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An international trend in market design: Endogenous effects of limit order book transparency on volatility, spreads, depth and volume

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An international trend in market design: Endogenous effects of limit order book transparency on volatility, spreads, depth and volume[1]

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Abstract

Following other leading international securities markets, the Tokyo stock exchange [TSE] has adopted a publicly displayed but anonymous limit order book, and we ask: how is market quality affected? Accounting for fixed effects and endogeneity, we find increased volatility and higher order book depth at the best bid and ask prices, while total depth is not significantly impacted. This predicts more competitive order strategies in a trading system with anonymous orders but with more visible price levels. Spreads are found to be unaffected by the market design change, in contradiction to previous literature. Complementing the literature, we find volume increases, indicating that the aggregate effect of the design change is positive.

JEL Classification: G10, G15, G18

Keywords: Market Quality, Limit Order Book; Transparency

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1. Introduction

A recent trend in international securities markets has been to cease disclosing pre-trade broker identification and at the same time increase the visibility of the now anonymous order book.[4] This paper investigates the impact of this common change in pre-trade transparency on market quality. This is an important question as the change in pre-trade transparency may affect market quality in several ways. Anonymous trader identities may potentially have negative effects as the search for counterparties becomes more costly. The ability for brokers perceived as informed to remain anonymous may again have positive effects. A greater transparency of the depth of the order book is expected to have positive effect, as trades can be executed with greater accuracy when the exact volume on several price levels is known. In this paper we measure market quality as volatility, bid-ask spreads, limit order book depth and volume as we investigate the Tokyo Stock Exchange (TSE), the second largest stock market in the world by market capitalization and fourth by traded value up to 2009[5]. The TSE ceased to display broker identity to exchange members in June 2003, and simultaneously increased the level of limit order book information by providing the three best bid- and ask-price levels and volumes to the public. This provides us with an excellent opportunity to study the impact on market quality of a common change in market design, and to do so using data

[4] Rindi (2008) points out that almost all the asset markets organized as electronic platforms are anonymous: NYSE's Open Book service shows the aggregate limit-order volume available in the NYSE Display Book system at each price point, but provides no identity of the participants behind these orders. The single platform for NASDAQ-listed securities (NASDAQ's Integrated Single Book), into which the NASDAQ Market Center, Inet and Brut recently merged, is anonymous; all European trading platforms are anonymous, as well as all electronic communication networks and foreign exchange electronic markets (e.g., Electronic Broking System). The Nordic markets have a more complex history. On June 2nd, 2008, NASDAQ OMX Nordic introduced post-trade anonymity on the Helsinki market and the five most heavily traded shares in Stockholm, but in April 2009 the decision regarding Stockholm was reversed and ex-post transparency restored to all but the five largest Helsinki stocks that remain anonymous in real time. Broker identities are revealed at the close of trading. Anonymity was instituted in the Italian secondary market for treasury bonds (MTS) in 1997, in Euronext Paris in 2001, in Tokyo in 2003, in the Italian Stock Exchange (Borsa Italiana) in 2004 and in the Australian Stock Exchange (ASX) in 2005. The Sao Paulo Stock Exchange in Brazil, which provides pre-trade transparency, and the KRX in South Korea, which provides post-trade transparency, are the only markets bucking this trend.

[5] Surpassed in market capitalisation by London SE Group in 2009 and Nasdaq OMX in 2010, (NYSE Euronext remaining largest) and surpassed by Shanghai SE in traded value in 2007 (source World Federation of Stock Exchanges).

from a highly significant stock market that also represents a pure limit order book market rather than a hybrid of dealer- and order-driven markets. The studied change in market design is common for limit order book markets, while hybrid markets tend to provide some transparency of dealer identity. Although we recognize that the market design change investigated in this paper is complex, it is the design of choice for most limit order markets, and hence it is important to provide a more complete picture of the impact of such a common design change. In one previous study, where the 2003 market design change at TSE is included, Comerton-Forde, Frino and Mollica (2005) focus on the impact on spreads, which does not provide a complete picture of the impact of the market design change studied here. In addition, we contribute to the literature by addressing the endogeneity problem of previous empirical research that typically examines one statistic for market quality and uses several others as exogenous controls[6].

