sizes for price ranges where the quoted spread was generally larger than the next larger tick size.

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【Appendix】 Trading Value of TOPIX100 Constituents
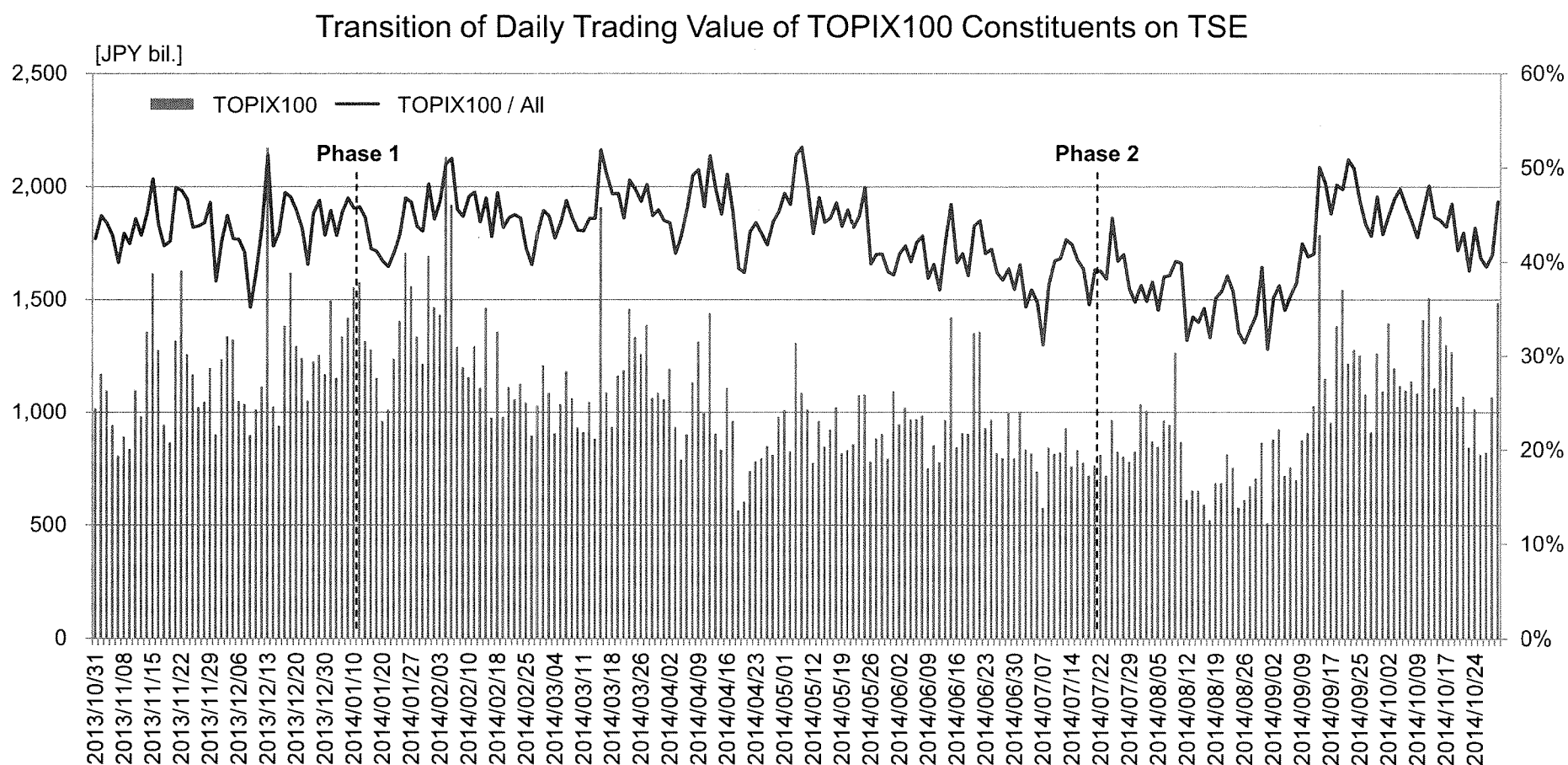
Transition of Daily Trading Value of TOPIX100 Constituents on TSE

Note1: During this period (2013/10/31 to 2014/10/30) there was no change in the constituents of TOPIX100.
Note2: Line chart indicates ratio of overall auction equity trading on TSE.

Transition of Number of Orders in TOPIX100 Constituents on TSE
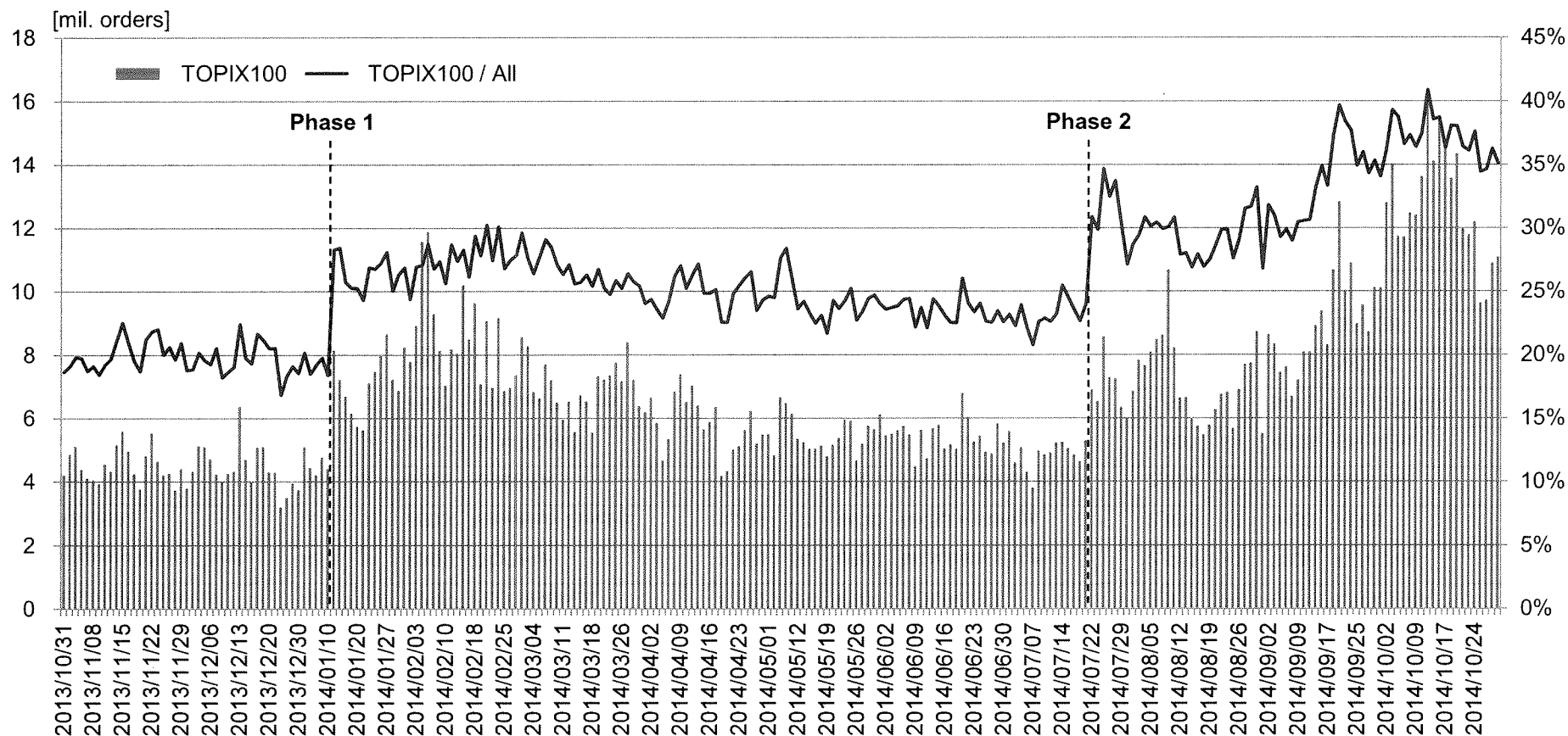

Note1: During this period (2013/10/31 to 2014/10/30) there was no change in the constituents of TOPIX100.
Note2: Line chart indicates ratio of overall auction equity trading on TSE.

【Appendix】 TOPIX100 Constituents

□ ... Core30   □ ... Large70

No.	Code	Name	Price	No.	Code	Name	Price	No.	Code	Name	Price	No.	Code	Name	Price
1	8411	Mizuho FG	200	26	8267	AEON CO.,	1,157	51	9064	YAMATO HOLDINGS	2,096	76	6988	NITTO DENKO	4,646
2	9202	ANA HOLDINGS	246	27	7752	RICOH	1,163	52	1925	DAIWA HOUSE	2,131	77	4502	Takeda	4,670
3	5401	Nippon Steel	304	28	6752	Panasonic	1,193	53	8058	Mitsubishi	2,149	78	6902	DENSO	4,701
4	9532	OSAKA GAS	438	29	9502	Chubu Electric Power	1,236	54	8725	MS&AD Insurance	2,305	79	9021	JR West	4,722
5	4188	Mitsubishi Chemical	443	30	8795	T&D Holdings	1,262	55	6301	KOMATSU	2,317	80	6971	KYOCERA	4,868
6	8309	Sumitomo Mitsui Trust	453	31	8001	ITOCHU	1,298	56	8802	Mitsubishi Estate	2,575	81	7203	TOYOTA	6,006
7	6502	TOSHIBA	470	32	6503	Mitsubishi Electric	1,299	57	8630	NKSJ Holdings	2,606	82	9433	KDDI	6,167
8	5020	JX Holdings	538	33	6326	KUBOTA	1,351	58	4901	FUJIFILM Holdings	2,874	83	9735	SECOM	6,182
9	8308	Resona Holdings	573	34	8053	SUMITOMO	1,358	59	7270	Fuji Heavy Industries	2,891	84	4063	Shin-Etsu	6,197
10	8332	The Bank of Yokohama	586	35	4503	Astellas Pharma	1,382	60	1963	JGC	3,052	85	8113	UNICHARM	6,359
11	5201	Asahi Glass	593	36	1928	Sekisui House	1,400	61	2502	Asahi Group	3,144	86	6594	NIDEC	6,577
12	9531	TOKYO GAS	595	37	8750	The Dai-ichi Life	1,413	62	4578	Otsuka	3,234	87	6367	DAIKIN	6,719
13	8306	Mitsubishi UFJ FG	598	38	2503	Kirin Holdings	1,436	63	8766	Tokio Marine	3,253	88	9432	NTT	6,734
14	7011	Mitsubishi Heavy	648	39	5802	Sumitomo Electric	1,480	64	7269	SUZUKI MOTOR	3,280	89	8035	Tokyo Electron	7,026
15	8604	Nomura Holdings	659	40	7731	NIKON	1,535	65	7741	HOYA	3,389	90	9984	SoftBank	7,654
16	7202	ISUZU MOTORS	672	41	2802	Ajinomoto Co.,	1,551	66	7751	CANON	3,390	91	9020	JR East	8,548
17	3402	TORAY INDUSTRIES	684	42	1605	INPEX	1,569	67	8801	Mitsui Fudosan	3,416	92	6981	MURATA	9,708
18	8002	Marubeni	729	43	8591	ORIX	1,616	68	7267	HONDA	3,569	93	1878	DAITO TRUST	12,010
19	6501	Hitachi	756	44	8031	MITSUI & CO.,	1,645	69	2914	JAPAN TOBACCO	3,703	94	7974	Nintendo	12,495
20	6702	FUJITSU	782	45	6758	SONY	1,680	70	5108	BRIDGESTONE	3,803	95	9022	JR Central	15,355
21	3407	ASAHI KASEI	787	46	5713	Sumitomo Metal Mining	1,713	71	8316	Sumitomo Mitsui FG	4,066	96	6954	FANUC	17,150
22	8601	Daiwa Securities	835	47	9437	NTT DOCOMO	1,790	72	4452	Kao Corp	4,208	97	4661	ORIENTAL LAND	18,870
23	7201	NISSAN MOTOR	987	48	4568	DAIICHI SANKYO	1,869	73	4523	Eisai	4,216	98	6273	SMC CORP	27,055
24	9503	The Kansai Electric	1,015	49	4911	Shiseido	1,998	74	8830	Sumitomo R&D	4,248	99	9983	FAST RETAILING	32,355
25	7912	Dai Nippon Printing	1,047	50	5411	JFE Holdings	2,076	75	3382	Seven & I HD	4,363	100	6861	KEYENCE	43,100

Note: Constituents during 2013/10/31 to 2014/10/30.

Price ... Base price on 2014/07/22 (beginning of Phase 2)

JAPAN EXCHANGE GROUP

JPX

Impact of Tick Size Pilot Program on Trading Costs
at Tokyo Stock Exchange

Masafumi Kondo

January 20, 2015

Vol. 07

Impact of Tick Size Pilot Program on Trading Costs at Tokyo Stock Exchange

Masafumi Kondo[*]

January 20, 2015

Abstract

   This paper analyzes the impact on trading from the change in tick size for TOPIX100 constituents implemented in January and July 2014 using the FLEX Full data, which is the real time market data feed service provided by the Tokyo Stock Exchange. Furthermore, it examines whether the objective of such change, which was to improve the trading costs for investors, has been achieved. In analyzing the trading cost, we measured the observable trading-related cost under the implementation shortfall (IS) method, i.e., spread cost, timing cost, and market impact cost, using the respective quoted spread, effective spread, intraday volatility, and calculated effective spread by order size as the assessment index and compared them before and after the tick size change. The quoted spread and effective spread fell for all issues following tick size reduction, and the effective half spread for all TOPIX100 constituents fell from 5.55bp to 1.79bp, which was a decline of 397 million yen per day on a value basis. In addition, comparison of the volatility of the fluctuation rate for the midpoint of BBO every one- and ten-minutes indicates a larger downward trend in one-minute volatility following tick size reduction. In the calculation of the effective spread by order size using order book information, no deterioration was evident in effective spread following tick size reduction, apart from some issues, even for extremely large-sized orders. These results confirmed that trading-related costs under the IS method fell, following the change in tick size.

1

1 Introduction

Auction trading at Tokyo Stock Exchange (hereafter, the "TSE") and other major stock exchanges around the world is conducted by executing orders based on the principles of price priority and time priority. Under these principles, buy (sell) orders at a higher (lower) price are given priority over buy (sell) orders at lower (higher) prices, and earlier orders have priority over later orders. That is, an order must be indicated at a better price for it to be prioritized over some or all orders already in the order book. As such, a compromise on the transaction price may be required at such time since the price of the order must be better by at least one tick. Therefore, tick size is not only the unit of price for providing a quote but also the minimum cost required to determine the priority ranking for buying and selling. The tick size needs to be sufficiently small to allow investors to indicate an appropriate price when quoting based on their individual investment decision. However, too small a tick size can cause the priority ranking of quotes to change even with very small differences in price that have virtually no discernible economic impact. This causes the balance between the principles of price priority and time priority to collapse and also creates an enormous volume of minute prices which negatively impacts practical complexities. Thus, the appropriate setting of tick size is a very important matter in trading rule design.

The focus of this paper is on the influence that the change in tick size implemented by the TSE on January 14, 2014 and July 22, 2014 had on trading and whether this improved investor trading costs, which was the stated objective of the change. The paper is organized as follows: Section 2 provides a general overview of tick size in Japan; whereas Section 3 provides a general overview of tick size outside Japan. Section 4 discusses previous studies concerning the impact of tick size on trading. Section 5 gives an outline of the data used for analysis in this paper together with the methodology of such analysis. Section 6 provides the results of the analysis. Section 7 discusses the conclusions of this paper and the prospective outlook for tick size.

2 Overview of Tick Size in Japan

The TSE had previously maintained a uniform tick size regardless of the price band for quoting. However, the TSE implemented a tiered regime with different tick sizes corresponding to price bands from December 2, 1985 for listings of high priced foreign shares and shares for the Nippon Telegraph and Telephone Corporation[*1]. There have been changes from time to time with increased sophistication and variety of trading methods leading to increased demand for price formation with smaller pricing increments as well as improvements in the capacity to process orders in the trading system (Table1) . The change in the tick size has consistently moved toward smaller

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[*1] Under the tiered regime, the tick size is differentiated for price bands. Thus, the ratio between price and tick size can be maintained at a certain level regardless of the price band of the quoted price.

increments, and immediately prior to the recent change there was a tick size reduction for some price bands on January 4, 2010 in conjunction with the launch of the current trading system known as arrowhead.

Table1   Transitional changes in tick size

Price		1985/12/02	1998/04/13	2000/07/17	2008/07/22	2010/01/04
Above	Up to 1,000 yen	1	1	1	1	
1,000 yen	2,000 yen					1
2,000 yen	3,000 yen	10	5	5	5	
3,000 yen	5,000 yen		10	10	10	5
5,000 yen	10,000 yen					10
10,000 yen	30,000 yen					
30,000 yen	50,000 yen	100	50	50	50	50
50,000 yen	100,000 yen		100	100	100	100
100,000 yen	300,000 yen					
300,000 yen	500,000 yen	1,000	1,000	1,000	1,000	500
500,000 yen	1 million					
1 million	3 million					1,000
3 million	5 million	10,000	10,000	10,000	10,000	5,000
5 million	20 million					10,000
20 million	30 million			50,000	50,000	
30 million	50 million			100,000	100,000	50,000
50 million						100,000

* Units are yen.

Although, the TSE has steadily addressed the need for tick size reduction in this manner, but it has been constantly noted that the tick size for high liquidity issues and low price bands has scope for further improvement even with the 2010 change in tick size. There are two factors behind this argument. First is the constraint in terms of trading rules that the difference between the best bid offer on the selling and buying sides (hereafter, the "quoted spread") cannot be smaller than the tick size. There is a tendency for the quoted spread on issues with high liquidity to become small due to the large number of orders quoted in the market; in TSE, the quoted spread had always been same as tick size on many high liquidity issues. As the fair price is between the best bid offer on the sell and buy sides, it can generally be considered the midpoint, and opportunities to trade at a price closer to the fair price i.e., opportunities for price improvement could possibly be lost for these issues. Second, for a long time the minimum tick size on the TSE had been the 1 yen used in the minimum units for currency[2]. Thus, the tick size had been extremely large as compared with the quoted price for low price bands (referring to what was left after dividing tick size by the price quoted. Hereafter, the "ratio between price and tick size"). When the ratio between price and tick size is very large, it is not only difficult for investors to appropriately indicate a price based on an investment decision but also becomes hard to reflect small changes in the value of stocks in the

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[2] Tick sizes smaller than 1 yen such as 0.1 yen were used prior to the abolition of the sub-yen currency in 1953.

execution price; i.e., the stock price, which could damage the price discovery mechanism in the financial market.

This was considered with the change in tick size on January 14, 2014 and July 22, 2014 (Table2) . This successive change is referred to as Phase 1 and 2 of the step-by-step adjustment in tick size, and once again is examined considering the appropriate tick size based on matters such as the change in trading status in Phases 1 and 2. When the U.S. introduces new trading rules, the lead is generally taken by the U.S. Securities and Exchange Commission (SEC) with a pilot program introduced on a provisional basis for a limited period of time to consider its effectiveness. This is the first time the TSE has changed its trading rules with such an experimental approach. In addition, in relation to the details of the change in tick size itself, two new trials are evident in dealing with the aforementioned matters.