We use several alternative metrics for market quality, and methodology that accounts for fixed effects and endogeneity in the included statistics for market quality. We find that volatility increases after the TSE market design change. The depth of the limit order book increases at the best bid and ask prices while total depth is not significantly impacted. Accounting for the interaction between spreads, volatility and volume, we find that spreads are not affected by the design change. Previous literature does not consider the volume effects of transparency. In our paper, we find that volume increases as a result of the TSE design change, which is consistent with the higher volatility.

2. Hypotheses based on the literature

2.1 Price volatility

[6] Some empirical work investigating the impact of transparency/opacity alteration begins by pointing out that the change alters trade volume and a variety of measures of volatility, effective and realized spread, depending on which variable the authors treat as the dependent variable. However, typically they treat the remaining market quality metrics as exogenous control variables with no attempt to construct instrumental variables or the use of Two Stage Least Squares. There is one notable exception in Eom, Ok and Park (2007), which examines the impact of expansions of the best bid and ask levels revealed to the public.

Madhavan (1996) concludes that “In a sufficiently large market transparency reduces volatility and improves market quality”. However, if the market is relatively thin, Madhavan (1996) demonstrates that “market transparency can actually increase price volatility and lower market liquidity. This occurs even though transparency increases the precision of traders’ predictions about the asset’s value”. Since volatility is essentially unobservable, several metrics for volatility have been developed, and hence it is important to measure the correct form of volatility. We expect measures less affected by market microstructure noise, such as range based volatility (see Alizadeh, Brandt and Diebold (2002)), not to be impacted by changes in pre-trade transparency. We expect measures that include transitory volatility, such as realized volatility (see Andersen and Bollerslev (1997)), to be significantly affected by changes in pre-trade transparency. The Fishman and Hagerty (1995) microstructure model can be applied in this context to show that broker identification anonymity results in increased intraday volatility and decreased trade volume. Informed traders do not have to disclose their intentions pre-trade, hence price discovery is delayed, causing higher volatility when information finally is impounded as the informed traders transact. The greater risk of trading with an informed trader makes uninformed traders cautious, resulting in lower trading volume.

Hypothesis 1: In larger market capitalization segments with more participants, where there is a higher level of competition, increased transparency is expected to reduce volatility and lower transaction costs. In smaller market capitalization segments, increased transparency is expected to raise volatility and transaction costs. The change in market design investigated in this paper is expected to increase volatility due to the removal of counterparty identity while the increased level of depth information may neutralize or even dominate the effect on volatility, particularly in smaller market capitalization segments.

To address this hypothesis, we study and assess the statistical significance of changes in range-based volatility, realized volatility and standard deviation of mid-quote returns for market capitalization segments around the TSE change in market design.

2.2 Quoted spreads

Foucault, *et al.* (2007) propose a theoretical model where informed bidders exploit less informed market participants by bidding as if the cost of liquidity provision was large, when in fact it is small. This strategy is less effective when traders cannot distinguish between informative and uninformative limit orders. Hence, informed bidders act more competitively in an anonymous market where average quoted spreads decline significantly. Simaan, Weaver and Whitcomb (2003) also expect that allowing anonymous quotes could improve price competition and narrow spreads due to higher competition between market makers.

Hypothesis 2: We expect to observe no significant change in quoted spreads in a market moves to anonymous broker IDs and simultaneously starts displaying more information about the depth of the limit order book. The lower spreads as result of more competition between liquidity providers in an anonymous market may be neutralized by the simultaneous introduction of more depth transparency in our investigated market. To address this hypothesis, we study changes in closing, equally-weighted and time-weighted quoted spreads around the TSE event.

2.3 Effective spreads

While quoted spreads measure aggressiveness in the order placement strategy of traders, effective spreads measure actual paid transaction costs on executed trades. According to Madhavan (1996), in sufficiently large market capitalization segments, market transparency may reduce transaction costs. But from a perspective of a strategic trader, effective spread is strictly higher in a transparent market. Following Foucault, *et al.* (2007) anonymous quotes is expected to improve price competition between liquidity providers and narrow effective spreads.

*Hypothesis 3***:** We expect to observe no significant change in effective spreads in a market that moved to anonymous broker IDs and simultaneously started displaying more information about the depth of the limit order book. The narrowing of effective spreads due to the switch to anonymous quotes may be neutralized by the simultaneous introduction of more depth transparency in our investigated market. The effects is expected to wary across segments of different liquidity following Madhavan (1996). To address this hypothesis we study and assess the statistical significance of changes in market-wide trade value-weighted effective spreads around the TSE event for the full sample and for market capitalization segmented sub-samples.

2.4 Order book depth

Foucault, *et al.* (2007) propose that informed bidders act more competitively in an anonymous market, which is expected to decrease the quoted depth. They find support for this proposal in their study of the effects of anonymization of broker ID on Euronext France.

Hypothesis 4: We expect to observe decreased total LOB depth in a market with anonymous broker IDs, while the depth at the best bid and ask level is expected to increase due to more competitive informed bidders. To address this hypothesis, we study the depth in the limit order book at the available limit order book levels in the TSE.[7] We analyze the average value at the best bid (ask) and at the three best levels in the order book, as well as best bid (ask) depth to total bid (ask) depth, before and after the TSE change in market design.

2.5 Volume

Rindi (2008) does not directly address the effects of transparency on volume, but her model predicts that pre-trade transparency will raise volatility and spreads. It is possible that the increased volatility leads to more trading even if trading is more expensive due to higher spreads. This counterintuitive result, observable in Comerton-Forde, *et al.* (2005), who report volume effects for

[7] Tokyo stock exchange displayed three levels of the order book to the public prior to June 2003, then they started displaying the five best levels after June 2003.

Euronext, Tokyo and Korea, is plausible if the narrower spreads are a result of more aggressive orders in a transparent market. Empirical support is found in Duong, Kalev and Krishnamurti (2009), who find that in Australia, traders posted more aggressive orders during a previous regime with visible broker IDs, as opposed to the current opaque policy. Studies comparing turnover rates and volatility of international markets also show that the world's largest markets with the highest turnover rates are also the most volatile markets.

Applying Kyle (1985), and more explicitly Rindi (2008), changes in transparency should impact the interaction of informed traders with liquidity or noise traders. In a transparent regime informed trading is less profitable, leading to a decrease in the number of traders that become informed. Traders that are informed will trade more aggressively, timing their trades to periods when there are more liquidity traders present. In sufficiently large market segments where the number of liquidity traders is inherently greater, more aggressive informed traders may lead to higher traded volume and more rapid dissemination of this information. In smaller market segments with fewer liquidity traders and a diminishing number of agents that have the incentive to become informed, traded volumes may be less affected or fall.

Hypothesis 5: We expect to observe lower traded volume in a market with anonymous broker IDs. This effect is expected to be strongest for large stocks and may weaken or reverse for smaller capitalization market segments. The simultaneous introduction of more depth transparency in our investigated market may neutralize the effects of anonymous broker IDs and in fact increase traded volume due to faster and greater order execution accuracy in a visible LOB. We investigate the volume effects around the TSE market design change.

3. Institutional details

The Tokyo Stock Exchange uses an electronic, continuous auction order-driven trading system. This means that brokers place orders in an online system and when a buy and sell price match, the trade is automatically executed. Transactions are hence made directly between buyer and seller, rather than through a market maker. The TSE uses price controls so that the price of a stock cannot rise or fall below a certain point throughout the day. These controls are used to prevent dramatic swings in prices. If a major change in price occurs, the exchange can halt trading in that stock for a specified period of time. Orders are hence subjected to a daily price variation range. (Comerton-Forde and Rydge (2003)).

The TSE offers two trading sessions each weekday, from 09:00 to 11:00 and from 12:30 to 15:00: the morning and afternoon sessions, respectively. The first transactions of each session, which start at 8:00 and 12:05, are executed during the 'opening auction' at the start of each session, and the last transactions are executed during the 'closing auction' at the end of each session. Thus there are two opening and two closing auctions each day. The opening and closing prices are determined by call auctions, called '*Itayose*'. Once the opening prices have been determined, a continuous auction commences, called '*Zaraba*'. During this continuous trading session, each order is matched individually to other orders during the rest of the trading session.

On June 30, 2003, the TSE discontinued displaying the identity of brokers for limit orders to their exchange members. On the same date the five best bid- and ask-price levels and volumes were made available to the public.