First, the change in tick size is limited to only some issues. To date, stock exchanges in Japan have applied the same tick size for the same types of listed products and not just at the TSE. However, this time a smaller tick size shall apply only to the constituent issues of the TOPIX100[3], which is a share price index calculated with reference to constituent issues determined by the TSE, and there is no change to the tick size of other issues[4]. Second, sub 1 yen tick sizes of 0.1 yen and 0.5 yen have been introduced for issues in low price bands. The TSE has been unifying the trading units for domestic stocks at 100 shares from November 2007, and the trading units of all TOPIX100 constituents were either 100 shares or 1,000 shares from July 22, 2014. Therefore, even if the execution price includes below the decimal point, the proceeds for shares purchased would not be below 1 yen. Thus, it became possible to have sub 1 yen tick sizes[5].

Furthermore, Proprietary Trading System (PTS)[6] employed smaller tick size for all issues when they commenced operation; however, TOPIX100 constituents for some price bands have had the same tick size as the TSE since July 22, 2014(Table3).

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[3] The constituents of TOPIX100 comprise domestic stocks listed on the 1st section of the TSE, which are selected from constituents of the share price index TOPIX. TOPIX Core30 comprises the 30 issues with the largest trading value and market capitalization, and TOPIX Large 70 comprises the next 70 largest issues in terms of trading value and market capitalization.

[4] There are precedents in overseas exchanges, as noted later, for applying different tick size in accordance with an issue's liquidity for the same type of listed products.

[5] When trading units started to be unified in 2007 there were eight types of trading units for domestic stocks listed in Japan, whereas as of January 20, 2015 there was either 100 shares or 1,000 shares.

[6] There were two PTS as of January 20, 2015: Japannext PTS (commenced operations on August 20, 2007) operated by SBI Japannext Co., Ltd. and Chi-X Japan (commenced operations on July 29, 2007) operated by Chi-X Japan, Ltd.

[7] Apart from markets using the noted tick size, Japannext PTS is opening markets that have the same tick size as the TSE.

Table2 Details of the recent change in tick size

Price		TOPIX100 constituents		Other issues
Above	Up to	2014/01/14	2014/07/22	
Above	Up to 1,000 yen	1	0.1	1
1,000 yen	3,000 yen	1	0.5	1
3,000 yen	5,000 yen	1	0.5	5
5,000 yen	10,000 yen	1	1	10
10,000 yen	30,000 yen	5	5	10
30,000 yen	50,000 yen	5	5	50
50,000 yen	100,000 yen	10	10	100
100,000 yen	300,000 yen	50	50	100
300,000 yen	500,000 yen	50	50	500
500,000 yen	1 million	100	100	1,000
1 million	3 million	500	500	1,000
3 million	5 million	500	500	5,000
5 million	10 million	1,000	1,000	10,000
10 million	30 million	5,000	5,000	10,000
30 million	50 million	5,000	5,000	50,000
50 million		10,000	10,000	100,000

* Units are yen.

Table3 Tick size for PTS

Price		Chi-X Japan	Japannext PTS*7	TSE	
Above	Up to			TOPIX100 constituents	Other issues
Above	Up to 1,000 yen	0.1	0.1	0.1	1
1,000 yen	3,000 yen	0.1	0.1	0.5	1
3,000 yen	5,000 yen	0.1	0.5	0.5	5
5,000 yen	10,000 yen	1	1	1	10
10,000 yen	30,000 yen	1	1	5	10
30,000 yen	50,000 yen	1	5	5	50
50,000 yen	100,000 yen	10	10	10	100
100,000 yen	300,000 yen	10	10	50	100
300,000 yen	500,000 yen	10	50	50	500
500,000 yen	1 million	10	100	100	1,000
1 million	3 million	10	100	500	1,000
3 million	5 million	10	100	500	5,000
5 million	10 million	10	100	1,000	10,000
10 million	30 million	10	100	5,000	10,000
30 million	50 million	10	100	5,000	50,000
50 million		10	100	10,000	100,000

* Units are yen.

3   Overview of Tick Size outside Japan

For a long time, fractions (units of 1/x per USD) were used for the tick size on the U.S. exchanges, and this used to be 1/8 of 1USD. However, in 1992, the American Stock Exchange (AMEX)[*8] started to use tick sizes of 1/16 of 1USD and 1/32 of 1USD for some price bands, and the New York Stock Exchange (NYSE) and NASDAQ[*9] also used similar small fraction tick sizes. Subsequently, the SEC instructed exchanges within the U.S. and NASDAQ to change to tick sizes of 1 cent in January 2000. In April 2001, all the exchanges and markets that were instructed to do so were using tick sizes of 1 cent. This shift to a tick size of 1 cent in the U.S. that started in January 2000 was referred to as decimalization. Furthermore, even after decimalization there was no specific regulation concerning tick size for the Electronic Communications Network (ECN, the equivalent of Japan's PTS). Subsequently, in 2004, the SEC adopted a minimum price increment of 1 cent that also applied to ECN under Rule 612 of Regulation National Market System (Reg. NMS)[*10], which is the legislation concerning comprehensive market system reforms[*11]. This does not make a tick size of 1 cent compulsory, with each respective exchange permitted to use tick sizes larger than 1 cent. However, ultimately all exchanges have used the minimum tick size prescribed in the Reg. NMS (Table4) . However, Section 106 of the Jumpstart Our Business Startups Act, which was enacted for the promotion of new business activities in April 2012, notes that too small a tick size can be a hindrance to stimulating trading in small capitalization companies' securities with insufficient liquidity and that the small tick size could be leading to the small number of IPOs in recent years. Consequently, there are plans to implement a 1-year pilot program for a tick size of 5 cents for issues that meet certain criteria[*12].

Table4   Tick size in the US

Price		Exchanges and ECN
or more	Below 1USD	0.0001
1USD		0.01

* Units are USD (0.01USD is 1 cent).

In Europe, the EU's Market in Financial Instrument Directive (MiFID), which was enacted in

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[*8] Bought by the New York Stocks Exchange's parent company -NYSE Euronext- in 2008, and is currently an exchange under that umbrella referred to as NYSE MKT.

[*9] Changed its status from an over-the-counter market to a national securities exchange on acquisition of a license in 2006.

[*10] Full implementation from October 2007, following a more than 2-year transitional period adopted in June 2006.

[*11] However, 0.01 cent is the minimum value for price bands that are less than 1USD. Furthermore, although the NYSE, NASDAQ, and BATS has jointly submitted a petition for approval for tick sizes smaller than 1 cent for price bands between 1USD and 20USD to the SEC on April 30, 2010, it has not been realized.

[*12] The outline of the three terms and conditions are as follows: (1) a market capitalization of USD5 billion or less; (2) a price of at least 2USD; and (3) a daily average trading volume of 1 million shares or less.

November 2007, abolished the requirement to trade stocks only through stock exchanges that had been approved by some EU member countries. Consequently, Chi-X Europe and BATS Europe[13] in 2007 and 2008, respectively started operations as Multilateral Trading Facilities (MTF) handling pan-European listed issues. Each country's exchange had independently set their own tick size. However, there was awareness that the emergence of MTF would result in tick size becoming a competitive factor between trading venues, with the London Stock Exchange (LSE) reducing the tick size on FTSE100[14] constituent issues in March 2007 to coincide with the start of Chi-X Europe's operations. To avoid confusing changes in tick size, MTF such as BATS Europe put forward a proposal to major exchanges within Europe that they jointly standardize the tick size across Europe. Following the start of a review and discussion by the parent companies of major exchanges such as the LSE Group, NYSE Euronext[15], and Deutsche Börse Group with the MTF that put forward the proposal in December 2008, the Federation of European Stock Exchanges (FESE) took over the lead in the review in March 2009 and conducted consultations up until the end of June that year. Ultimately, there was an agreement for each trading venue to adhere to a scheme for the tick size of each issue listed on an exchange in Europe to be designated from four types of tick sizes (all tiered regime)[16]. Furthermore, this scheme is a so-called industry rule managed predominantly by the FESE. However, the European Securities and Market Authority (ESMA) stipulated in the MiFID 2, released in October 2011[17], that there would be a minimum tick size for trading in major financial products within the region. At the same time, it required the regulatory authorities in each EU member country to set appropriate tick size for their respective home country market. At present, in terms of issues listed on the LSE, issues with particularly high liquidity designated by the LSE that are FTSE100 constituents[18] have tick sizes that are smaller than other issues(Table5).

Looking at the Asia-Pacific region, the Australian government promoted competition between markets in March 2010 announcing that it would grant a market license to Chi-X Australia[20]. The Australian Securities and Investments Commission (ASIC) then released a consultation paper concerning market system reforms needed for market competition in November 2010, which also

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[13] Purchased Chi-X Europe in 2011 with a change of name to BATS Chi-X Europe.

[14] The share price index of the weighted average of market capitalization for the top 100 issues listed on the LSE by market capitalization.

[15] Euronext, which started in 2000 with the merger of exchanges in Paris, Brussels, and Amsterdam, was acquired by NYSE in 2007. Furthermore, NYSE Euronext was acquired by Intercontinental Exchange (ICE) in 2013 and ceased to exist. Euronext was divested from ICE in 2014 in a new issue of public stocks.

[16] Refer to BATS (2009) for the explanation used here.

[17] The reform proposal for MiFID. This was adopted by the European Parliament in April 2014 at the end of nearly two and a half years of subsequent debate, and regulations are currently being formulated based on this.

[18] Revised quarterly based on certain criteria. This applied to 21 issues as of January 20, 2015.

[19] A share price index that uses the weighted average market capitalization of the next top 250 issues by market capitalization is listed on the LSE after the FTSE100 constituents.

[20] Commenced operations in October 2011.

Table5 Tick size in the UK

Price		FTSE100 Constituents		FTSE250 Constituents[19]
		high liquidity issue	Other Issues	
or more	Below 0.5GBP	0.0001	0.0001	0.0001
0.5GBP	1GBP		0.0005	0.0005
1GBP	5GBP	0.0005	0.001	0.001
5GBP	10GBP	0.001	0.005	0.005
10GBP	50GBP	0.005	0.01	0.01
50GBP	100GBP	0.01	0.05	0.05
100GBP	500GBP	0.05	0.1	0.1
500GBP	1,000GBP	0.1	0.5	0.5
1,000GBP	5,000GBP	0.5	1	1
5,000GBP	10,000GBP	1	5	5
10,000GBP		5	10	10

* Units are GBP (0.01GBP is 1 penny).

included a proposal to standardize tick size[21]. This paper provided a proposal to standardize tick size on the Australian Stock Exchange (ASX) and Chi-X Australia proposed the establishment of a committee for prudent discussion about the process of standardization; whereas, the National Stock Exchange of Australia (NSX) proposed that tick size be uniform regardless of the price band. The results of the consultation released by ASIC in March 2011 supported the majority view in favor of the proposal and concluded that the other trading venues should conform to the tick size at the ASX, which is standard. In regions where major exchanges for cash products are located in other parts of Asia, there is an absence of significant alternative trading venues. Thus, trading is concentrated at the exchanges and there has been no noticeable debate concerning tick size （Table6）.

4 Related Studies

There has been a lot of empirical research regarding the impact of tick size on trading in the U.S. market, particularly, in relation to decimalization. The SEC (2012) took note of such research noting the features that were common to various research and analytical results. First, it states that tick size is an element for determining the tradeoff between the trading costs of investors and the profit of market makers[22]. It highlights that since quoted spreads cannot be smaller than the tick size, the larger the tick size the wider the gap between the best bid offer and fair price, thus increasing investors' trading cost. In contrast, market makers can generate a large profit by placing orders to the best bid offer. In addition, the SEC noted that the trading costs of investors

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[21] The assumed objective is preventing market operators from competing in relation to tick size, thus avoiding the priority ranking of quotes being determined by differences in price with virtually no economic significance.

[22] Investors that quote both sell and buy side of the order book and have an investment strategy of profiting from the price difference.

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Table6　Tick size in the Asia-Pacific Region

Price		Australia (ASX etc.)	Singapore (SGX)	Hong Kong (HKEx)	South Korea (KRX)
or more	Below 0.10	0.001	0.001	0.001	
0.10	0.20	0.005			
0.20	0.25		0.005		0.001
0.25	0.5			0.005	
0.5	1				
1	2	0.01			
2	5			0.01	0.005
5	10		0.01		0.01
10	20			0.02	
20	50			0.05	0.05
50	100				0.1
100	200			0.1	
200	500			0.2	0.5
500	1,000			0.5	
1,000				1	1

have improved with the reduction in quoted spread and effective spread[*23] as a result of tick size reduction following decimalization. However, it also notes that small market capitalization stocks listed on the NASDAQ cannot achieve statistically significant results. Furthermore, the total number of quoted shares indicated on the order book (the number of shares for orders on the order book, hereafter, the "depth") will be reduced due to tick size reduction. Trading costs are thought to increase when there is insufficient depth and a tendency for liquidity to decrease. However, investors will always be able to trade at close to fair price provided there is quick liquidity replenishment due to new orders even if depth has been reduced because of executions. Thus, the effective spread, which is the actual trading cost considering such hidden liquidity on the order book, is a better indicator than depth.

Focusing on specific research projects, Harris (1994) noted from before decimalization that tick size reduction would reduce quoted spreads while causing a reduction in depth. Therefore, he states that it is clearly positive for small lot investors who do not require enormous depth. Goldstein and Kavajecz (2000) noted that tick size reduction causes increase in trading cost for issues with insufficient liquidity and that tick size needs to consider the liquidity of an issue. The price competition for limit orders will become more active between investors by setting small tick size, and trading costs are likely to be reduced for high liquidity issues. Furthermore, they note

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[*23] The price difference between the execution price and the fair price, with the midpoint of BBO usually used to calculate the fair price. It means the spread cost actually borne by investors.

that there will be an incentive for investors to display quotes on the order book for curbing spread costs by setting large tick size, and this can prevent a decline in liquidity for low liquidity issues.

In terms of studies on decimalization, Bessembinder (2003) also noted that the quoted spread and effective spread will decline because of tick size reduction and that impact is more pronounced for issues with large market capitalization. In addition, he noted that in relation to the impact of price volatility the variance of the fluctuation rate in the midpoint of BBO[*24] observed hourly declines following tick size reduction. Furthermore, the study looked at the variance ratio comparing the variance calculated using the observations of fluctuation rate for the data on the same time line but with different time intervals. The variance ratio[*25] of the fluctuation rate of the midpoint of BBO observed hourly and daily (in the 6 hours from 10am to 4pm) was close to 1 following tick size reduction; i.e., price formation became more efficient[*26]. Bacidore, Battalio and Jennings (2003) projected an increase in market orders that could be immediately executed because of the reduction in the quoted spread. However, no change of statistical significance was observed in the ratio of limit orders to the total number of orders. In addition, depth declines, but the observed results of the effective spreads by order size was that effective spreads declined even for executions of large lot order of more than 10,000 shares; thus, the reduction in depth did not directly lead to increases in trading cost. Chakravarty, Panchapagesan and Wood (2005) used the trading data of institutional investors provided by Plexus[*27] to analyze the impact that decimalization had on the trading cost of institutional investors. The result was that the trading costs fell for institutional investors as a whole, regardless of their size or investment style when comparing actual execution results and the price when making an investment decision. However, they noted that trading cost only increased in the case where all scheduled volume was executed in a short period (i.e., within one day), and that trades needed to be executed gradually to improve the trading cost.

In relation to studies about previous changes in tick size on the TSE, a similar trend to that noticed in the analysis of the U.S. markets was observed. Ahn et al. (2001) noted the analysis results of the impact on trading from the change in tick size implemented by the TSE in 1998 stating that the quoted spread and effective spread decreased with the impact particularly pronounced for high liquidity issues. In addition, the reduction in the quoted spreads means that the tick size becomes smaller and price competition between investors becomes more active for limit orders; however,

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[*24] The fluctuation rate of the midpoint of BBO was used to avoid negative impact induced by bid-ask bounce.

[*25] The variance ratio is calculated by adjusting the differences in the observed time intervals. Here, the variance ratio is calculated by dividing six-times multiple of the variance of the hourly fluctuation rate by the variance of the daily fluctuation rate.

[*26] The closer the variance ratio to 1, the more the long-term level of fluctuation in price will be an extension of the short-term level of fluctuation. This is considered to be efficient for price formation with little short-term noise, etc. In addition, Conrad, Wahal and Xiang (2014) categorized issues by the frequency of change in BBO and noted the results of comparison of the variance ratio of the fluctuation rate in the midpoint of BBO that issues with high frequency of change were close to 1.

[*27] A company that provides trading cost analysis services for institutional investors was acquired by J.P. Morgan Chase in 2002 and further sold to ITG (Investment Technology Group, Inc.) in 2006.

there was no change in trading value. That is, they noted that there was no link to an increase in trading volume. Uno (2014) analyzed the impact of the change in tick size implemented by the TSE in 2010 by separating issues into three groups by market capitalization. The result was that a reduction in both effective spreads and depth had a more pronounced impact on issues with large market capitalization. In addition, based on the actual average order size for each issue in December 2009, a comparison of the trading costs when executing orders of the same volume around the time that the tick size was changed indicates that there was no statistical significance for the improvement in trading costs for large lot orders (defined as order size of 10 times the average) other than for issues with large market capitalization. Nevertheless, recently, order sizes have become smaller due to the spread of algorithm trades, etc. and they state that it would be one-sided to conclude that tick size reduction does not have a positive impact on issues with small market capitalization.

In terms of the method for appraising trading cost, IS, which was advocated by Perold (1988), and variations thereof have now become the industry standard. Under IS, trading cost is defined as the difference between paper return based on the price when investors make an investment decision and the real portfolio return. Furthermore, trading cost comprises the three elements of investment-related costs, trading-related costs, and opportunity costs. Kissell (2006) went further by breaking down the trading costs involved in actual investment based on IS, as shown in Table7, and provides an explanation of each component. Delay cost is the cost incurred when the price moves following an investment decision by an investor to invest until the actual execution commences in the market and is defined as the difference between the anticipated price when the decision was made and the price immediately prior to the start of execution. Market impact cost is the cost incurred due to the difference between the price in the market immediately prior to execution and the actual price paid (hereafter, "market impact"). The market impact has a temporary impact caused by temporary movement in price due to execution and a permanent impact due to the change in the price level following the signal[28] given to other investors from the movement in price and depth caused by execution (refer to Figure1) [29]. Timing cost is the ex-post factor cost attributed to the movement in price and depth when the transaction is being executed. Borkovec and Heidle (2010) refer to this as volatility cost and make comparison using the variance of the fluctuation in price[30]. Spread cost means the quoted spread and is the cost of not being able to execute the transaction at the price within the BBO. Opportunity cost indicates lost profit when a transaction cannot be executed because of factors such as the market not moving in the

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[28] For example, when the price temporarily falls or when depth has fallen on the buy side because of execution by sell order and other investors predict that the price will fall based on such events.

[29] Breen, Hodrick and Korajczyk (2002) have attempted to estimate a linear correlation for the permanent impact using the bias for buying and selling in the trading volume for each unit of time.

[30] However, they note that it is extremely difficult to separate the actual price movement into the permanent impact of price movement caused by execution and the volatility cost that is the natural price movement.

anticipated direction or insufficient market liquidity[31].

Table7   Trading cost classification

Brokerage Costs	Fees, Commissions
Investment Costs	Delay Cost, Taxes
Trading Costs	Spread cost, Timing Cost Market Impact Cost
Other Costs	Opportunity Cost

* Compiled by Sugihara (2011) based on Kissell (2006).