4. Data and methodology

4.1 Data

The initial dataset includes all constituents of Nikkei 225[8] during the period from March 1, 2003 to September 30, 2003. We eliminate stocks that have non-trading periods per day during the sample period. Of the 175 stocks that met our criteria, we have access to the limit order book (LOB) data of 99 stocks; this is necessary for our analysis of book depth. As a result, our final dataset includes intraday trade and quote data for the 99 stocks, with associated prices, volumes, and bid and ask sizes. The history of the LOB available for 99 stocks contains the best available price levels,

[8] We choose Nikkei 255 which is a widely followed index designed to reflect the complete Japanese Market.

including the total number of shares demanded and offered at each level. Specifically, we obtain the displayed three best bid/ask prices and volumes in the LOB before June 30, 2003 and the five best bid/ask prices after this date. The intraday data are provided by Thomson Reuters Tick History (TRTH) through the Securities Industry Research Centre of Asia-Pacific (SIRCA). The market capitalization data are obtained from the Thomson Reuters DataStream. The data from Thomson Reuters is verified using a database maintained by Nikkei, Tokyo, Japan.

4.2 Methodology

We examine the changes in market quality variables around the event date, dividing the sample into a pre- and post-period around the event date. Consistent with Madhavan, Porter and Weaver (2005), we eliminate the month of the event to avoid possible biases from proximity to the event. The pre-period is March 1, 2003 to May 31, 2003 and the post period is July 1, 2003 to September 30, 2003. Aiming to determine the different impacts on various market segments, we split the sample into five groups by market capitalization on January 2, 2003 – the first trading day of the same year.

We examine the changes in three measures of volatility – realized volatility, daily range-based volatility and standard deviation of fifteen-minute mid-quote prices – and a range of spread measures. Realized volatility is calculated by using the mid-quote every five minutes during the trading day to avoid bid-ask bounce, then squaring each of these returns, and summing them up for the trading day[9]. In Section 3.1 we discussed the expected differences in impacts of transparency on these statistics. Consistent with Madhavan, *et al.* (2005), transaction cost is measured both as traded value-weighted effective percentage spread, and spread in yen. The yen effective spread is the absolute value of the difference between the trade price and the mid-point price in the LOB when the trade is executed. The effective percentage spread is the effective spread in yen scaled by the prevailing mid-point price in the LOB when the trade is executed. Consistent with Madhavan, *et*

[9] All of the variables are stationary: see details in Appendix.

al. (2005), we use the average time-weighted quoted spread in percentage and market depth to capture market liquidity. For robustness, we examine the percentage closing spread and equally-weighted quoted spread to determine the impact of the events on the cost of demanding immediate execution (Demsetz (1968)). We calculate relative closing spread as the closing spread in dollar terms divided by the midpoint price where close values are recorded at the end of the trading day. We use eight depth measures, including the volume at the best bid and ask; the total volume at the three best levels; and the fraction on best ask and bid versus all visible orders to buy and sell, both by size and traded value. All of these proxies are calculated in intraday data and averaged across daily to produce one observation per stock per day.

Wilcoxon signed-rank tests are used in our univariate tests to examine the differences in medians for each proxy.

In all multivariate analyses, we use log transformations of volatility, bid-ask spreads, depths and volume metrics to derive a log-linear relationship with other variables in the regressions. We implement the same regressions of each measure on the full sample and the five individual quintiles. Following Foucault and Menkveld (2008), total depth is measured by consolidated depth at a certain price (i.e., the sum of all shares available at that price or better). A time trend variable is included in all our regressions in order to capture daily changes in the dependent variable holding all other explanatory variables constant, and to prevent the possibility that our findings on design changes are simply due to trends. The time trend variable begins with a value of 1 and increases by 1 unit for each investigated day. In our unbalanced panel data, we expect the estimated time effect would represent the time effects for all the proxies of market quality.

5. Results

5.1 Changes in price volatility

5.1.1 Univariate tests

We provide three statistics for volatility, including logarithm of high-low price, realized volatility and standard deviation in the midpoint price measured every 15 minutes. Following Hendershott and Jones (2005), we use the daily difference between the logarithm of highest and lowest transaction price as the first volatility metric, denoted $\ln\_hi\_lo$.

<INSERT Table 1 here>

Table 1 presents the difference in volatility metrics between pre- and post-periods and reveals a quite small but highly significant increase in all three volatility proxies for the full sample. Examining the adjustments for historical volatility and standard deviation in each size quintile also reveals results consistent with that hypothesis. The change in the high-low volatility is significant only for the smallest quintile. Realized volatility increased significantly in all of the market capitalization segments. Based on these results, we conclude that the market design change of the TSE in 2003 does affect price volatility in the univariate setting.