Figure1   Image of market impact
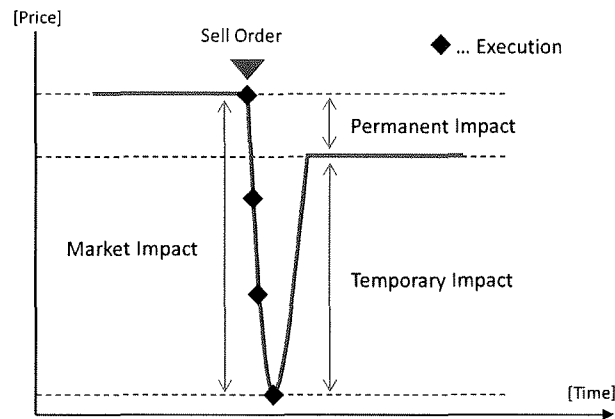
* Compiled by the author based on Kissell (2006).

5   Details of Analysis

5.1   Data

The main analysis in this paper uses the FLEX Full Data, which is a real time market data feed service provided by the TSE. This service distributes the present value, trading volume, trading value, and change in volume of all the quoted prices in the order book, which provides an overall picture of the change in the order book for each issue as well as how the orders were executed. The issues that are the subject of analysis are the 100 issues that make up the TOPIX100 constituents for which the tick size has changed. Furthermore, since there are changes to the constituent issues in TOPIX 100 at the end of October each year, this paper analyzes the constituent issues during the period from October 31, 2013 to October 30, 2014[32]. This time there were changes to the tick size broken up into Phases 1 and 2 for each price band. Thus, even within the TOPIX100

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[31] Refer to Sugihara (2011) for the explanation used here.
[32] While it is possible for the constituents to change at special times such as when there are new listings, there was no such change during this period.

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constituents, the timing of the change in tick size differs depending on the stock price level. TOPIX100 constituents are the top 100 issues by market capitalization and trading value among domestic stocks listed on the TSE 1st Section. As these issues share many aspects in terms of liquidity and investor type, TOPIX100 constituents affected by tick size change were compared with unaffected TOPIX100 constituents to analyze the impact of changing tick sizes near the start of Phases 1 and 2[*33].

In Phase 1, the tick size changed for issues in the price band of more than 3,000 yen. Thus, issues with share price of more than 3,000 yen were separated into Analysis Group A (38 issues), and issues with share price of less than or equal to 3,000 yen were separated into Analysis Group B (62 issues). In Phase 2, there was a large difference in the tick size reduction level depending on price band with reduction in the tick size from 1 yen to 0.1 yen for issues with price band below or equal to 1,000 yen and from 1 yen to 0.5 yen for issues with price band above 1,000 yen and below or equal to 5,000 yen[*34]. Thus, issues with share price of less than or equal to 1,000 yen were separated into Analysis Group C (24 issues), issues with share price of more than 1,000 yen and less than or equal to 5,000 yen were separated into Analysis Group D (56 issues), and issues with share price of more than 5,000 yen were separated into Analysis Group E (20 issues). Furthermore, it is important to note that the tick size for Analysis Group D was reduced in stages from 5 yen to 1 yen in Phase 1 and further from 1 yen to 0.5 yen in Phase 2. Analysis Group A in Phase 1 and Analysis Groups C and D in Phase 2 are referred to as test groups; whereas, Analysis Group B in Phase 1 and Analysis Group E in Phase 2 are referred to as control groups. The list of issues that were subject to analysis and the breakdown of the Analysis Groups are provided in Table14.

5.2   Methodology

This paper considers the impact that the change in tick size had on trading cost. The categories of trading costs based on IS are shown in Table7, and trading-related cost is the only component that can be observed from the trading data at the exchange. Thus, in this paper, spread cost, timing cost, and market impact cost are compared around the time of the change in tick size. The period of data used in the analysis was one month (20 business days) before and after the first day of Phase 1 (January 14, 2014) and Phase 2 (July 22, 2014).

For spread cost, we measure it using quoted spread and effective half spread. Quoted spread qs^t is defined as the difference between the best ask price P^t_{ba} and best bid price P^t_{bb} divided by the

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[*33] The comparison is made between the TOPIX100 constituents, so there is a constraint on the comparison being limited to 100 issues; whereas, there are concerns about the possibility of noise caused by the difference in price bands for share price. However, the analysis in this paper focuses on the similarity of aspects of the TOPIX100 constituents.

[*34] Although the level of tick size reduction differed according to price band in Phase 1 as well, there was a large reduction in the tick size for issues with share price of more than 3,000 yen and less than or equal to 10,000 yen, which were the majority of Analysis Group A. Thus, there was no need to break up the group further.

midpoint of BBO P^t_{mid} at each one-minute interval t^{*35}. We Compare $\bar{q}s$, the average quoted spread qs^t, for each issue during each period.

$$qs^t = \frac{P^t_{ba} - P^t_{bb}}{P^t_{mid}} \qquad (1)$$

Effective half spread es^i is defined as the difference between the execution price P^i_{exec} and the midpoint of BBO just before execution P^i_{mid} divided by P^i_{mid} for each execution i in continuous trading[*36]. We calculate the volume weighted effective half spread es^d using execution volume Q^i_{exec} on each business day d, and compare $\bar{e}s$, the average es^d, for each issue during each period.

$$es^i = \frac{|P^i_{exec} - P^i_{mid}|}{P^i_{mid}} \qquad (2)$$

$$es^d = \frac{\sum_{i=1}^n (es^i \times Q^i_{exec})}{\sum_{i=1}^n Q^i_{exec}} \qquad (3)$$

In the calculation of es^i, execution i is defined as all simultaneous executions due to a single order. For executions striding more than a single price level $j(j = 1, 2, 3, \cdots, m)$, volume weighted execution price based on execution shares Q^j_{part} of each execution price P^j_{part} is used for P^i_{exec} and the total of execution volume Q^j_{part} for each price is used for Q^i_{exec}.

$$Q^i_{exec} = \sum_{j=1}^m Q^j_{part} \qquad (4)$$

$$P^i_{exec} = \frac{\sum_{j=1}^m (P^j_{part} \times Q^j_{part})}{\sum_{j=1}^m Q^j_{part}} \qquad (5)$$

For timing cost, we follow the example of Borkovec and Heidle (2010) and use intraday volatility σ^d, defined as the standard deviation of the natural logarithm of the fluctuation rate of the midpoint of BBO at each one- and ten-minute time interval t^{*37} on each business day d. We calculate σ^d_1 and σ^d_{10} at one- and ten-minute intervals respectively, and compare $\bar{\sigma}_1$ and $\bar{\sigma}_{10}$, the respective averages of σ^d_1 and σ^d_{10} for each issue during each period.

[*35] Using the status of the order book at 00 seconds for each minute, while excluding data that was not in a continuous trading session such as opening-auction session. Since the TSE is in continuous trading session for five hours (300 minutes) each day, there are roughly 6,000 pieces of data for each issue during the period (20 business days).

[*36] The effective spread in accordance with such a calculation method will be at minimum half the quoted spread. Thus, it is referred to as the effective half spread.

[*37] Since it uses the status of the order book at time 00 seconds for one minute intervals and 00 seconds for ten minute intervals during the continuous trading session, the number of t for each day of σ^d_1 is 300, and σ^d_{10} is 30.

Figure2   Image of spread cost
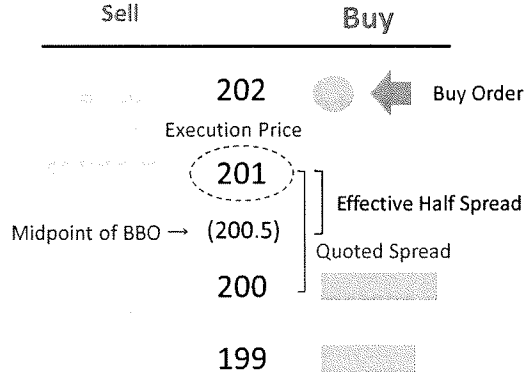
* In calculating the effective half spread, the execution shares shall be the aggregate of each price when there are simultaneous executions at multiple price levels due to a single order, and the execution price shall use the weighted average price based on the execution shares for each price.
* For example, where there is a market order to buy 400 shares and it is immediately executed with 300 shares at 201 yen and 100 shares at 202 yen, the execution shall be treated as 400 shares at 201.25 yen.

$$\mu = \frac{1}{N} \sum_{t=1}^{N} (\log P^t_{mid} - \log P^{t-1}_{mid}) \tag{6}$$

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

In addition, we calculated variance ratio vr^d using σ^d_1 and σ^d_{10}, and compare $\bar{vr}$, the average vr^d, for each issue during each period.

$$vr^d = \frac{(\sigma^d_{10})^2}{10 \times (\sigma^d_1)^2} \tag{8}$$

Figure3   Image of intraday volatility

Natural log of fluctuation rate of midpoint of BBO

$$\log \frac{P^t_{mi\ d}}{P^{t-1}_{mi\ d}} = \log P^t_{mi\ d} - \log P^{t-1}_{mi\ d}$$

[Time]
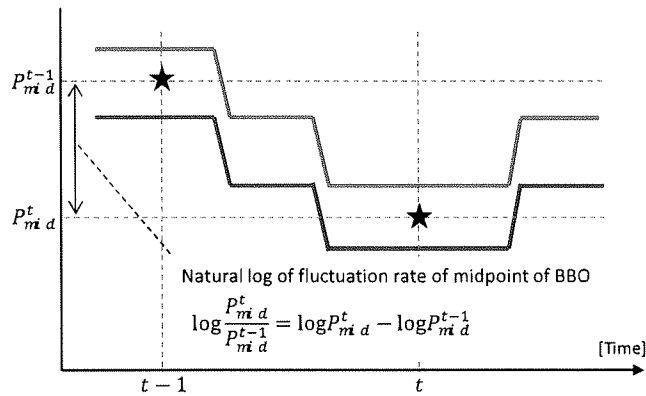
In terms of market impact cost, effective spread is used as an inherent indicator of market

impact(Refer to Figure4)[*38], thus we measure market impact cost using the virtual effective half spread cost to compare changes in trading cost for executing equal volume orders before and after tick size change. We Calculate the effective half spread es_{50}^{t}[*39], the virtual effective half spread caused by immediate execution of market orders at Q_{50}, the 50th percentile of execution volume[*40] for each issue in continuous trading during the period before tick size change, based on order book information, at one-minute interval t. $(P_{ask,1}^{t}, Q_{ask,1}^{t}), (P_{ask,2}^{t}, Q_{ask,2}^{t}), (P_{ask,3}^{t}, Q_{ask,3}^{t}), \cdots$ are quoted ask prices and volumes from the midpoint of BBO at t, $(P_{bid,1}^{t}, Q_{bid,1}^{t}), (P_{bid,2}^{t}, Q_{bid,2}^{t}), (P_{bid,3}^{t}, Q_{bid,3}^{t}), \cdots$ are for bids. We compared $\bar{es}_{50}$, the average of es_{50}^{t}, for each issue during each period[*41].

$$Q_{50} = \sum_{x=1}^{k} Q_{ask,x}^{t} + \alpha^{t} = \sum_{y=1}^{l} Q_{bid,y}^{t} + \beta^{t} \qquad (Q_{ask,k+1}^{t} > \alpha^{t} \geq 0, \quad Q_{bid,l+1}^{t} > \beta^{t} \geq 0) \qquad (9)$$

$$es_{50}^{t} = \frac{1}{2}(es_{50,buy}^{t} + es_{50,sell}^{t})$$

$$= \frac{1}{2}(\frac{\{\sum_{x=1}^{k}(P_{ask,x}^{t} \times Q_{ask,x}^{t}) + P_{ask,k+1}^{t} \times \alpha^{t}\}/Q_{50} - P_{mid}^{t}}{P_{mid}^{t}}$$

$$+ \frac{P_{mid}^{t} - \{\sum_{y=1}^{l}(P_{bid,y}^{t} \times Q_{bid,y}^{t}) + P_{bid,l+1}^{t} \times \beta^{t}\}/Q_{50}}{P_{mid}^{t}}) \qquad (10)$$

Figure4   Relationship between market impact cost and spread cost

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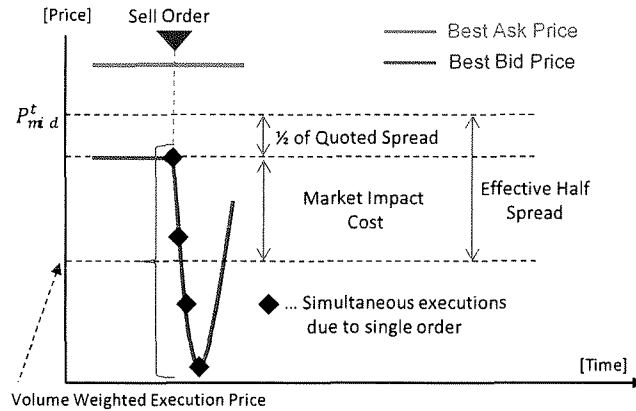
[*38] Effective half spread is the combination of 1/2 of the quoted spread and market impact cost.

[*39] es_{50}^{t} is the average value of the effective half spread $es_{50,buy}^{t}$ when the market order is a buy quote, and the effective half spread $es_{50,sell}^{t}$ when the market order is a sell quote.

[*40] In the calculation of percentile volumes, simultaneous executions at multiple price levels due to a single order are regarded as one execution and the sum of the execution volumes at each price level is used.

[*41] Similarly for $\bar{es}_{90}$ and $\bar{es}_{99}$.

6 Results

6.1 Overview of Trading

Before analyzing trading cost, we provide an overview of the trading of the TOPIX100 constituents. The daily trading value of TOPIX100 constituents on the TSE are provided in Figure5. The ratio to total trading value did not change before and after Phases 1 and 2, and while a slight drop was evident in July and August 2014, there was a recovery from September to approximately 40%, which was the level prior to Phase 1. Thus, there was no evident impact from the change in tick size.

Figure5 Transition of daily trading value of TOPIX100 constituents on TSE
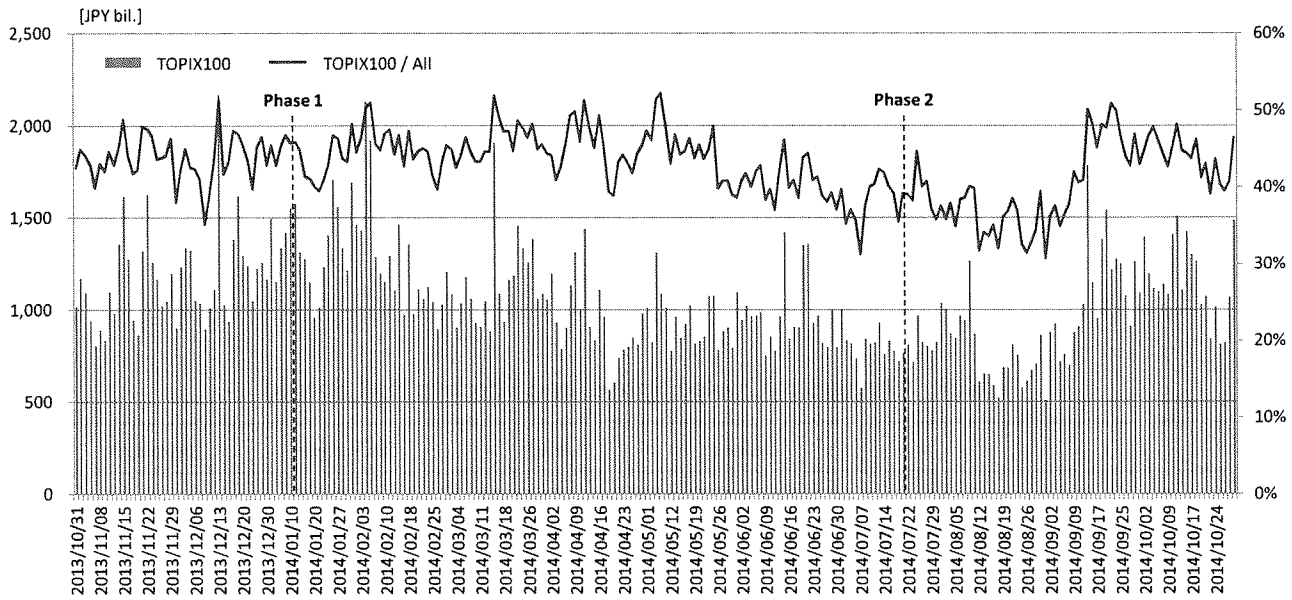
* The red line indicates the ratio to the overall trading value on the TSE.
* The figures only show auction trading and do not include off-auction trading.

The number of daily orders for TOPIX100 constituents on the TSE is provided in Figure6. The ratio to total number of orders rose with the commencement of both Phases 1 and 2, suggesting that the number of orders for TOPIX100 constituents increased because of the tick size reduction. There was a further increase in the ratio from the start of Phase 2 as well, with the ratio moving at approximately 35%–40%, which is nearly twice the level prior to the start of Phase 1.

6.2 Change in Trading Cost

The comparison of quoted spread and effective spread between Analysis Groups conducted to investigate whether spread cost changed because of a change in tick size is shown in Table 8.

Comparing the periods before and after Phases 1 and 2, the quoted spread and effective spread

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Figure6　Transition of daily number of orders in TOPIX100 constituents on TSE
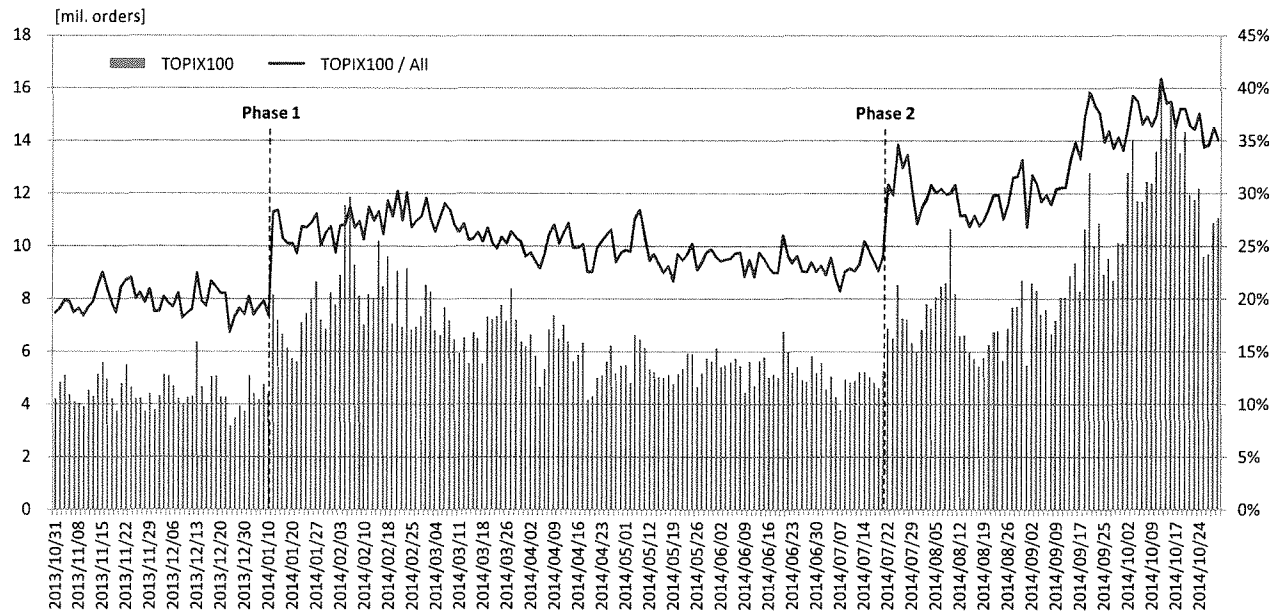
* The number of orders are the aggregate of new orders, modification orders, and cancel orders and are calculated using internal TSE data and not the FLEX Full data.
* The red line indicates the ratio to the overall number of orders on the TSE.
* The figures only show auction trading and do not include off-auction trading.

Table8　Changes in Quoted Spread and Effective Half Spread

	Before	After	%Change	t-statistic
Panel A: Quoted Spread $\bar{qs}$(bps)				
Phase 1				
Group A (changed)	14.48	5.96	-56.52%	16.412 ***
Group B (unchanged)	12.52	12.50	+0.09%	–
Phase 2				
Group C (changed from 1 to 0.1)	19.27	4.80	-71.94%	25.758 ***
Group D (changed from 1 to 0.5)	6.44	4.90	-22.67%	9.423 ***
Group E (unchanged)	5.25	5.07	-1.37%	–
Panel B: Effective Half Spread $\bar{es}$(bps)				
Phase 1				
Group A (changed)	7.06	2.71	-58.26%	17.765 ***
Group B (unchanged)	6.19	6.21	+0.76%	–
Phase 2				
Group C (changed from 1 to 0.1)	9.74	2.27	-73.94%	28.603 ***
Group D (changed from 1 to 0.5)	3.12	2.28	-24.68%	10.036 ***
Group E (unchanged)	2.28	2.27	+1.53%	–

* Analyzed by separating the TOPIX100 constituents into groups according to whether there was change in tick size in Phases 1 and 2, respectively. The detailed definition of the Analysis Groups is provided in Section 5.1 (Number of issues: A…38, B…62, C…24, D…56, and E…20).
* The figures are the average for each analysis group of the average for each issue, and the average for each analysis group of the average change for each issue in the period before and after.
* t-statistics are obtained using a two-tailed t-test symmetric about zero of the difference in % change between test groups and control groups. *, ** and *** indicate 10%, 5% and 1% significance levels respectively.

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of the test groups both decreased substantially. Particularly, in relation to Phase 2, in Analysis Group C where the tick size was changed from 1 yen to 0.1 yen, the change in the quoted spread was as much as -90%, with an average of -71.94% and a substantial reduction in quoted spread for many issues due to the smaller tick size. In contrast, the tick size was changed from 1 yen to 0.5 yen for Analysis Group D; thus, the change in quoted spread was a maximum of -50% with an average of -22.67%. There were also a certain number of issues not affected by the tick size reduction in terms of spread size. In addition, the effective half spread for individual executions was at minimum; i.e., approximately half of the quoted spread on the order book immediately prior to execution. For the test groups, the average effective half spread following the change in tick size was about half of the average quoted spread; thus, the majority of executions were only BBO even after tick size reduction, suggesting that there was virtually no market impact caused by striding more than a single price level. We analyze the trend for the change in spread cost by issue in the next section. Furthermore, the Value-Based effective spread calculated by multiplying the effective half spread (before dividing by the midpoint of BBO and converting to bps) by execution shares[42] aggregated for all TOPIX100 constituents and each analysis group is presented in Table9.

The ratio of Value-Based effective spread relative to the trading value for all TOPIX100 constituents fell from 5.55bp before the start of Phase 1 to 1.79bp following the start of Phase 2. Converting this difference of 3.76bp to the value of average daily trading value[43] of all TOPIX100 constituents is 397 million yen, or 99.2 billion yen when converted to an annual figure of 250 business days.

Table9   Changes in Value-Based Effective Half Spread

| | Effective Half Spread (JPY 100 mil.) | | | Ratio to Trading Value (bps) | | |
	Before	After	Change	Before	After	Change
Phase 1						
All TOPIX100 constituents	7.04	5.85	-1.20	5.55	4.17	-1.38
Group A (changed)	3.53	1.46	-2.07	5.37	2.08	-3.29
Group B (unchanged)	3.52	4.39	+0.87	5.73	6.25	+0.52
Phase 2						
All TOPIX100 constituents	2.93	1.48	-1.45	3.54	1.79	-1.75
Group C (changed from 1 to 0.1)	1.62	0.37	-1.25	8.31	1.91	-6.39
Group D (changed from 1 to 0.5)	0.95	0.72	-0.24	2.37	1.82	-0.54
Group E (unchanged)	0.35	0.39	+0.04	1.53	1.63	+0.10

* Analyzed by separating the TOPIX100 constituents into groups according to whether there was change in tick size in Phases 1 and 2, respectively. The detailed definition of the Analysis Groups is provided in Section 5.1 (Number of issues: A⋯38, B⋯62, C⋯24, D⋯56, and E⋯20).
* The figures are the average for each analysis group of the average for each issue, and the average for each analysis group of the average change for each issue in the period before and after.
* Ratio for trading value is calculated by dividing total value-based effective half spread by total trading value in each group.

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[42] This signifies the trading cost actually paid by investors by comparing the actual trading value and the trading value assuming transactions were executed at the midpoint of BBO immediately prior to the execution.

[43] The daily average trading value of all TOPIX100 constituents during the period from October 31, 2013 to October 30, 2014 was JPY1,057 billion.

Next, Table10 indicates the results of the comparison of the intraday volatility between analysis groups to examine whether the change in tick size changed timing cost.

Table10   Changes in Intraday Volatility

	Before	After	%Change	t-statistic
Panel A: One-Minute Volatility$\bar{\sigma}_1$(bps)				
Phase 1				
Group A (changed)	6.64	7.63	+15.41%	6.420 ***
Group B (unchanged)	6.32	8.63	+37.78%	–
Phase 2				
Group C (changed from 1 to 0.1)	5.86	5.55	-5.14%	4.259 ***
Group D (changed from 1 to 0.5)	5.08	5.25	+4.56%	1.023
Group E (unchanged)	4.86	5.21	+7.38%	–
Panel B: Ten-Minute Volatility$\bar{\sigma}_{10}$(bps)				
Phase 1				
Group A (changed)	17.33	22.04	+27.15%	2.179 **
Group B (unchanged)	17.17	23.00	+35.97%	–
Phase 2				
Group C (changed from 1 to 0.1)	14.68	15.98	+10.07%	0.399
Group D (changed from 1 to 0.5)	13.45	14.69	+10.65%	0.345
Group E (unchanged)	13.31	14.84	+11.85%	–

* Analyzed by separating the TOPIX100 constituents into groups according to whether there was change in tick size in Phases 1 and 2, respectively. The detailed definition of the Analysis Groups is provided in Section 5.1 (Number of issues: A⋯38, B⋯62, C⋯24, D⋯56, and E⋯20).
* The figures are the average for each analysis group of the average for each issue, and the average for each analysis group of the average change for each issue in the period before and after.
* t-statistics are obtained using a two-tailed t-test symmetric about zero of the difference in % change between test groups and control groups. *, ** and *** indicate 10%, 5% and 1% significance levels respectively.

The period following the start of Phase 1 experienced volatile fluctuations such as the drop in share prices on February 4[44]; thus, a comparison with the prior period indicates an increase in intraday volatility for all analysis groups. However, even under such circumstances, the decline in volatility for the test groups had a 1% significance level for one-minute volatility and a 5% significance level for ten-minute volatility. Before and after the start of Phase 2, the one-minute volatility fell with a 1% significance level for Analysis Group C, which was subject to a large reduction in tick size; however, there was no significant change for Analysis Group D and there were no significant changes for any of the groups in relation to ten-minute volatility. From these results we can deduce that tick size reduction constrained the variation (lowered the standard deviation) in the intraday short-term fluctuation rate for the midpoint of BBO. There was a small reduction in the level of tick size for Analysis Group D, which is thought to have led to no significant change. A specific example of a change in the intraday movement in BBO due to tick size reduction is demonstrated in Figure7. When the ratio between price and tick size is large, the price of stocks are unable to reflect small movements and examination of one-minute intervals indicates there were many periods with no change in BBO. However, there are large movements

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[44] The Nikkei 225 average dropped 610.66 points from the previous day on February 4.

where there are fluctuations and the variance of the fluctuation rate for the midpoint of one-minute intervals becomes larger. In contrast, when the ratio between price and tick size is small, the BBO frequently changes even at one-minute intervals reflecting the small movements in price. However, the variance of the fluctuation rate for the midpoint of the one-minute intervals becomes small to sequentially reflect the price movements. The longer the observation period for the price, the larger the movement in price per unit of time. As it is difficult for price to be constrained by the magnitude of the tick size, the impact of tick size reduction is reduced. Furthermore, Chart11 demonstrates the variance ratio calculated from one- and ten-minute volatility, and indicates how the variance ratio of the test groups approached 1 due to a decline in short-term volatility.

Figure7 Example of changes in Intraday BBO price movement
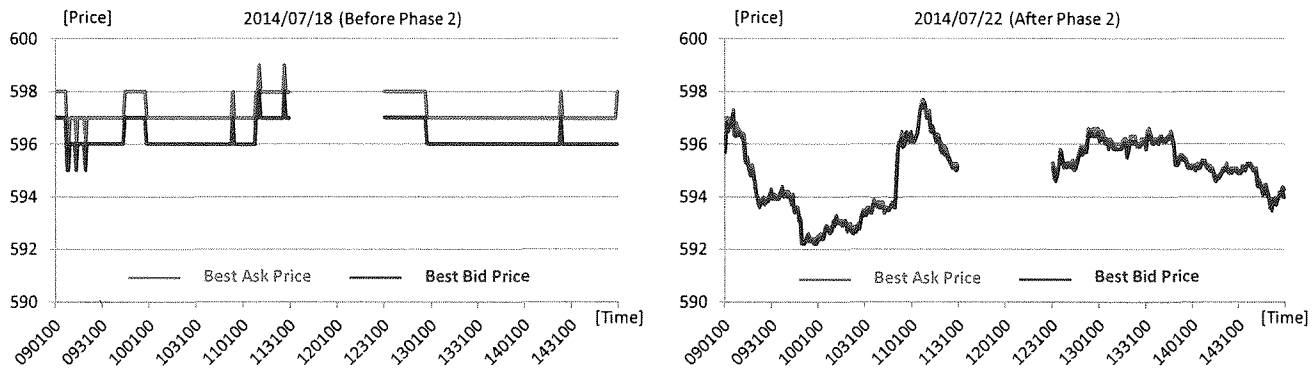
* Example of Mitsubishi UFJ Financial Group (Issuer Code: 8306).
* BBO price movement every minute. The time on the X-axis is in HHMMSS format.

Table11 Changes in Variance Ratio

| | Variance Ratio $\overline{vr}$ | | $|1 - vr|$ | |
	Before	After	Before	After
Phase 1				
Group A (changed)	0.82	0.91	0.21	0.15
Group B (unchanged)	0.86	0.84	0.18	0.20
Phase 2				
Group C (changed from 1 to 0.1)	0.79	0.91	0.22	0.17
Group D (changed from 1 to 0.5)	0.83	0.88	0.20	0.18
Group E (unchanged)	0.87	0.89	0.18	0.17

* Analyzed by separating the TOPIX100 constituents into groups according to whether there was change in tick size in Phases 1 and 2, respectively. The detailed definition of the Analysis Groups is provided in Section 5.1 (Number of issues: A···38, B···62, C···24, D···56, and E···20).
* The figures are the average for each analysis group of the average for each issue. $|1 - vr|$ is the average for each analysis group of the absolute value of the difference between the daily variance ratio vr^d and 1 for each issue.

Lastly, to examine whether the change in tick size had an impact on market impact cost, we first present the results of the analysis of the status of executions in the subject period in Table12.

While no significant change in daily trading volume was evident for test groups, there was an increase in the number of daily executions as well as a reduction in the execution shares per execution. This was particularly noticeable in Analysis Group A in Phase 1 and Analysis Group

Table12　Daily trading volumes, the number of executions, and the change in execution shares per single execution

	Before	After	%Change	t-statistic
Panel A: Trading volume (ahare)				
Phase 1				
Group A (changed)	2,773,235	3,074,274	+13.57%	0.764
Group B (unchanged)	12,657,233	15,029,514	+18.49%	–
Phase 2				
Group C (changed from 1 to 0.1)	15,947,471	17,712,127	+8.71%	0.219
Group D (changed from 1 to 0.5)	3,132,477	3,139,599	+2.00%	1.545
Group E (unchanged)	1,404,508	1,461,076	+10.32%	–
Panel B: Number of executions				
Phase 1				
Group A (changed)	2,227	5,378	+128.64%	-9.727 ***
Group B (unchanged)	2,842	3,544	+27.42%	–
Phase 2				
Group C (changed from 1 to 0.1)	1,764	4,425	+157.06%	-11.538 ***
Group D (changed from 1 to 0.5)	2,723	3,566	+36.56%	-3.982 ***
Group E (unchanged)	3,265	3,417	+7.80%	–
Panel C: Execution size: 50th percentile (shares)				
Phase 1				
Group A (changed)	264	227	-17.33%	5.816 ***
Group B (unchanged)	908	898	-1.82%	–
Phase 2				
Group C (changed from 1 to 0.1)	1,426	1,130	-20.19%	3.648 ***
Group D (changed from 1 to 0.5)	405	364	-12.60%	6.908 ***
Group E (unchanged)	123	127	+2.89%	–
Panel D: Execution size: 90th percentile (shares)				
Phase 1				
Group A (changed)	1,905	995	-45.54%	16.086 ***
Group B (unchanged)	7,108	7,826	+3.45%	–
Phase 2				
Group C (changed from 1 to 0.1)	13,073	7,029	-47.03%	5.967 ***
Group D (changed from 1 to 0.5)	2,331	1,776	-23.82%	12.183 ***
Group E (unchanged)	563	585	+4.00%	–
Panel E: Execution size: 99th percentile (shares)				
Phase 1				
Group A (changed)	8,891	3,172	-57.19%	15.509 ***
Group B (unchanged)	42,547	48,682	+0.16%	–
Phase 2				
Group C (changed from 1 to 0.1)	90,883	31,470	-68.07%	16.609 ***
Group D (changed from 1 to 0.5)	9,025	6,227	-27.03%	10.050 ***
Group E (unchanged)	1,876	2,005	+7.59%	–

* Analyzed by separating the TOPIX100 constituents into groups according to whether there was change in tick size in Phases 1 and 2, respectively. The detailed definition of the Analysis Groups is provided in Section 5.1 (Number of issues: A⋯38, B⋯62, C⋯24, D⋯56, and E⋯20).
* The figures are the average for each analysis group of the average for each issue, and the average for each analysis group of the average change for each issue in the period before and after.
* Execution shares shall be the aggregate of each price when there are simultaneous executions at multiple price levels due to a single order.
* t-statistics are obtained using a two-tailed t-test symmetric about zero of the difference in % change between test groups and control groups. *, ** and *** indicate 10%, 5% and 1% significance levels respectively.

C in Phase 2 with, on average, a doubling of the number of execution shares, suggesting a sharp contraction in the size of executions due to tick size reduction. In addition, there was a decline in the level of significance for execution shares at the 50th percentile, 90th percentile, and 99th percentile. Although, the change in the 50th percentile was not comparatively large, there was a decline of approximately 40%–50% for the 90th percentile and approximately 60% for the 99th percentile. These results indicated that while there was not a large change in the execution size that accounts for half of the number of executions because the execution size was as small as it could be before the reduction, the tick size reduction led to an increase in small lot transactions for comparatively large executions even though there was not a large number of such executions.

Table13 indicates the virtual effective half spread for each issue in the period before Phase 1 and the start of Phase 2; i.e., it compares the trading cost including market impact for executing equal volume orders before and after tick size change[*45].

Table13   Changes in virtual effective half spread by order size

	Before	After	%Change	t-statistic
Panel A: Effective half spread at 50th percentile of execution size before tick size change $e\tilde{s}_{50}$(bps)				
Phase 1				
Group A (changed)	7.24	3.05	-55.66%	16.398 ***
Group B (unchanged)	6.27	6.27	+0.21%	–
Phase 2				
Group C (changed from 1 to 0.1)	9.64	2.47	-71.02%	24.917 ***
Group D (changed from 1 to 0.5)	3.23	2.49	-21.53%	8.890 ***
Group E (unchanged)	2.63	2.54	-1.35%	–
Panel B: Effective half spread at 90th percentile of execution size before tick size change $e\tilde{s}_{90}$(bps)				
Phase 1				
Group A (changed)	7.60	4.62	-37.89%	13.139 ***
Group B (unchanged)	6.69	6.81	+2.60%	–
Phase 2				
Group C (changed from 1 to 0.1)	9.82	3.68	-57.35%	15.677 ***
Group D (changed from 1 to 0.5)	3.61	3.15	-11.39%	4.067 ***
Group E (unchanged)	3.11	2.98	-2.57%	–
Panel C: Effective half spread at 99th percentile of execution size before tick size change $e\tilde{s}_{99}$(bps)				
Phase 1				
Group A (changed)	9.34	9.77	+4.00%	1.554
Group B (unchanged)	8.55	9.17	+8.57%	–
Phase 2				
Group C (changed from 1 to 0.1)	11.12	8.61	-15.96%	2.053 **
Group D (changed from 1 to 0.5)	5.27	5.22	-0.20%	-2.751 ***
Group E (unchanged)	4.65	4.35	-5.73%	–

* Analyzed by separating the TOPIX100 constituents into groups according to whether there was change in tick size in Phases 1 and 2, respectively. The detailed definition of the Analysis Groups is provided in Section 5.1 (Number of issues: A···38, B···62, C···24, D···56, and E···20).
* The figures are the average for each analysis group of the average for each issue, and the average for each analysis group of the average change for each issue in the period before and after.
* t-statistics are obtained using a two-tailed t-test symmetric about zero of the difference in % change between test groups and control groups. *, ** and *** indicate 10%, 5% and 1% significance levels respectively.

[*45] Detailed definition is referred in Section 5.2.

The virtual effective half spread for the test groups when executing market orders for the number of shares in the 50th percentile and the 90th percentile of the execution shares before tick size reduction fell with a 1% significance level following tick size reduction. For order sizes in the 99th percentile, there was no change of significance for Analysis Group A in Phase 1, a decline with a 5% significance level for Analysis Group C in Phase 2, and a rise with a 1% significance level for Analysis Group D. As the quoted spread declined in the test groups, without a change in the quoted shares in the vicinity of BBO the effective half spread should fall when the same number of shares is executed for the market impact to be the same. The lack of significant change in the virtual effective half spread for order sizes in the 99th percentile for Analysis Group A signifies that the quoted shares in the vicinity of BBO fell due to the tick size reduction and the effective spread would be at the same level as in the past to offset the impact of the reduction in quoted spread due to the need for many more prices (a larger market impact) when executing large sized orders striding more than a single price level. However, for Analysis Group C in Phase 2, there was a very large ratio between price and tick size for low price bands of less than 500 yen in particular; thus, the quoted shares in the vicinity of BBO were at comparatively high levels even after tick size reduction for issues in those price bands. It is thought that the virtual effective half spread also fell for orders in the 99th percentile. In contrast, the effective spread rose for order sizes in the 99th percentile for Analysis Group D meaning that the increase in market impact was greater than the reduction in quoted spread when executing large sized orders. Nevertheless, as shown in Table 12, the 99th percentile for execution shares for Analysis Group D fell, on average, i.e., approximately by 27%; thus, the effective spread avoided deterioration due to investors slicing their orders. As a result, the effective half spread actually declined, as shown in Table8.