5.1.2 Multivariate regressions

We estimate a regression in which volatility depends on control variables, including the number of trades and the TSE total depth, in order to capture the effect of extension of the public LOB on volatility. Madhavan, *et al.* (2005) document evidence of the impact of the opening of LOB on volatility in the Toronto Stock Exchange. Following Foucault, *et al.* (2007), we apply a stock fixed effect approach to control for some of the heterogeneity across stocks. We extend the model of Madhavan, *et al.* (2005) to control for the relationship between price volatility and trading frequency:

$$Vola_{it} = \alpha_{it} + \beta_1 Num\_Trade_{it} + \beta_2 Trend_{it} + \gamma TotalDepthVal_{it} + \beta Dummy_{it} + \varepsilon_{it}, \quad (1)$$

where for each stock i at day t, $Vola_{it}$ represents three measurements of volatility, including range-based volatility, realized volatility and standard deviation of fifteen-minute mid-quote prices; $Dummy_{it}$ is the dummy variable for broker ID opacity taking the value 0 prior to the TSE design change and 1 after the event; $Trend_{it}$ is the time variable; Num_trade_{it} is daily number of trades; $TotalDepthVal_{it}$ is the daily average of total depth in yen; and α_{it} represents $n-1$ stock fixed dummies in which n is the number of the sample stocks.

5.1.2.1 Fixed effect OLS results

First, we use Ordinary Least Squares with fixed effect to estimate coefficients in the model. The first three columns of Table 2 report the coefficients for β1 as 0.0122, 0.0444 and 0.597, all statistically significant, which reinforces the positive relationship between trade frequency and the three metrics of volatility, as shown in the literature. The coefficient of the number of trades variable is highly significant, implying that an increase in the number of trades is associated with an increase in intra-day volatility. The negatively significant coefficients of the time trend variable in range-based range volatility and standard deviation of mid-quote prices in the regressions suggest that volatility trends down over time.

<INSERT Table 2 here>

The positively significant coefficient of the broker dummy variable suggests broker ID anonymity may lead to an increase in the volatility of stock prices. To separate the mutual effects of simultaneous events, a market depth variable (measured in yen) is included in the regression, and this result is presented in Table 2. Negative coefficients of the log of total depth in yen for the range-based range and standard deviation of mid-quote prices measures are significant at 0.1 per cent, showing that changes in market depth may adjust volatility in the opposite direction.

5.1.2.2 Fixed effects two stage least squares results: Full sample

Foucault, *et al.* (2007) confirm in their univariate analysis that volatility co-moves with a variety of other variables, such as the number of trades, when opacity is introduced. Thus, we implement a two-stage least-squares model with stock fixed effect approach using the number of trades and total value of order depth as endogenous variables, while the first and second lags of the dependent variable, time trend and logarithm of market capitalization are instruments. These are valid instruments, as they are either predetermined or explicitly exogenous.

The validity of these predetermined and exogenous variables in the equation system are examined by conducting over-identification tests. We use Basmann (1960) approach provided in the statistical package SAS to test for over-identifying restrictions and use the F-statistic for an over-identification test. For a majority of our models, the over-identification tests are not statistically significant; thus, we cannot reject the null hypothesis of no over-identification. In those cases where the F-statistics are high enough to reject the null hypothesis, almost all our results remain when we omit the two predetermined variables of market value and relative tick size. These test results suggest that there is no strong evidence against the validity of the instrumental variables in our models.

The results of these estimations, presented in the last three columns of Table 2, strengthen the findings of prior literature regarding the association between the number of trades and volatility. Correcting endogenous characteristics in the models emphasizes the negative effect of the time trend variable on volatility at the 5 per cent and 0.1 per cent significance levels for all stock exchanges. We also find a negatively significant relationship between the logarithm of volatility (apart from realized volatility) and the logarithm of total depth by value under the new market design.

All of the three volatility metrics are significantly positively related to anonymity and a higher level of the depth display in all three model specifications. We observe that the dummy coefficients of realized volatility and standard deviation over fifteen minutes are 0.0856 and 0.2136, respectively, which is higher than the coefficient of range-based volatility of 0.002185. These figures imply that the effect of the simultaneously conflicting events on the logarithm of high-low volatility is similar to the impact on the two other measures; however, the realized volatility and intra-day standard deviation are more positively affected, suggesting that the slower price discovery caused by removal of counterparty identity has been offset by the faster order execution caused by the extension of the LOB.