6.3 Change in Spread Cost by Issue

In the previous section, the paper examined the trend for change in all TOPIX100 constituents in relation to trading-related cost under the IS method due to the change in tick size. In this section, we look at spread cost, which is considered to have a particularly strong relationship with tick size among the different measures of trading cost, by analyzing the trend in the change by issue. First, Figure8 compares the change in quoted spread before and after the tick size reduction and the BBO quoted shares before tick size reduction for the test groups. There was a tendency for larger reduction in quoted spread on issues that had larger BBO quoted shares before the tick size reduction. Furthermore, there were many issues within Analysis Group D with comparatively smaller BBO quoted shares before reduction. We believe this is related to the gradual change in the tick size in Phases 1 and 2 for issues within Analysis Group D with share prices of more than 3,000 yen and less than 5,000 yen. Figure9 compares the change in quoted spread and the change in BBO quoted shares before and after tick size reduction. The larger the reduction in BBO quoted shares,

the larger is the reduction in quoted spread on issues. From this trend, approximately 40%[46] of the issues in Analysis Group D had a reduction in quoted spread together with a reduction in BBO quoted shares in Phase 1; thus, it is thought that the BBO quoted shares had shrunk prior to Phase 2. Furthermore, there was also a large reduction in BBO quoted shares for issues that had a large decline in quoted spread; thus, the situation was conducive to market impact when executing orders that raised concerns of a negative impact on trading cost. However, there was a large decline in effective spread for issues that recorded a substantial decline in BBO quoted shares, as shown in Figure10. Thus, the majority of orders were executed at BBO or thereabouts and there was no major impediment to executing orders from the perspective of trading cost. Lastly, Figure11 indicates the quoted spread in unit of yen[47] after the beginning of Phase 2 for each issue in the price band below 5,000 yen that implemented below 1 yen tick sizes of 0.1 yen and 0.5 yen in Phase 2. Obviously, the higher an issue's share price the larger the quoted spread in unit of yen. Thus, for a tiered regime of tick size, as used by the TSE, it is appropriate to set tick size and price band so that the quoted spread on most of the issues in a certain price band will not exceed the tick size in one price band higher. Almost all the issues (23 of 24 issues) in the price band below 1,000 yen have quoted spreads of below 0.5 yen. In addition, approximately 70% (24 or 35 issues) with price bands of more than 1,000 yen and less than 3,000 yen that changed to a tick size of 0.5 yen this time, and had a tick size of 1 yen before the change, have quoted spreads below 1 yen. However, there are few (2 of 21 issues) with quoted spread of below 1 yen with price bands of more than 3,000 yen and less than 5,000 yen that had tick size of 5 yen before Phase 1.

7 Conclusion

This paper analyzes the impact on trading from the change in tick size for TOPIX100 constituents implemented in January and July 2014 using the FLEX Full data (the real time market data feed service provided by the TSE) and examines whether the objective to improve the trading costs for investors has been achieved. In analyzing the trading cost, comparison was made of the trading-related costs in the IS that can be observed in stock exchange trading data before and after the tick size change; i.e., by taking the respective quoted spread, effective spread, intraday volatility, and the calculation of effective spread for order size for each of spread cost, timing cost, and market impact as an assessment index. The quoted spread and effective spread fell for all issues following tick size reduction, and the effective half spread for all TOPIX100 constituents fell from 5.55bp to 1.79bp, which was a decline of 397 million yen per day on a value basis. In addition, comparison of the volatility of the fluctuation rate for the midpoint of BBO every one-

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[46] 21 of the 56 issues in Analysis Group D had a base price of more than 3,000 yen and less than 5,000 yen on July 22, which was the first day of Phase 2.

[47] The price difference between the sell side and buy side of BBO before deducting the midpoint of BBO and converting to bps.

Figure8 Comparison of the reduction in average quoted spread and average BBO quoted shares
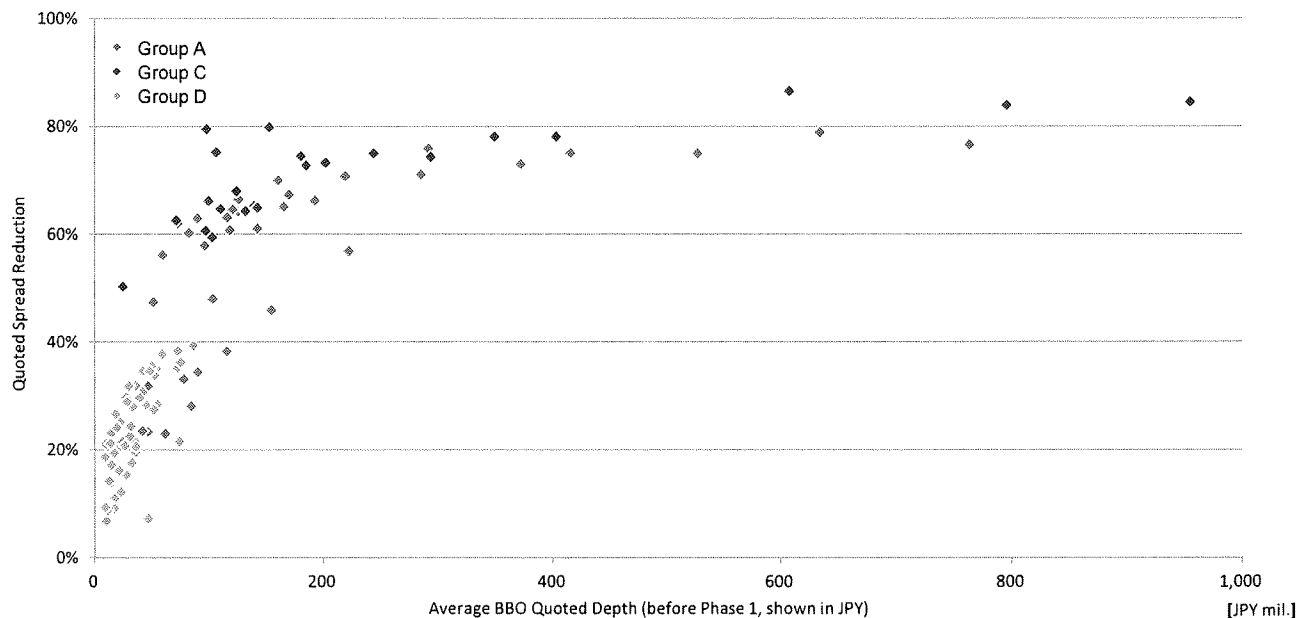
* Average BBO quoted shares (value base) is the average value calculated by multiplying the total number of BBO quoted shares by the BBO midpoint every minute.

Figure9   Comparison of the reduction in average quoted spread and the reduction in average BBO quoted shares
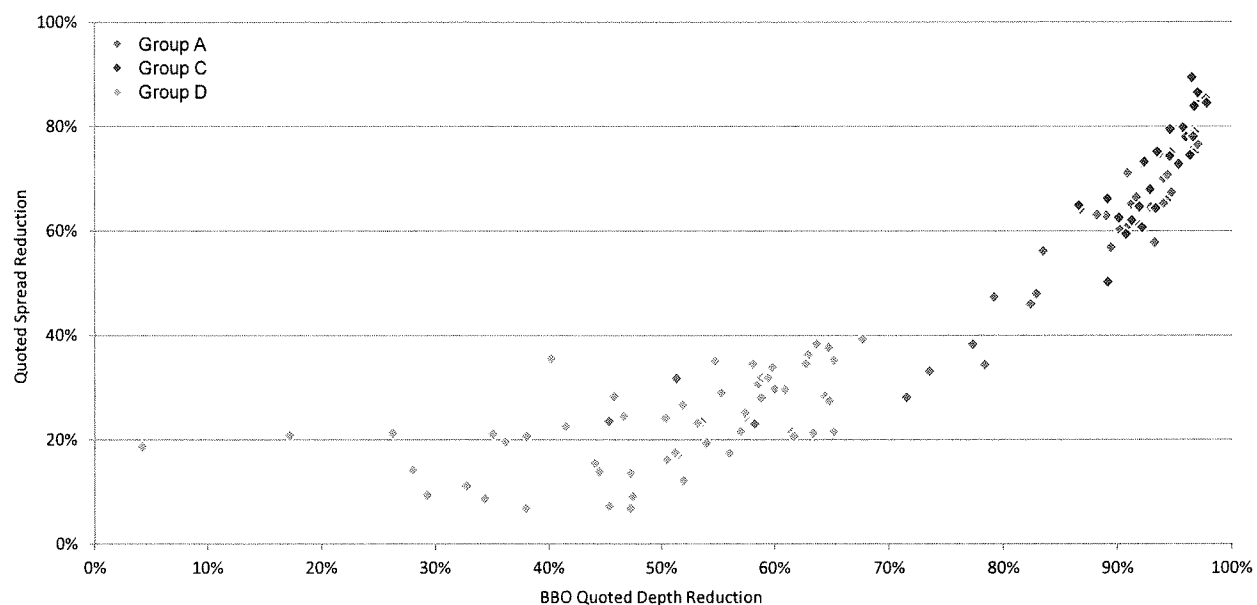
* The reduction in the average BBO quoted shares is the extent of reduction in the average value calculated by multiplying the total number of BBO quoted shares by the BBO midpoint every minute before and after the period.

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Figure10 Comparison of the Reduction in Average effective half spread and the reduction in average BBO quoted shares
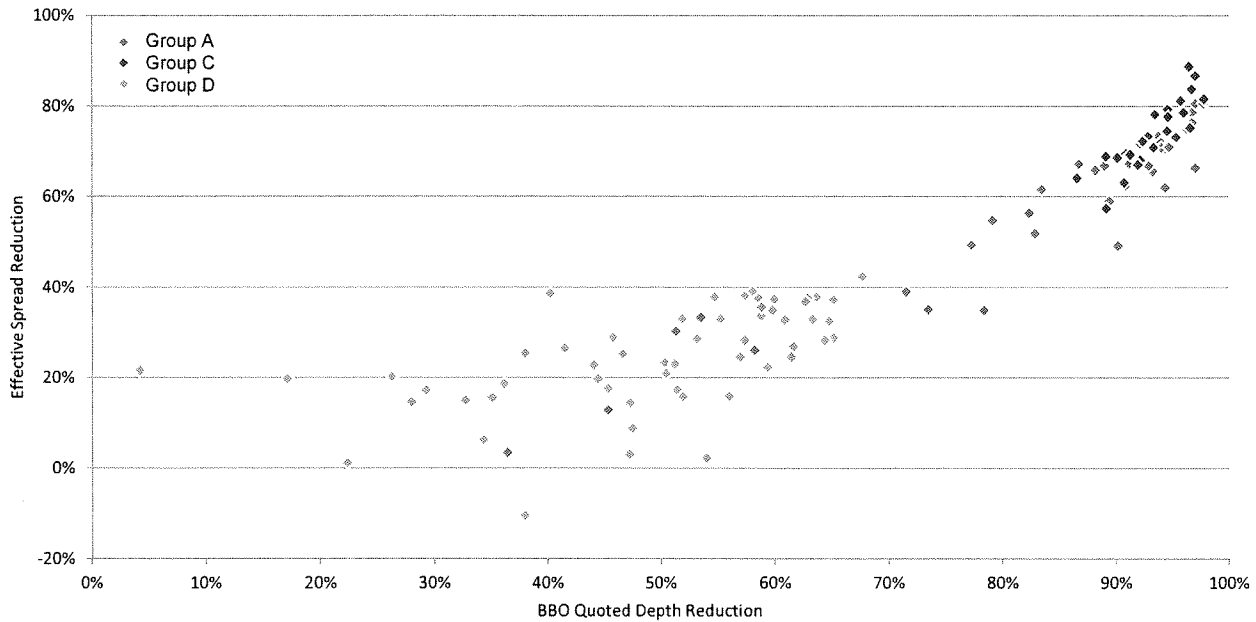
* The reduction in the average BBO quoted shares is the extent of reduction in the average value calculated by multiplying the total number of BBO quoted shares by the BBO midpoint every minute before and after the period.

Figure11 The average quoted spread for issues in price bands with decimal tick size
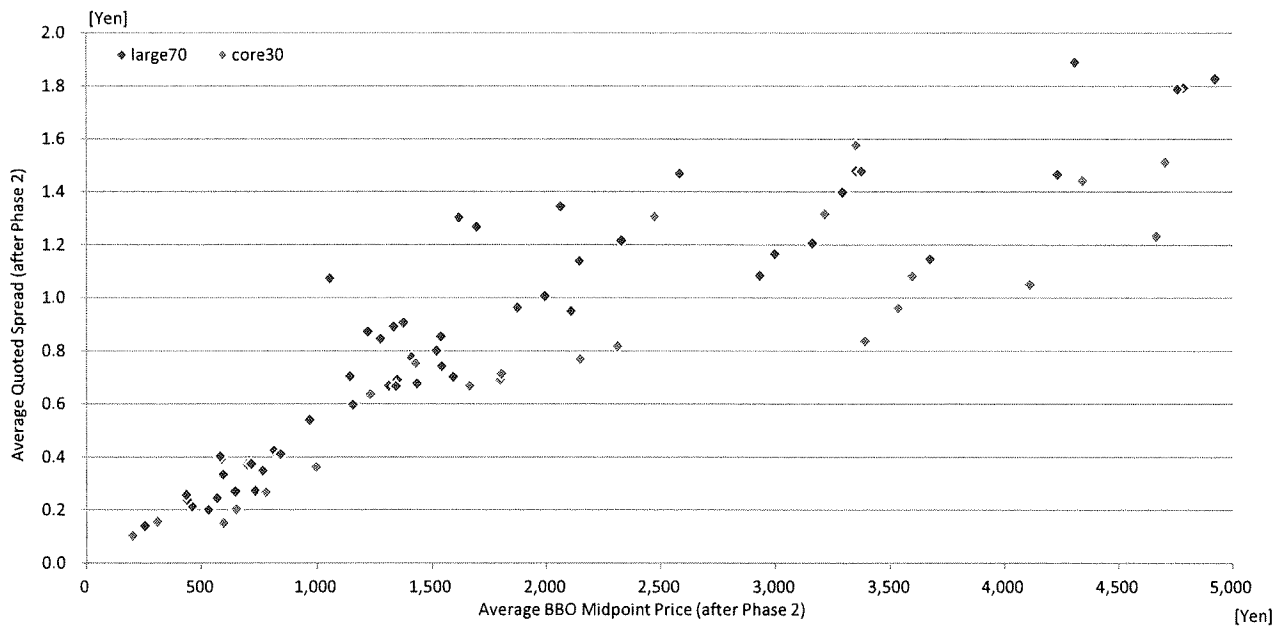
* The Average BBO midpoint is the average of the midpoint of BBO calculated every minute during the period used in the analysis .
* Within the TOPIX100 constituents, the red dots indicate issues belonging to the TOPIX Core30, while the blue dots indicate issues belonging to the TOPIX Large70.

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and ten-minute indicates a larger downward trend in one-minute volatility following tick size reduction. In the calculation of the effective spread by order size using order book information, no deterioration was evident in effective spread following tick size reduction, apart from some issues, even for extremely large-sized orders. These results confirmed the decline in trading-related costs in IS following the change in tick size.

However, issues that suffered a large decline in quoted spread also suffered a large decline in BBO quoted shares coupled with an increase in the number of prices in the order book due to tick size reduction, and it became harder to confirm the market trends by looking at the order book on the screen such as on a computer. In particular, there is no denying the possibility of reduced convenience in trading that cannot be measured in the aforementioned trading cost, especially for those investors placing orders by hand. There was concern that the reduction in the quoted spread itself would lead to a decline in profit margins for some investors such as market makers, and the assessment differed depending on the aspects of investors based on matters such as investment strategies and order methods. In addition, the increase in the number of orders and the number of executions led to an increase in the frequency of quoted shares on BBO updates in the order book. Thus, it is simplistic to justify there being more stability in price formation based on the reduction in the volatility of the fluctuation rate of the BBO midpoint per unit of time. In relation to effective spread, even if the figures are the same, the case that there was execution only because of BBO and the case of multiple prices striding more than a single price level could possibly have a different impact on the subsequent price formation (permanent impact).

Considering the trading changes implemented in Phases 1 and 2, the TSE once again considered appropriate tick size and plans to make a further change in tick size in Phase 3 on September 24, 2015. The results of the analysis in this paper provide three suggestions ahead of Phase 3. First, since a correlation is evident between the size of the BBO quoted shares before the tick size reduction and the reduction in the quoted spread when tick size was reduced, we cannot expect a large reduction in quoted spread for issues with insufficient liquidity even if the tick size is reduced. The effective spread will not decline without a reduction in quoted spread; thus, the objective of improved trading cost cannot be achieved. Second, since quoted spread reduction accompanies the decline in the BBO quoted shares, the improvement in the trading cost for TOPIX100 constituents with the decline in quoted spread in Phases 1 and 2 means that it will be hard to expect further improvements in trading costs even if tick size falls further since BBO quoted shares have already fallen because of the quoted spread reduction Phase 1 and 2. Therefore, there appears to be little scope for further improvement in trading costs due to tick size reduction for the TOPIX100 constituents. Third, since for some price bands the quoted spread in units of yen for the majority of TOPIX100 constituents is larger than the tick size for one level higher price band, from the perspective of setting an appropriate tick size, consideration also needs to be given to a slight widening of the tick size for some price bands in relation to the tick size that was implemented for TOPIX100 constituents in Phases 1 and 2.

As noted at the beginning of this paper, there are adverse effects if the tick size is either too large or too small; thus, it is desirable to set the appropriate size. However, there is not necessarily a unique determination for tick size, and the desired level will differ depending on the aspects of the investors. In overseas markets, the regulatory authorities have led the way toward unified tick sizes at trading venues within the same region. However, in Japan, each trading venue independently sets its own tick size, and difference in tick size can influence investor choice of trading venue. However, the setting of tick size in a biased way toward increasing the convenience of specific investors to promote increased trading can lose the market's social function of discovering the appropriate price through participation by various investors with different investment strategies. There has been an increase in the number of trading venues in the U.S. and Europe in recent years with increased market fragmentation; however, a large part of trading in Japan continues to be executed on the TSE market. As such, the trading rules must consider investor diversity. For matters such as tick sizes, opinions should be sought from a wide range of investors while continuing to monitor trading patterns so that the necessary revisions are made to reflect changes in the market environment.

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Table14 TOPIX100 Constituents

Code	Name	Base Price(Yen)		Analysis Group	
		2014/1/17	2014/7/22	Phase 1	Phase 2
1605	INPEX CORPORATION	1,286	1,545	B	D
1878	DAITO TRUST CONSTRUCTION CO.,LTD.	9,940	12,075	A	E
1925	DAIWA HOUSE INDUSTRY CO.,LTD.	1,973	2,143	B	D
1928	Sekisui House,Ltd.	1,510	1,414	B	D
1963	JGC CORPORATION	4,005	3,083	A	D
2502	Asahi Group Holdings,Ltd.	2,839	3,180	B	D
2503	Kirin Holdings Company,Limited	1,435	1,454	B	D
2802	Ajinomoto Co.,Inc.	1,470	1,557	B	D
2914	JAPAN TOBACCO INC.	3,195	3,760	A	D
3382	Seven & I Holdings Co.,Ltd.	4,395	4,424	A	D
3402	TORAY INDUSTRIES,INC.	702	688	B	C
3407	ASAHI KASEI CORPORATION	846	796	B	C
4063	Shin-Etsu Chemical Co.,Ltd.	5,860	6,250	A	E
4188	Mitsubishi Chemical Holdings Corporation	473	446	B	C
4452	Kao Corporation	3,300	4,245	A	D
4502	Takeda Pharmaceutical Company Limited	4,820	4,715	A	D
4503	Astellas Pharma Inc.	6,300	1,394	A	D
4523	Eisai Co.,Ltd.	3,990	4,256	A	D
4568	DAIICHI SANKYO COMPANY,LIMITED	2,006	1,895	B	D
4578	Otsuka Holdings Co.,Ltd.	3,180	3,270	B	D
4661	ORIENTAL LAND CO.,LTD.	15,100	18,845	A	E
4901	FUJIFILM Holdings Corporation	3,065	2,910	B	D
4911	Shiseido Company,Limited	1,658	1,983	B	D
5020	JX Holdings,Inc.	527	542	B	C
5108	BRIDGESTONE CORPORATION	3,945	3,832	A	D
5201	Asahi Glass Company,Limited	637	596	B	C
5401	NIPPON STEEL & SUMITOMO METAL CORPORATION	340	305	B	C
5411	JFE Holdings,Inc.	2,359	2,110	B	D
5713	Sumitomo Metal Mining Co.,Ltd.	1,385	1,745	B	D
5802	Sumitomo Electric Industries,Ltd.	1,747	1,497	B	D
6273	SMC CORPORATION	28,000	27,395	A	E
6301	KOMATSU LTD.	2,064	2,331	B	D
6326	KUBOTA CORPORATION	1,755	1,376	B	D
6367	DAIKIN INDUSTRIES,LTD.	6,260	6,795	A	E
6501	Hitachi,Ltd.	846	764	B	C
6502	TOSHIBA CORPORATION	469	472	B	C
6503	Mitsubishi Electric Corporation	1,325	1,311	B	D
6594	NIDEC CORPORATION	10,650	6,535	A	E
6702	FUJITSU LIMITED	544	768	B	C
6752	Panasonic Corporation	1,338	1,208	B	D
6758	SONY CORPORATION	1,835	1,688	B	D
6861	KEYENCE CORPORATION	44,750	43,160	A	E
6902	DENSO CORPORATION	5,590	4,753	A	D
6954	FANUC CORPORATION	17,800	17,280	A	E
6971	KYOCERA CORPORATION	5,130	4,930	A	D
6981	MURATA MANUFACTURING COMPANY,LTD.	9,860	9,828	A	E
6988	NITTO DENKO CORPORATION	4,355	4,730	A	D
7011	Mitsubishi Heavy Industries,Ltd.	686	654	B	C
7201	NISSAN MOTOR CO.,LTD.	942	992	B	C
7202	ISUZU MOTORS LIMITED	641	677	B	C

Code	Name	Base Price(Yen) 2014/1/17	Base Price(Yen) 2014/7/22	Analysis Group Phase 1	Analysis Group Phase 2
7203	TOYOTA MOTOR CORPORATION	6,290	6,049	A	E
7267	HONDA MOTOR CO.,LTD.	4,265	3,601	A	D
7269	SUZUKI MOTOR CORPORATION	2,905	3,311	B	D
7270	Fuji Heavy Industries Ltd.	3,045	2,926	B	D
7731	NIKON CORPORATION	1,954	1,546	B	D
7741	HOYA CORPORATION	3,015	3,438	B	D
7751	CANON INC.	3,235	3,393	A	D
7752	RICOH COMPANY,LTD.	1,124	1,167	B	D
7912	Dai Nippon Printing Co.,Ltd.	1,102	1,063	B	D
7974	Nintendo Co.,Ltd.	16,080	12,560	A	E
8001	ITOCHU Corporation	1,316	1,310	B	D
8002	Marubeni Corporation	752	736	B	C
8031	MITSUI & CO.,LTD.	1,473	1,656	B	D
8035	Tokyo Electron Limited	5,740	7,162	A	E
8053	SUMITOMO CORPORATION (SUMITOMO SHOJI KAISHA,LTD.)	1,318	1,368	B	D
8058	Mitsubishi Corporation	1,994	2,152	B	D
8113	UNICHARM CORPORATION	5,910	6,238	A	E
8267	AEON CO.,LTD.	1,445	1,161	B	D
8306	Mitsubishi UFJ Financial Group,Inc.	686	604	B	C
8308	Resona Holdings, Inc.	550	585	B	C
8309	Sumitomo Mitsui Trust Holdings,Inc.	552	458	B	C
8316	Sumitomo Mitsui Financial Group,Inc.	5,380	4,117	A	D
8332	The Bank of Yokohama,Ltd.	580	593	B	C
8411	Mizuho Financial Group,Inc.	237	201	B	C
8591	ORIX CORPORATION	1,785	1,630	B	D
8601	Daiwa Securities Group Inc.	1,042	846	B	C
8604	Nomura Holdings, Inc.	819	665	B	C
8630	NKSJ Holdings,Inc.	2,928	2,675	B	D
8725	MS&AD Insurance Group Holdings,Inc.	2,688	2,341	B	D
8750	The Dai-ichi Life Insurance Company,Limited	1,769	1,426	B	D
8766	Tokio Marine Holdings,Inc.	3,355	3,290	A	D
8795	T&D Holdings, Inc.	1,490	1,289	B	D
8801	Mitsui Fudosan Co.,Ltd.	3,615	3,450	A	D
8802	Mitsubishi Estate Company,Limited	2,942	2,587	B	D
8830	Sumitomo Realty & Development Co.,Ltd.	4,990	4,327	A	D
9020	East Japan Railway Company	8,130	8,261	A	E
9021	West Japan Railway Company	4,425	4,731	A	D
9022	Central Japan Railway Company	12,230	15,420	A	E
9064	YAMATO HOLDINGS CO.,LTD.	2,018	2,115	B	D
9202	ANA HOLDINGS INC.	226	248	B	C
9432	NIPPON TELEGRAPH AND TELEPHONE CORPORATION	5,660	6,740	A	E
9433	KDDI CORPORATION	6,260	6,229	A	E
9437	NTT DOCOMO,INC.	1,749	1,794	B	D
9502	Chubu Electric Power Company,Incorporated	1,303	1,250	B	D
9503	The Kansai Electric Power Company,Incorporated	1,198	1,029	B	C
9531	TOKYO GAS CO.,LTD.	504	596	B	C
9532	OSAKA GAS CO.,LTD.	408	440	B	C
9735	SECOM CO.,LTD.	6,030	6,272	A	E
9983	FAST RETAILING CO.,LTD.	41,100	32,875	A	E
9984	SoftBank Corp.	9,020	7,677	A	E

* Constituents from 31 October, 2013 to 30 October, 2014.
* The analysis group categories are based not only on the base price on January 17, 2014 and July 22, 2014, but the movement in the base price during the entire period of analysis.

Table15　Quoted spread and effective half spread

Code	Quoted Spread $\tilde{q}s$				Effective Half Spread $\tilde{e}s$			
	Phase 1		Phase 2		Phase 1		Phase 2	
	Before	After	Before	After	Before	After	Before	After
1605	8.70	9.28	7.33	5.55	4.61	4.92	3.91	2.42
1878	13.66	7.19	7.81	7.75	6.08	2.75	3.35	3.19
1925	9.78	11.33	9.57	6.53	3.70	4.26	3.60	2.80
1928	8.37	8.13	7.80	5.11	4.05	3.98	4.16	2.53
1963	18.33	12.03	10.41	10.43	7.23	4.71	4.02	3.97
2502	5.57	6.06	4.30	3.82	2.62	2.71	2.12	1.81
2503	9.40	10.14	7.62	5.48	3.92	4.11	3.77	2.50
2802	11.80	12.27	10.64	8.04	4.81	4.81	4.23	3.16
2914	14.72	3.98	3.57	3.02	7.45	2.11	1.89	1.46
3382	12.88	4.76	3.86	3.33	6.59	2.26	1.89	1.52
3402	14.40	14.97	14.87	5.32	7.26	7.64	7.96	2.33
3407	13.83	14.75	13.86	5.20	6.74	7.10	6.82	2.14
4063	16.91	5.53	4.27	4.25	8.56	2.49	1.83	1.97
4188	21.36	22.12	22.61	4.65	10.74	11.48	11.32	2.35
4452	15.92	5.91	4.40	3.47	8.08	2.68	2.03	1.62
4502	16.49	3.49	3.15	2.64	8.30	1.78	1.60	1.27
4503	16.58	5.61	8.04	5.26	8.42	2.47	4.17	2.64
4523	13.02	5.12	4.70	4.38	6.53	2.46	2.12	2.34
4568	6.59	6.99	6.47	5.14	3.33	3.54	3.06	2.24
4578	8.76	6.13	5.13	4.25	4.99	3.00	2.33	1.93
4661	9.19	7.05	5.70	5.97	4.26	2.84	2.37	2.59
4901	6.06	4.77	4.82	3.88	3.17	2.50	2.37	2.32
4911	8.18	8.49	6.41	5.05	4.15	3.78	3.33	2.23
5020	19.02	19.60	18.58	3.76	9.64	10.02	9.41	1.77
5108	13.09	4.57	3.56	3.13	6.65	2.18	1.88	1.59
5201	16.40	16.97	16.97	6.68	8.08	8.69	8.82	2.82
5401	29.48	31.32	31.46	5.09	14.77	15.70	15.80	2.59
5411	5.20	5.71	5.75	4.51	2.78	3.05	2.86	2.16
5713	10.62	11.31	9.66	7.48	4.51	4.55	4.44	3.26
5802	7.31	7.50	7.49	5.26	3.63	3.68	3.95	2.48
6273	11.19	11.36	10.62	8.50	4.29	4.15	3.92	3.27
6301	5.20	5.39	4.98	3.54	2.76	3.07	2.68	1.80
6326	9.84	9.34	9.14	6.56	4.14	4.24	4.01	2.85
6367	16.00	5.67	4.54	4.12	8.11	2.69	2.28	2.13
6501	12.87	12.42	13.30	3.43	6.53	6.46	6.86	1.75
6502	23.04	21.80	21.09	4.64	11.55	10.98	10.66	2.30
6503	10.58	10.22	8.52	6.68	4.78	4.77	4.28	3.05
6594	11.67	7.81	4.02	4.01	5.76	3.74	1.83	2.01
6702	19.78	18.79	13.48	4.57	9.90	9.50	6.76	2.11
6752	8.59	8.35	8.37	5.16	4.73	5.46	4.41	2.74
6758	5.65	6.05	6.18	3.85	3.08	3.44	3.29	2.23
6861	15.87	11.41	10.94	9.49	6.83	4.17	3.96	3.56
6902	18.85	4.56	3.75	3.22	9.61	2.28	1.73	1.48
6954	6.80	5.23	4.77	4.70	3.34	2.47	2.16	2.19
6971	19.48	5.84	4.56	3.71	9.87	2.77	2.12	1.66
6981	11.93	6.21	4.21	4.78	5.99	2.89	1.80	2.22
6988	13.50	5.37	4.09	3.74	5.51	2.81	1.83	1.71
7011	15.77	14.99	15.52	4.16	8.01	7.74	7.88	2.19
7201	11.29	11.05	10.30	3.62	5.85	5.67	5.27	1.90
7202	16.25	16.34	14.84	5.25	8.35	8.25	7.60	2.51

| Code | Quoted Spread$\tilde{q}s$ | | | | Effective Half Spread$\tilde{e}s$ | | | |
| | Phase 1 | | Phase 2 | | Phase 1 | | Phase 2 | |
	Before	After	Before	After	Before	After	Before	After
7203	16.05	2.34	2.06	2.21	8.04	1.56	1.23	1.22
7267	11.87	3.44	3.44	2.73	6.02	1.84	1.82	1.36
7269	6.26	6.51	5.11	4.42	2.78	2.94	2.69	2.61
7270	6.78	4.96	4.87	3.70	3.60	2.79	2.46	1.89
7731	6.37	6.41	6.83	4.81	3.21	3.34	3.56	2.40
7741	7.09	6.78	5.54	4.38	3.52	3.30	2.49	2.10
7751	15.18	3.81	3.40	2.47	7.71	2.06	1.86	1.26
7752	10.93	9.70	8.85	6.13	5.05	5.05	4.61	2.87
7912	13.98	15.38	12.91	10.14	5.49	6.05	5.34	4.03
7974	9.33	7.13	6.77	6.91	4.49	3.92	3.28	3.28
8001	8.25	8.25	7.85	5.08	4.33	4.38	4.11	2.58
8002	13.86	13.83	13.61	3.71	7.04	7.04	7.03	1.89
8031	7.29	7.37	6.28	4.01	3.86	4.10	3.85	2.40
8035	18.33	6.37	4.72	4.99	9.28	2.71	2.17	2.44
8053	8.12	8.14	7.63	4.95	4.44	4.21	3.96	2.46
8058	5.31	5.56	5.00	3.59	2.77	2.95	2.92	2.09
8113	16.62	5.58	4.79	4.71	8.42	2.61	2.01	2.07
8267	7.97	8.10	8.47	5.14	4.00	4.12	4.34	2.51
8306	15.20	15.63	16.21	2.52	7.71	7.95	8.20	1.52
8308	19.23	17.99	16.93	4.33	9.62	9.11	8.68	2.18
8309	19.02	19.91	21.71	5.44	9.55	10.10	10.87	2.44
8316	18.89	2.99	3.10	2.56	9.38	1.83	1.83	1.41
8332	19.17	20.61	18.26	6.94	9.29	9.66	8.82	2.71
8411	45.95	44.78	48.84	5.19	23.04	22.40	24.43	2.77
8591	6.29	6.75	6.46	4.40	3.41	3.73	3.53	2.28
8601	10.26	10.66	11.92	4.85	5.45	5.61	5.98	2.21
8604	12.73	13.41	14.20	3.12	6.53	6.93	7.35	1.83
8630	7.53	7.20	6.11	5.69	3.17	3.16	2.63	2.25
8725	7.13	7.01	6.36	5.25	3.17	3.00	2.75	2.32
8750	7.18	7.23	7.31	4.71	3.89	3.87	3.91	2.40
8766	15.23	5.46	4.52	4.11	7.60	2.50	2.07	1.89
8795	8.96	9.29	8.85	6.62	4.37	4.54	4.24	3.04
8801	14.84	8.02	5.08	4.71	7.41	3.24	2.45	2.02
8802	11.08	7.32	6.57	5.29	5.16	3.13	2.74	2.23
8830	16.01	9.88	8.78	6.96	7.33	3.72	3.35	2.69
9020	12.51	4.88	3.52	3.84	6.33	2.03	1.54	1.72
9021	12.06	5.29	4.14	3.76	5.92	2.27	1.86	1.54
9022	11.47	7.83	5.97	6.09	4.69	3.27	2.47	2.57
9064	7.15	7.17	6.91	5.31	3.15	3.48	3.15	2.25
9202	47.35	45.27	41.31	5.58	23.70	22.78	21.11	2.82
9432	18.35	4.59	3.69	3.24	9.29	2.20	1.69	1.58
9433	15.91	4.66	3.58	3.44	8.08	3.07	1.70	1.62
9437	6.13	6.30	5.98	3.96	3.25	3.34	3.23	2.10
9502	9.29	10.44	9.72	7.13	4.55	4.95	4.71	3.16
9503	9.87	10.40	11.16	5.55	5.02	5.54	5.80	2.48
9531	19.98	19.95	17.47	5.61	10.09	10.07	8.63	2.31
9532	24.59	24.24	23.88	5.94	12.41	12.32	11.78	2.59
9735	16.99	7.17	5.10	5.10	8.49	2.92	2.14	2.17
9983	13.32	5.75	5.91	5.16	6.60	2.71	2.58	2.31
9984	11.23	2.63	2.09	2.16	5.91	2.00	1.27	1.38

* The figures of the quoted spread are the average during each period. The figures of the effective half spread are the average value of the weighted average during each period based on the daily execution shares. Units are bps.

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Table16   Intraday volatility

Code	One-minute Volatility σ_1				Ten-minute Volatility σ_{10}			
	Phase 1		Phase 2		Phase 1		Phase 2	
	Before	After	Before	After	Before	After	Before	After
1605	6.42	8.33	7.40	5.94	18.28	21.35	18.12	16.89
1878	5.31	6.85	5.45	5.32	12.71	19.74	13.70	16.60
1925	5.30	7.48	4.89	7.24	14.96	21.82	14.15	17.53
1928	5.62	7.48	4.33	4.33	15.67	19.51	11.60	13.16
1963	6.12	7.60	4.77	6.06	16.86	24.52	13.01	16.96
2502	5.77	7.26	4.99	4.92	17.33	19.59	11.72	14.41
2503	4.95	6.89	4.19	4.61	14.00	17.71	11.35	13.54
2802	5.17	7.97	5.07	4.52	14.98	22.15	15.87	13.42
2914	6.20	6.96	4.06	5.35	15.87	19.35	10.71	14.74
3382	6.77	7.31	4.64	4.54	17.39	20.13	13.34	11.85
3402	5.46	7.53	4.91	3.70	12.33	18.91	12.16	11.09
3407	6.11	9.92	5.31	4.75	16.30	27.16	12.65	13.26
4063	6.60	7.14	4.35	4.99	16.50	19.72	12.12	13.70
4188	7.12	9.32	5.65	6.67	18.09	22.45	14.16	20.16
4452	6.76	7.56	5.09	5.15	16.80	22.43	13.08	13.40
4502	5.13	4.74	3.19	2.99	14.23	12.04	8.19	8.38
4503	7.42	8.49	5.44	5.36	18.66	23.88	14.73	16.17
4523	5.29	5.66	4.43	4.50	12.59	15.36	11.40	12.40
4568	5.53	7.45	4.26	4.72	14.95	19.42	11.77	13.93
4578	5.39	7.03	5.52	5.06	14.17	21.48	13.70	12.75
4661	4.19	5.37	3.95	4.82	13.11	16.56	10.86	15.73
4901	6.44	8.10	4.64	6.96	19.88	22.97	12.98	17.61
4911	6.74	7.88	5.89	5.68	18.32	20.12	15.82	15.97
5020	6.58	8.80	6.38	5.53	17.42	23.59	16.56	14.72
5108	6.45	7.14	4.48	4.60	15.91	19.57	12.32	12.23
5201	6.53	7.68	5.62	5.49	16.31	19.26	13.28	16.81
5401	7.52	10.89	6.23	6.07	19.34	28.62	14.98	17.66
5411	6.68	8.42	5.41	6.74	20.25	25.27	14.33	19.36
5713	5.40	7.43	6.94	6.32	16.20	21.24	19.73	21.20
5802	6.90	8.41	5.82	5.54	20.21	22.41	16.83	17.33
6273	6.27	8.23	5.61	6.33	18.58	24.95	15.22	17.75
6301	5.03	7.66	5.06	5.43	13.66	21.21	13.24	15.29
6326	6.58	9.52	5.64	5.90	19.38	26.03	14.32	16.10
6367	7.40	7.65	5.78	5.22	17.85	23.43	16.38	15.98
6501	6.50	9.03	5.63	5.49	17.62	25.51	13.85	15.37
6502	7.10	10.10	6.32	5.11	16.55	25.49	15.91	15.17
6503	6.37	9.06	5.31	6.07	19.46	25.45	13.62	18.25
6594	6.20	8.46	5.11	5.67	16.78	26.82	14.19	16.83
6702	8.60	12.65	6.97	7.85	22.89	35.17	18.11	23.31
6752	7.31	11.49	5.96	5.43	20.09	31.58	15.43	16.49
6758	5.98	8.50	4.84	6.41	16.71	24.00	12.38	17.16
6861	6.86	8.02	5.38	5.67	19.21	24.29	14.61	14.95
6902	6.70	8.20	4.75	4.75	17.72	21.94	12.11	11.35
6954	6.75	8.02	4.82	5.16	18.99	22.76	12.59	14.86
6971	7.93	7.61	5.06	4.64	20.33	23.28	13.83	11.31
6981	6.70	8.24	4.67	5.08	16.96	25.06	13.42	13.72
6988	8.46	7.97	4.96	5.03	21.04	23.75	13.91	14.33
7011	6.91	10.23	5.65	5.56	17.91	28.76	15.18	16.28
7201	6.32	8.28	5.28	5.54	17.95	21.25	12.47	14.91
7202	8.03	8.66	6.74	6.60	21.64	21.49	16.93	17.78