5.1.2.3 Fixed effect two stage least squares results: Individual quintiles

To examine the effect of contrasting changes in the LOB on different market segments, we implement the two-stage least squares with fixed effect approach on five individual quintiles, reported in Table 3. The table presents the stock fixed effect results of 2SLS regressions on five quintiles for three volatility metrics in Panels 1, 2 and 3, respectively. T-statistics are stated in brackets under the coefficients of each control variable with significance levels.

<INSERT Table 3 here>

The coefficient β_1 for range-based volatility and standard deviation of mid-quote prices is positive and highly significant at the 0.1 per cent level for all capitalization quintiles. We observe a similar pattern for coefficient β_2 for the time trend variable. The same result is observable for realized volatility only for the second largest quintile. Coefficients of the opacity dummy variable β are significant and positive only for the two quintiles with the smallest market capitalization stocks in the range-based volatility and standard deviation of mid-quote prices. These increases in volatility in the smallest stocks by market capitalization may result from faster information dissemination following the extension of the LOB price level and order size visibility, showing greater trade aggressiveness for this segment. These outcomes suggest that minor stocks are more sensitive to greater visibility of the LOB price levels than they are to anonymous broker IDs. This does not hold for major market capitalization stocks. For larger market capitalization segments, trading no longer sufficiently incorporates private information due to anonymity, which neutralizes the combined effect of removal of broker identity and more visible LOB price levels, leading to no clear changes in volatility in these stocks. These results are in line with our Hypothesis 1.

5.2 Changes in spreads

5.2.1 Univariate tests

Following the literature, we analyze spreads to measure the immediate transaction cost dimension of market quality. Trade-value-weighted effective spreads in local currency and percentage act as our transaction cost metrics. Panels 1, 2 and 3 in Table 4 show the changes in quoted spreads for the full sample and for the five size quintiles.

<INSERT table 4 here>

Consistent with Foucault, *et al.* (2007), Tokyo has narrower quoted spreads after discontinuing the dissemination of the broker information when examining all stocks and each quintile. Although we observe quite small differences in percentage measures between the two periods, most of these results are statistically significant at the 0.1 per cent level. We also observe a larger decline in quoted spreads for the smaller market capitalization market segments. The reduction in equal-weighted and time-weighted quoted spreads is 0.00084 per cent and 0.00195 per cent, respectively, for the TSE smallest quintiles, and these figures present a gradual downward trend to 0.00011 and 0.00036 for the TSE largest quintile. A robustness check using closing spread provides additional evidence of a decrease in quoted spread during the post-period: it falls by 0.00036 per cent for the full sample, at a 0.1 per cent significance level. The highest reduction occurs in the lowest market capitalization group, with approximately 0.00097 per cent, while there is no significant evidence of a decrease in closing spread for the highest market capitalization group.

Panels 4 and 5 in Table 4 show that, for the full sample and five size quintiles, there is a significant change in effective spread in percentage terms. Panel 5 in this table shows the statistically narrower spread in the TSE after the change in market design. In order to separate the impact of volatility on effective spread, we estimate a regression model in the next section.

5.2.2 Multivariate regression

Previous research suggests that there are at least three variables influencing bid-ask spreads: trading volume, price and variance of return. Moreover, Madhavan, *et al.* (2005) find that the opening of LOB to the public affected quoted and effective spreads on the Toronto Stock Exchange. Thus, we estimate a regression in which the width of the spread depends on control variables, including volatility, trading volume, time trend and total depth:

$$Spd_{it} = \alpha_{it} + \beta_1 Vol_{it} + \beta_2 Vola_{it} + \beta_3 Trend_{it} + \gamma TotalDepthVal_{it} + \beta Dummy_{it} + \varepsilon_{it}, \qquad (2)$$

where for each stock i at day t, Spd_{it} is either the quoted spread or the effective spread in percentage and local currency; Vol_{it} is daily volume; $Vola_{it}$ is high-low volatility; $Trend_{it}$ is the time variable; $Dummy_{it}$ is the dummy variable for broker ID opacity, taking the value 0 prior to the TSE design change and 1 after the event; and $TotalDepthVal_{it}$ is the daily average of total depth in yen. We would expect to find β to be significantly different from zero, which provides evidence that the investigated event affects spreads.