| | One-minute Volatility σ_1 | | | | Ten-minute Volatility σ_{10} | | | |
| Code | Phase 1 | | Phase 2 | | Phase 1 | | Phase 2 | |
	Before	After	Before	After	Before	After	Before	After
7203	5.18	5.19	3.41	3.49	12.44	15.25	9.59	9.61
7267	5.77	6.21	4.39	4.43	14.28	16.67	11.43	12.00
7269	7.11	8.25	6.27	6.28	20.51	22.87	16.24	15.07
7270	5.89	8.34	5.01	5.70	16.19	24.39	12.88	15.66
7731	6.48	8.64	3.74	5.17	17.60	23.48	9.49	14.62
7741	6.63	9.04	5.27	6.08	18.24	26.76	13.22	16.66
7751	4.75	5.38	3.26	3.52	11.40	13.94	8.93	8.93
7752	7.39	10.97	5.77	5.56	20.79	29.55	15.65	15.72
7912	5.67	7.71	4.72	4.46	15.84	22.98	12.62	13.42
7974	8.12	15.08	6.11	6.95	22.64	44.61	16.75	19.26
8001	5.18	7.23	4.41	4.62	13.66	19.31	11.35	13.07
8002	4.87	7.57	3.92	4.07	11.33	16.40	8.80	12.78
8031	4.52	7.39	4.48	4.78	12.45	20.24	11.65	14.38
8035	7.14	7.10	4.21	4.68	17.42	19.70	12.29	14.10
8053	4.46	6.31	3.84	4.07	11.52	16.84	9.31	12.17
8058	4.01	5.68	3.98	4.26	10.46	15.74	10.72	13.64
8113	7.08	8.12	5.05	4.68	18.86	23.48	12.61	13.68
8267	5.07	6.62	3.90	3.38	13.28	16.24	9.20	9.27
8306	6.30	7.75	5.98	4.66	15.64	18.39	13.76	13.46
8308	5.85	8.80	6.73	7.06	13.62	23.55	16.91	17.91
8309	8.07	9.78	6.77	5.96	20.87	24.99	17.21	17.07
8316	6.71	6.73	4.78	4.93	17.93	19.38	12.95	13.67
8332	7.07	8.93	5.82	5.24	19.57	23.88	14.41	13.76
8411	6.18	9.30	4.38	3.76	16.10	20.69	11.00	9.63
8591	7.33	10.81	6.28	6.19	21.50	29.19	15.40	17.46
8601	7.07	8.67	5.95	5.27	18.04	21.75	15.22	15.48
8604	6.73	8.78	6.17	5.19	16.63	21.42	15.39	15.31
8630	7.97	8.95	6.28	6.26	24.00	22.99	16.49	16.21
8725	7.64	8.52	6.35	6.61	23.15	20.58	16.64	17.93
8750	8.10	9.75	6.56	5.22	22.05	27.70	18.33	15.25
8766	7.48	7.12	5.40	5.54	19.90	19.63	13.76	14.06
8795	8.22	9.68	7.05	6.33	23.66	25.77	18.67	18.17
8801	7.70	8.36	5.09	4.94	19.58	25.17	14.23	14.53
8802	6.90	8.35	5.46	5.10	17.46	22.84	14.90	14.55
8830	8.05	8.41	5.84	5.84	21.69	25.15	15.55	15.96
9020	5.66	6.69	4.09	4.55	14.77	18.18	11.45	12.52
9021	5.21	6.38	3.51	4.30	13.61	17.31	9.52	13.14
9022	5.21	7.61	4.36	4.67	13.92	19.05	12.96	13.72
9064	6.70	8.81	5.85	5.70	17.92	24.31	15.52	14.60
9202	5.28	9.40	4.78	5.18	14.05	24.17	11.50	15.85
9432	6.55	7.46	4.88	5.64	17.08	23.01	13.19	15.45
9433	8.22	10.51	5.48	5.53	20.50	28.43	14.21	14.79
9437	4.48	6.71	4.36	4.94	11.69	16.87	10.66	13.12
9502	6.14	9.49	5.53	5.18	17.61	25.98	14.36	15.99
9503	7.06	11.23	8.35	7.24	19.12	30.35	23.68	21.83
9531	5.11	8.63	5.47	5.45	11.96	20.34	14.34	16.07
9532	5.75	9.45	5.54	5.64	14.90	24.34	13.90	17.91
9735	6.92	7.86	4.46	4.72	17.92	22.72	12.71	12.69
9983	9.36	8.07	5.22	5.07	26.17	23.49	14.47	13.77
9984	7.54	10.50	4.87	5.84	20.36	32.72	12.86	17.07

* The figures are the average for the daily calculated intraday volatility for each period. Units are bps.

Table17 Daily trading volume and number of executions

Code	Trading Volume				Number of Execution			
	Phase 1		Phase 2		Phase 1		Phase 2	
	Before	After	Before	After	Before	After	Before	After
1605	4,639,520	4,101,535	3,779,470	3,101,225	2,896	2,968	3,456	3,785
1878	313,130	422,260	280,395	349,795	701	1,683	1,035	1,228
1925	2,395,950	2,555,050	1,702,300	2,367,885	899	1,081	758	3,075
1928	4,250,880	4,613,275	2,781,115	2,856,005	2,738	3,153	1,900	2,405
1963	1,285,750	1,400,900	1,020,300	1,197,700	486	791	559	735
2502	2,309,840	1,902,545	1,946,405	1,992,950	3,375	3,068	2,928	3,880
2503	3,916,900	3,919,400	2,222,460	2,175,705	1,149	1,193	1,550	2,247
2802	2,275,500	2,753,400	1,947,800	1,834,550	810	1,102	800	912
2914	7,086,810	6,924,505	3,193,365	3,353,665	3,597	7,603	3,860	5,521
3382	3,281,910	3,320,810	1,789,935	1,551,710	2,877	5,892	3,496	3,699
3402	7,461,250	8,232,350	5,747,200	4,339,700	1,394	1,448	842	1,408
3407	6,184,450	7,508,950	3,394,350	4,373,650	1,238	1,539	703	1,809
4063	1,577,840	1,655,685	1,057,530	1,074,025	1,464	4,130	2,796	2,898
4188	5,895,150	7,986,770	3,999,500	6,537,100	1,194	1,716	1,118	4,321
4452	1,724,190	1,836,810	1,840,785	2,171,995	1,391	3,283	3,633	4,617
4502	4,479,330	3,235,880	1,917,735	1,628,805	3,425	5,278	2,955	3,564
4503	2,047,940	2,110,135	4,917,110	5,473,950	1,647	5,100	2,812	4,482
4523	1,549,895	1,491,835	798,530	1,001,585	1,457	2,813	1,746	2,784
4568	2,494,785	3,793,880	1,659,750	1,515,755	2,264	3,674	1,831	2,254
4578	2,134,550	1,452,900	1,731,785	1,293,385	2,048	2,524	2,851	3,292
4661	275,950	345,315	235,415	261,330	946	1,359	1,100	1,271
4901	3,175,280	3,629,320	1,757,115	3,027,990	4,191	5,262	2,647	5,424
4911	1,972,085	2,142,420	2,351,280	1,798,140	2,048	2,703	2,578	3,015
5020	8,915,895	12,535,810	8,607,380	7,315,795	2,045	2,591	1,938	4,984
5108	3,161,395	3,090,405	3,027,405	2,492,390	2,449	5,115	4,326	4,862
5201	6,061,250	6,962,500	4,884,650	5,533,400	1,072	1,218	818	2,021
5401	44,572,750	60,353,400	29,850,650	32,941,950	2,223	2,637	1,494	3,861
5411	4,067,140	4,498,185	2,789,515	3,505,140	4,706	4,911	2,924	4,903
5713	3,083,650	2,992,700	3,414,900	3,525,250	989	1,159	1,323	1,632
5802	4,083,495	4,073,290	2,939,565	2,864,095	3,595	4,236	2,855	3,751
6273	196,310	229,910	150,125	167,590	872	1,294	812	1,013
6301	7,026,730	9,722,905	3,575,460	3,654,750	5,042	6,981	3,151	4,627
6326	4,890,550	6,975,950	4,361,300	5,245,900	1,618	2,410	1,426	1,908
6367	1,545,375	1,635,465	1,165,810	1,441,785	1,850	4,385	3,578	3,939
6501	35,686,400	42,716,350	19,600,350	20,344,150	3,659	4,447	2,234	5,282
6502	34,702,600	51,928,300	26,604,150	17,843,450	2,825	3,919	1,963	3,642
6503	7,637,950	8,382,500	5,527,050	5,653,200	1,828	2,416	1,424	1,904
6594	665,960	1,001,405	1,070,155	1,250,455	1,334	2,979	3,299	3,762
6702	12,882,950	22,155,800	8,894,900	13,073,700	1,518	2,851	1,558	4,426
6752	13,539,665	24,338,480	8,003,465	6,723,335	6,391	11,179	3,500	4,081
6758	12,240,195	14,821,370	6,221,565	9,326,680	7,913	9,949	4,013	8,056
6861	152,685	171,845	127,890	121,075	613	1,030	824	799
6902	2,356,815	2,407,575	1,718,440	1,636,570	1,735	5,468	3,880	3,959
6954	1,449,205	1,308,135	684,345	836,785	3,113	4,156	2,121	2,443
6971	1,954,855	2,045,510	1,238,770	1,402,595	1,430	4,236	3,016	3,679
6981	942,860	1,148,940	676,420	601,035	1,663	3,972	2,640	2,190
6988	2,996,330	2,103,235	1,173,755	1,290,555	3,421	4,910	2,791	3,686
7011	18,981,150	25,957,550	10,818,700	14,644,150	2,184	3,040	1,410	3,456
7201	18,021,960	15,087,695	9,730,535	13,466,285	4,747	4,379	2,946	9,331
7202	12,458,650	11,595,050	9,197,950	9,289,900	1,791	1,612	1,333	2,992

Code	Trading Volume				Number of Execution			
	Phase 1		Phase 2		Phase 1		Phase 2	
	Before	After	Before	After	Before	After	Before	After
7203	10,071,940	11,182,265	7,318,930	5,821,590	5,549	14,449	8,651	7,045
7267	5,740,615	6,702,535	4,897,640	4,819,750	3,507	8,227	5,307	6,399
7269	2,317,255	1,938,110	2,016,980	1,559,555	2,930	3,096	3,373	3,590
7270	5,888,845	5,226,245	2,926,455	3,027,050	4,708	5,691	3,767	5,122
7731	3,364,015	4,332,680	2,619,155	3,777,515	3,179	4,170	2,083	3,872
7741	1,611,610	1,705,325	920,300	1,141,225	2,369	3,185	1,958	3,156
7751	5,800,250	7,013,655	4,573,675	3,242,415	3,133	7,882	4,269	4,676
7752	5,874,505	7,026,005	4,156,660	4,216,960	2,027	4,275	2,705	3,429
7912	1,960,750	2,411,400	1,425,850	1,131,350	598	857	483	485
7974	979,920	2,837,480	495,835	847,000	2,882	8,909	1,749	2,553
8001	6,394,660	6,907,305	4,907,165	4,886,420	3,183	3,936	2,420	3,643
8002	11,679,150	12,115,750	6,974,700	7,011,050	1,692	1,987	970	3,619
8031	9,190,855	11,643,475	6,940,130	6,174,275	4,033	5,810	3,563	4,352
8035	1,359,445	1,071,235	753,905	845,680	1,211	2,681	2,145	2,402
8053	6,341,165	6,284,735	3,183,570	3,812,645	2,795	3,666	1,866	2,886
8058	7,159,370	7,734,565	4,466,600	3,974,745	4,202	5,165	3,042	4,064
8113	1,075,865	1,420,960	689,635	586,120	1,676	4,103	2,325	1,982
8267	3,395,130	4,826,845	3,832,175	3,122,500	2,592	4,079	2,997	2,907
8306	70,945,730	73,190,170	52,859,820	43,859,220	6,789	6,992	4,542	14,084
8308	14,862,710	28,111,755	12,078,520	12,020,435	2,239	3,404	2,371	8,081
8309	20,608,600	23,076,100	15,164,000	16,084,850	1,721	2,101	1,121	3,259
8316	7,240,470	9,228,520	6,297,910	5,451,335	3,432	12,024	7,667	8,447
8332	5,968,500	5,141,900	3,281,600	3,893,450	964	990	580	1,539
8411	173,492,160	200,212,765	83,810,435	138,583,380	6,694	7,242	3,962	7,989
8591	7,248,890	8,744,135	4,684,855	4,881,855	5,679	6,826	3,906	5,354
8601	14,828,750	14,691,400	8,932,300	7,502,950	2,580	2,707	1,508	2,357
8604	47,496,225	45,151,825	33,320,800	18,707,480	7,074	6,658	4,679	7,596
8630	1,383,940	1,657,520	1,062,195	1,021,455	2,630	3,154	2,109	2,692
8725	1,816,560	2,012,215	1,681,665	1,364,335	2,948	3,690	2,655	3,032
8750	4,385,770	5,259,595	7,346,750	9,475,860	4,622	5,065	3,686	5,293
8766	2,515,150	3,190,150	2,441,905	2,088,085	1,873	4,572	3,892	3,993
8795	2,647,845	3,191,985	2,553,155	2,271,575	2,900	3,202	2,330	2,733
8801	3,860,450	4,165,150	7,304,800	3,690,100	1,228	2,082	2,550	1,880
8802	5,473,600	6,840,000	4,158,750	4,186,900	1,719	2,771	1,796	1,905
8830	2,510,100	2,535,500	1,810,400	2,023,000	940	1,442	1,083	1,271
9020	1,092,685	1,349,685	972,355	873,705	1,557	4,008	3,248	2,988
9021	835,080	1,007,410	630,285	676,245	1,077	2,535	1,676	2,340
9022	427,070	604,330	358,780	425,785	987	1,857	1,284	1,624
9064	2,019,065	3,368,270	1,452,810	1,509,865	2,299	3,826	2,004	2,703
9202	22,642,100	25,887,050	12,355,100	14,108,900	1,292	1,410	855	2,205
9432	3,396,290	2,795,130	1,926,560	2,605,060	2,584	6,158	5,296	6,589
9433	3,658,720	4,427,525	2,045,585	2,181,555	2,869	10,303	5,164	5,216
9437	6,963,995	7,276,180	4,456,885	5,276,295	3,901	4,825	3,024	4,939
9502	1,978,185	2,153,335	1,321,555	1,350,785	1,820	2,136	1,308	1,777
9503	2,483,765	3,822,425	2,992,115	2,447,060	2,018	3,203	2,104	4,504
9531	8,168,600	11,197,850	5,807,750	6,837,500	913	1,238	779	2,132
9532	6,197,000	9,001,300	3,831,850	4,331,550	699	985	509	1,309
9735	1,038,200	854,575	516,335	553,970	1,102	2,430	1,639	1,734
9983	1,148,410	901,130	489,370	460,385	2,864	3,997	2,217	2,002
9984	13,587,725	17,648,610	7,074,785	7,916,785	9,695	31,239	13,375	14,663

* The figures are the daily averages during each period. The units of trading volume are shares.

Table18 Execution shares per single execution

Code	50th percentile				90th percentile				99th percentile			
	Phase 1		Phase 2		Phase 1		Phase 2		Phase 1		Phase 2	
	Before	After	Before	After	Before	After	Before	After	Before	Afterr	Before	After
1605	360	325	320	290	3,145	2,766	2,160	1,620	13,528	11,241	8,978	5,348
1878	140	110	100	105	817	430	455	510	2,575	1,230	1,320	1,633
1925	1000	1000	1000	530	3,780	3,555	3,200	1,845	9,739	9,541	8,732	4,940
1928	405	425	355	290	3,096	3,018	2,737	2,331	11,278	10,429	12,940	9,028
1963	1000	1000	1000	1000	3,445	2,150	2,500	2,050	9,115	5,296	6,019	5,071
2502	215	200	230	195	1,160	1,135	1,329	975	3,913	3,561	4,827	4,285
2503	1050	1150	340	273	5,700	5,900	2,780	1,972	15,225	15,914	10,915	6,561
2802	1000	1000	1000	1000	3,780	4,095	3,995	3,000	10,982	11,020	11,657	8,295
2914	295	260	235	200	3,390	1,815	1,619	1,130	18,892	6,147	5,963	4,310
3382	218	195	195	170	1,891	1,065	905	709	9,125	3,368	3,021	2,444
3402	1350	1600	1400	1100	9,460	11,350	12,025	5,350	40,234	50,358	62,492	17,879
3407	1375	1400	1200	1000	8,860	9,545	8,435	3,765	30,336	33,304	32,479	12,118
4063	205	150	155	165	1,688	675	595	613	7,283	2,217	1,985	1,967
4188	1170	910	560	450	9,354	9,844	6,219	3,010	44,528	52,025	40,816	12,518
4452	240	195	195	165	1,945	1,025	930	839	8,263	3,177	3,020	3,366
4502	240	200	205	160	2,325	1,190	1,145	790	14,341	4,170	4,064	3,060
4503	275	140	350	310	2,129	737	3,268	2,270	8,411	2,364	12,885	8,812
4523	230	190	185	120	1,728	995	806	616	7,276	3,030	2,268	2,185
4568	275	285	263	230	1,911	1,987	1,667	1,215	7,285	7,482	6,038	4,039
4578	250	195	225	175	1,850	1,105	1,134	695	9,123	3,531	3,751	2,560
4661	100	100	100	100	513	438	362	330	1,563	1,263	1,037	941
4901	210	200	220	195	1,340	1,354	1,209	945	5,049	4,678	4,438	3,637
4911	265	235	275	210	1,595	1,515	1,779	1,155	5,680	5,185	7,357	3,720
5020	718	710	625	463	7,961	9,804	8,143	3,030	44,383	57,681	55,509	11,355
5108	260	205	210	190	2,288	1,180	1,350	940	10,733	3,648	4,955	3,298
5201	1700	1750	1600	1050	10,245	11,000	10,010	4,645	41,980	46,251	53,924	14,814
5401	2550	2700	1975	2600	30,745	38,975	27,615	17,850	266,235	328,610	281,427	70,115
5411	270	305	318	260	1,735	1,870	1,859	1,425	7,014	7,221	7,234	5,278
5713	1000	1000	1000	1000	4,950	4,300	4,150	3,445	15,049	12,517	16,565	10,600
5802	305	290	245	250	2,137	2,020	2,066	1,580	7,552	6,447	8,281	5,197
6273	100	100	100	100	336	250	255	230	878	589	587	536
6301	345	355	305	250	2,830	2,858	2,175	1,475	11,018	11,998	8,449	5,522
6326	1000	1000	1000	1000	4,800	5,250	5,175	4,500	13,614	15,702	17,324	13,048
6367	195	135	115	138	1,391	647	524	639	6,054	2,113	1,849	2,217
6501	2000	2050	1900	1300	17,900	19,750	17,210	7,050	100,713	99,141	80,899	25,631
6502	2100	2250	2100	2000	20,150	23,910	22,450	9,320	137,748	153,946	151,033	34,937
6503	1100	1050	1150	1050	7,250	6,815	7,100	5,150	22,837	19,972	24,031	15,947
6594	180	120	140	140	966	625	584	590	3,332	2,010	1,887	1,936
6702	1950	1900	1600	1100	16,640	16,575	11,295	5,250	74,137	67,669	47,913	17,743
6752	460	415	450	390	4,040	4,265	4,645	3,250	20,636	24,781	23,413	14,572
6758	375	370	305	310	3,127	3,037	3,207	2,320	14,136	14,739	14,317	10,160
6861	100	100	100	100	376	215	206	200	976	557	440	462
6902	215	175	195	160	2,201	825	810	733	11,188	2,503	2,566	2,416
6954	130	100	105	100	785	540	550	585	2,151	1,479	1,520	1,714
6971	230	195	185	150	2,164	832	625	625	9,081	2,601	2,057	2,168
6981	190	103	100	105	1,045	553	440	482	4,408	1,825	1,332	1,645
6988	200	185	180	115	1,560	785	760	565	6,464	2,584	2,495	2,146
7011	2000	1950	1600	1650	15,855	18,750	14,620	8,205	77,989	81,052	74,056	30,232
7201	530	560	580	405	7,019	7,084	6,283	2,975	43,195	38,489	35,121	13,619
7202	2000	2000	1950	1050	13,195	15,435	13,330	5,500	62,283	62,426	59,924	17,531

| | 50th percentile | | | | 90th percentile | | | | 99th percentile | | | |
| Code | Phase 1 | | Phase 2 | | Phase 1 | | Phase 2 | | Phase 1 | | Phase 2 | |
	Before	After	Before	After	Before	After	Before	After	Before	Afterr	Before	After
7203	200	200	205	205	2,226	1,447	1,685	1,665	24,054	6,481	6,783	6,675
7267	250	210	265	210	2,808	1,645	1,815	1,420	13,222	5,716	7,096	5,968
7269	250	210	215	175	1,370	1,185	1,130	715	4,775	3,576	3,548	2,703
7270	380	300	260	200	2,520	1,981	1,530	1,125	10,286	6,544	5,138	4,428
7731	300	325	300	275	1,912	2,061	2,402	1,790	7,725	8,093	11,458	7,498
7741	220	200	200	168	1,187	969	875	650	4,246	3,195	2,658	2,261
7751	295	250	280	220	2,797	1,860	2,085	1,255	19,196	6,491	8,247	4,857
7752	875	465	360	335	5,631	3,490	2,928	2,669	18,189	13,518	14,253	9,162
7912	1000	1000	1050	1000	4,545	4,400	4,920	3,550	11,976	12,928	14,077	8,261
7974	115	100	100	110	655	605	510	610	2,043	1,902	1,409	2,023
8001	430	415	395	280	3,919	3,680	3,975	2,843	16,128	14,648	19,970	11,347
8002	1950	1650	1600	690	11,380	12,025	12,960	4,250	67,213	56,786	63,889	16,815
8031	445	405	365	350	4,169	4,052	3,616	2,770	22,160	19,456	19,973	12,930
8035	255	170	125	135	1,806	695	575	585	7,850	2,061	1,765	1,813
8053	430	380	335	320	4,111	3,634	3,351	2,683	20,870	15,793	15,094	10,706
8058	385	370	325	280	3,298	3,131	2,876	1,949	14,385	13,472	13,242	8,127
8113	170	120	115	100	1,208	675	520	541	5,899	2,296	1,794	1,640
8267	265	215	220	225	2,533	2,544	2,536	2,153	10,891	11,126	15,577	10,770
8306	985	850	770	685	14,732	15,868	13,824	6,000	157,514	169,208	206,085	31,377
8308	780	1008	720	455	12,353	16,209	9,416	3,071	86,202	106,226	67,302	13,157
8309	2850	2500	2500	2000	23,335	22,905	27,210	9,560	101,265	96,501	125,205	31,685
8316	275	230	265	205	3,566	1,530	1,645	1,213	26,496	5,972	6,288	4,948
8332	1900	1725	1900	1000	11,795	10,450	11,195	4,480	44,464	37,205	40,800	12,252
8411	1310	1130	845	1515	17,351	20,368	12,784	30,271	301,329	485,164	234,623	244,668
8591	375	355	265	275	2,610	2,748	2,316	1,765	9,730	10,433	10,467	6,559
8601	1950	1950	1950	1050	11,050	11,100	11,965	5,475	41,244	40,094	44,073	18,243
8604	985	990	850	530	11,387	13,191	11,696	4,723	82,459	89,420	95,424	22,589
8630	205	210	195	200	895	990	950	675	2,723	2,952	2,885	1,975
8725	215	210	235	200	980	1,015	1,233	831	3,401	3,254	3,852	2,476
8750	260	310	380	375	1,886	2,150	3,454	2,805	7,626	7,816	15,446	12,010
8766	290	235	245	210	2,506	1,416	1,140	950	11,004	4,453	3,795	3,302
8795	250	275	320	295	1,870	2,179	2,281	1,720	6,202	6,974	8,635	5,567
8801	1000	1000	1000	1000	5,100	3,000	3,905	3,000	16,092	7,821	12,583	8,707
8802	1000	1000	1000	1000	5,450	4,250	3,600	3,550	17,024	11,550	9,908	9,019
8830	1000	1000	1000	1000	4,200	2,450	2,050	2,050	11,233	6,205	5,680	5,251
9020	163	105	100	103	1,228	592	480	495	4,887	1,915	1,561	1,605
9021	208	190	175	100	1,509	730	681	516	5,450	2,392	2,080	1,583
9022	110	105	100	100	655	564	440	436	2,031	1,561	1,167	1,218
9064	265	295	270	245	1,494	1,645	1,330	1,040	4,956	6,449	4,520	2,891
9202	1900	1950	1675	2050	14,450	23,315	14,030	12,490	225,402	310,305	196,334	50,287
9432	220	190	145	170	2,173	880	600	720	12,830	2,870	2,187	2,713
9433	235	165	160	155	2,308	825	695	700	9,944	2,735	2,325	2,555
9437	360	370	300	305	3,275	3,094	2,833	2,075	16,894	13,121	13,416	8,588
9502	290	310	305	295	2,004	2,080	2,004	1,539	7,144	7,437	6,929	4,829
9503	315	325	385	225	2,305	2,531	2,960	1,015	8,936	9,975	11,602	3,653
9531	1950	2050	1850	1150	14,535	18,465	14,455	5,510	72,295	82,378	62,776	16,821
9532	1900	2325	2100	1600	14,765	18,650	13,620	5,910	64,870	75,807	57,480	15,251
9735	190	110	100	105	1,498	540	454	460	5,168	1,672	1,373	1,411
9983	100	100	100	100	664	335	315	325	2,111	1,001	949	936
9984	210	180	200	200	2,516	1,047	1,015	995	16,223	4,821	4,251	4,452

* The figures are the average of each statistic calculated daily for each period. Units are shares.

Table19 Virtual effective half spread by order size

Code	$e\bar{s}_{50}$(50th percentile size)				$e\bar{s}_{90}$(90th percentile size)				$e\bar{s}_{99}$(99th percentile size)			
	Phase 1		Phase 2		Phase 1		Phase 2		Phase 1		Phase 2	
	Before	After	Before	After	Before	After	Before	After	Before	Afterr	Before	After
1605	4.37	4.67	3.68	2.81	4.75	5.32	3.97	3.35	6.79	8.58	5.60	5.46
1878	6.85	3.68	3.90	3.87	7.40	5.24	4.46	4.38	9.66	9.75	6.49	6.13
1925	4.88	5.65	4.78	3.58	5.47	6.55	5.20	4.74	7.35	8.81	6.74	7.48
1928	4.20	4.09	3.91	2.59	4.57	4.61	4.20	3.13	6.24	6.68	6.03	5.46
1963	9.16	6.00	5.20	5.20	9.66	7.56	5.96	6.05	11.49	11.36	7.97	8.25
2502	2.85	3.10	2.17	1.97	3.63	4.00	2.67	2.69	5.62	6.26	4.42	4.58
2503	4.70	5.07	3.81	2.77	5.26	5.76	4.12	3.38	7.03	7.75	5.74	5.58
2802	5.89	6.13	5.32	4.02	6.51	6.91	5.81	4.73	8.80	9.49	7.73	7.05
2914	7.35	2.01	1.79	1.55	7.41	2.97	2.12	2.15	8.34	7.36	3.61	3.81
3382	6.45	2.43	1.95	1.71	6.79	3.76	2.37	2.32	8.78	8.45	4.01	3.94
3402	7.21	7.49	7.44	2.72	7.55	7.84	7.72	4.25	9.32	10.01	9.83	11.05
3407	6.92	7.39	6.94	2.64	7.32	8.02	7.46	3.85	9.21	10.65	9.65	7.88
4063	8.45	2.88	2.17	2.17	8.63	4.97	2.65	2.62	10.32	11.35	4.33	4.09
4188	10.69	11.06	11.31	2.39	10.93	11.25	11.39	3.58	12.59	13.19	12.37	9.00
4452	7.97	3.06	2.22	1.77	8.43	4.82	2.67	2.30	10.51	10.05	4.27	3.71
4502	8.25	1.79	1.59	1.36	8.29	2.98	1.98	1.95	8.90	7.88	3.37	3.43
4503	8.29	3.00	4.02	2.66	8.52	5.58	4.28	3.33	10.13	14.04	5.76	5.36
4523	6.51	2.65	2.38	2.26	6.95	4.11	2.94	2.97	8.75	8.49	4.47	4.58
4568	3.31	3.51	3.24	2.61	3.87	4.07	3.55	3.36	6.26	6.35	4.97	5.50
4578	4.42	3.18	2.60	2.19	5.13	4.79	3.11	3.05	8.32	10.75	4.84	5.54
4661	4.59	3.51	2.84	2.98	5.19	4.40	3.33	3.52	7.08	6.76	4.98	5.24
4901	3.05	2.41	2.42	2.00	3.56	3.02	2.78	2.74	5.46	5.16	4.50	4.83
4911	4.15	4.32	3.21	2.58	4.92	5.23	3.58	3.46	7.62	7.72	5.63	6.31
5020	9.50	9.80	9.29	1.94	9.63	9.86	9.35	3.02	10.75	10.57	10.38	7.52
5108	6.54	2.33	1.78	1.60	6.73	3.67	2.12	2.21	8.20	8.03	3.63	4.00
5201	8.21	8.49	8.49	3.42	8.65	8.78	8.72	4.75	10.94	10.90	10.96	11.58
5401	14.74	15.66	15.73	2.56	14.75	15.67	15.73	3.54	15.18	16.26	15.91	9.88
5411	2.63	2.90	2.89	2.32	3.22	3.56	3.26	3.14	5.59	6.02	5.04	5.67
5713	5.30	5.65	4.83	3.74	5.88	6.44	5.36	4.46	8.32	9.30	8.47	7.59
5802	3.67	3.76	3.75	2.66	4.23	4.46	4.09	3.31	6.51	7.04	5.81	5.41
6273	5.59	5.67	5.31	4.25	6.38	6.54	5.78	4.81	8.57	9.26	7.07	6.19
6301	2.61	2.71	2.50	1.81	2.89	3.12	2.88	2.52	4.18	4.90	4.63	4.54
6326	4.90	4.66	4.56	3.27	5.69	5.37	4.86	3.81	8.15	7.68	6.80	5.88
6367	8.00	2.97	2.29	2.08	8.31	4.95	2.86	2.50	10.54	11.21	4.84	3.95
6501	6.43	6.20	6.65	1.75	6.56	6.36	6.68	2.85	7.72	8.54	7.46	6.53
6502	11.51	10.90	10.55	2.36	11.57	10.94	10.56	3.57	12.58	12.04	11.12	8.70
6503	5.29	5.11	4.26	3.36	5.88	5.77	4.54	4.19	8.39	8.77	6.19	6.61
6594	5.87	4.04	2.05	2.04	6.47	5.76	2.57	2.51	8.86	10.35	4.24	4.01
6702	9.89	9.40	6.74	2.33	10.18	9.84	7.01	3.40	12.63	13.23	9.20	7.36
6752	4.31	4.18	4.19	2.61	4.67	4.57	4.43	3.27	6.59	6.80	6.28	5.86
6758	2.82	3.03	3.09	1.95	2.97	3.22	3.31	2.59	4.31	5.09	4.66	4.71
6861	7.93	5.69	5.46	4.74	8.64	6.94	5.78	5.07	11.03	10.48	6.70	5.97
6902	9.42	2.40	1.89	1.65	9.52	4.76	2.30	2.11	10.71	12.89	3.74	3.47
6954	3.40	2.65	2.38	2.35	3.94	3.76	2.90	2.85	5.74	6.02	4.36	4.02
6971	9.74	3.05	2.33	1.91	10.00	5.24	2.81	2.31	11.93	11.64	4.54	3.66
6981	5.98	3.23	2.10	2.39	6.41	4.82	2.58	2.82	8.93	10.78	3.98	4.03
6988	6.77	2.76	2.09	1.93	7.42	4.58	2.65	2.55	9.74	10.16	4.47	4.43
7011	7.88	7.49	7.76	2.12	8.13	7.87	7.87	3.13	10.07	10.61	9.21	7.02
7201	5.63	5.52	5.15	1.86	5.76	5.75	5.24	2.57	6.80	7.98	6.36	5.30
7202	8.12	8.17	7.42	2.71	8.47	8.54	7.66	4.33	11.27	11.45	10.20	11.58

| | $e\tilde{s}_{50}$(50th percentile size) | | | | $e\tilde{s}_{90}$(90th percentile size) | | | | $e\tilde{s}_{99}$(99th percentile size) | | | |
| Code | Phase 1 | | Phase 2 | | Phase 1 | | Phase 2 | | Phase 1 | | Phase 2 | |
	Before	After	Before	After	Before	After	Before	After	Before	Afterr	Before	After
7203	8.02	1.20	1.04	1.11	8.02	1.87	1.30	1.41	8.07	6.48	2.23	2.36
7267	5.93	1.74	1.73	1.40	5.99	2.64	2.04	1.85	6.86	5.65	3.36	3.16
7269	3.21	3.35	2.58	2.30	4.04	4.42	3.14	3.26	6.68	7.59	4.89	5.42
7270	3.44	2.56	2.45	1.92	3.82	3.42	2.89	2.70	5.36	6.56	4.49	4.60
7731	3.20	3.23	3.42	2.43	3.79	3.77	3.66	3.02	6.42	6.39	5.37	5.69
7741	3.59	3.47	2.81	2.25	4.30	4.55	3.38	2.97	6.78	7.91	5.12	4.91
7751	7.59	1.92	1.71	1.26	7.60	2.54	1.92	1.79	8.03	6.27	2.99	3.42
7752	5.47	4.98	4.42	3.09	6.06	6.21	4.67	3.54	8.38	9.99	6.34	6.02
7912	6.99	7.69	6.46	5.08	7.76	8.66	6.99	6.05	9.88	10.95	8.79	8.93
7974	4.68	3.59	3.38	3.45	5.48	4.80	4.04	3.95	8.30	7.89	5.91	5.51
8001	4.12	4.13	3.92	2.56	4.41	4.61	4.05	3.13	6.11	7.06	5.36	5.65
8002	6.93	6.92	6.80	2.05	7.03	7.17	6.86	3.48	8.33	10.18	7.78	8.26
8031	3.64	3.68	3.14	2.03	3.84	4.04	3.26	2.59	5.38	6.35	4.57	4.94
8035	9.16	3.37	2.38	2.51	9.50	5.90	2.86	2.94	12.25	16.00	4.55	4.37
8053	4.07	4.08	3.81	2.50	4.29	4.50	3.97	2.99	5.79	7.22	5.31	4.95
8058	2.66	2.78	2.50	1.83	2.85	3.09	2.67	2.52	4.04	4.95	4.07	4.80
8113	8.31	2.88	2.41	2.38	8.52	4.45	2.95	2.88	10.81	11.06	4.98	4.80
8267	3.99	4.05	4.23	2.58	4.40	4.44	4.35	2.90	6.28	6.11	5.53	4.70
8306	7.59	7.81	8.10	1.31	7.61	7.83	8.10	2.05	7.92	8.40	8.37	6.85
8308	9.62	8.99	8.46	2.27	9.64	9.06	8.52	3.67	10.42	10.38	9.62	9.91
8309	9.51	9.95	10.85	2.81	9.79	10.30	10.98	4.53	11.75	12.75	12.23	9.74
8316	9.44	1.54	1.57	1.32	9.45	2.83	1.96	1.87	9.80	9.24	3.22	3.38
8332	9.62	10.36	9.15	3.59	10.13	11.30	9.80	5.43	12.32	15.15	12.16	11.04
8411	22.98	22.39	24.42	2.59	22.98	22.39	24.42	2.65	22.98	22.39	24.42	3.37
8591	3.17	3.39	3.23	2.23	3.67	3.91	3.49	2.83	5.63	6.01	5.27	5.17
8601	5.14	5.33	5.97	2.52	5.49	5.79	6.31	3.83	7.69	8.60	8.22	7.24
8604	6.36	6.70	7.10	1.67	6.42	6.74	7.11	2.89	7.18	7.76	7.56	7.95
8630	3.88	3.67	3.10	2.91	4.86	4.41	3.71	3.81	7.20	6.46	5.50	5.93
8725	3.66	3.58	3.21	2.71	4.53	4.34	3.74	3.73	7.07	6.73	5.38	6.43
8750	3.61	3.63	3.66	2.38	4.11	4.20	4.03	2.87	6.97	6.89	6.23	4.87
8766	7.62	2.78	2.29	2.11	8.03	4.06	2.64	2.70	10.12	8.14	4.03	4.46
8795	4.50	4.67	4.44	3.36	5.27	5.52	4.99	4.18	8.08	8.11	7.09	6.78
8801	7.41	3.99	2.53	2.35	7.97	5.56	2.94	2.93	10.09	9.98	4.69	4.87
8802	5.53	3.64	3.28	2.64	6.35	4.81	3.63	3.13	8.58	8.37	5.05	4.51
8830	7.99	4.92	4.38	3.47	8.68	6.58	4.70	3.76	11.04	10.54	6.27	4.98
9020	6.26	2.52	1.75	1.91	6.50	4.02	2.15	2.35	7.85	8.77	3.54	3.68
9021	6.04	2.73	2.11	1.94	6.47	4.50	2.65	2.51	8.37	9.32	4.35	4.20
9022	5.74	3.93	2.98	3.04	6.29	4.91	3.45	3.45	8.33	7.86	4.93	4.67
9064	3.65	3.67	3.50	2.74	4.48	4.43	4.01	3.52	6.84	6.44	5.76	5.73
9202	23.67	22.63	20.65	2.81	23.67	22.63	20.65	3.41	23.71	22.93	20.70	9.71
9432	9.17	2.39	1.86	1.64	9.20	4.31	2.23	1.90	10.18	14.19	3.81	3.09
9433	7.95	2.47	1.81	1.73	8.17	5.21	2.22	2.05	9.90	14.26	3.56	3.21
9437	3.06	3.15	2.99	1.99	3.24	3.42	3.16	2.48	4.81	6.07	4.54	4.54
9502	4.68	5.28	4.89	3.62	5.36	6.41	5.52	4.38	7.96	9.54	7.53	6.46
9503	4.95	5.24	5.60	2.92	5.44	5.99	6.13	4.66	8.26	9.43	8.61	10.53
9531	9.99	9.97	8.74	2.88	10.19	10.17	9.12	4.39	11.30	12.09	10.91	9.31
9532	12.30	12.12	11.94	3.08	12.52	12.40	12.26	4.61	13.67	14.45	13.78	9.37
9735	8.49	3.74	2.54	2.54	8.95	6.60	3.15	3.10	11.08	12.96	4.86	4.64
9983	6.64	2.85	2.94	2.57	7.22	4.57	3.45	3.11	9.47	8.45	5.20	4.64
9984	5.61	1.38	1.07	1.10	5.64	2.74	1.42	1.42	6.25	7.86	2.50	2.47

* The figures are the average of the virtual effective half spread, which is the effective half spread caused by execution of market order using each statistic in the period preceding Phase 1 and Phase 2 on Table 18 as the order size, for each period. Units are bps.