5.2.2.1 Fixed effect OLS results

The first four columns in Table 5 present the results of the fixed effect OLS regression for four spread models. Our results are consistent with previous literature showing that spreads are negatively related to volume. Our regressions also confirm the positive association between the dependent variable and volatility. This table indicates a significant coefficient of the dummy variable in percentage terms pre- and post-introduction of the identity of brokers, but in controversial directions. The positive coefficient of percentage measures of quoted spread implies that, after controlling for other factors influencing spreads, the market design change causes an increase in the logarithm of quoted spread. These findings contradict our previous inferences from the univariate tests that the two mixing events may lead to narrower quoted spreads. However, the dummy coefficient in the percentage bid-ask effective spread model demonstrates the reverse.

Similarly, for volatility, it is very likely that spread, volatility and volume are endogenous variables justifying the two stage least squares regression model we apply in the following section.

<INSERT Table 5 here>

5.2.2.2 Fixed effect 2SLS results: Full sample

We estimate the two stage least squares regression with a stock fixed effect specification for four measures of spreads, in which volume, volatility and total depth are used as endogenous variables, while the first two lagged dependent variables, time trend, log of market capitalization and the logarithm of relative tick size are used as instruments. We conduct a similar over-identification test as in Section 5.1.2.2, and cannot reject the null hypothesis of no over-identification.

We find that the total depth variable is positively related to both percentage spread measures. Accounting for the endogeneity problem also clarifies the contentious results in the fixed effect OLS regressions. As such, all diverse coefficients of dummy variables in spreads are insignificant, as shown in the last four columns of Table 5. While our OLS results are consistent with Comerton-Forde, *et al.* (2005), our fixed effect 2SLS implies that the concurrent changes in LOB does not have any direct effect in Tokyo when the effects of volatility, time trend, volume and depth are accounted for.

5.2.2.3 Fixed effect 2SLS results: Individual quintiles

We implement the fixed effect 2SLS regressions for individual quintiles on four spread models. As for the full sample, volume, volatility and total depth are treated as endogenous variables, while the first and second lagged dependent variables, time trend, log of market capitalization and the logarithm of relative tick size are used as instruments. The estimated coefficients are reported in Table 6 including t-statistics below each coefficient.

<INSERT Table 6 here>

The dummy coefficients for quintile 1 are approximately 0.06 to 0.088 and significant for dollar effective spread and both measurements of quoted spreads. We do not observe any evidence of changes in the percentage effective spread as well as in other spread models for larger stocks. The outcome indicates the smallest stocks with less liquidity are most affected and are traded more aggressively in an anonymous environment, conditional on traders having access to greater information on the bid and ask price levels. The results also are consistent with higher volatility for this market segment in the post market design change environment. The combined effect of removal of broker identity and more visible LOB price levels has in aggregate no effect on quoted spreads and effective spread in line with our Hypotheses 2 and 3.

5.3 Changes in limit order book depth

5.3.1 Univariate tests

Following Foucault and Menkveld (2008), we compute the consolidated depth at all (available) levels as total depths; that is, the total number of shares of three best buy and sell quotes in the LOB at the end of each interval. These metrics include three best price levels of depth throughout the sample period to obtain comparable results (while the exchange starts displaying five levels of depth during the second half of the period).

<INSERT Table 7 here>

Generally we do not find significant changes in depth measured by the number of shares, as shown in Panels 1, 2, and 4 in Table 7. Panel 1 shows there is a significant decline in depth for the smallest stock category at-best level. However, the depths measured in yen indicate the opposite results in Panels 5 and 6. These increases in both average best depth and total depth in yen suggest that overall depth increases after the TSE market design change.

Panels 3 and 7, and 4 and 8, in Table 7 present changes in the ratio bid depth and ask depth by volume and by value, respectively, around the June, 2003 event. According to these panels, we find that best bid depth versus total depth weakens both by volume and by value for the medium-size stocks and for the full sample. We observe no change in the ratio between best ask depth and total ask depth, either by size or by value (see Panels 4 and 8). A slight reduction in the ratio of the best bid size indicates bidders' diminishing capability to forecast trade flows in the anonymous environment although they can perceive greater bid and ask levels in the limit order book.

5.3.2 Multivariate regression

Following O'Hara (1995), the change of the depth of the LOB can be explained by trading volume and price volatility. It is important to control for changes in these variables to ensure that any changes in depth observed in this study are attributable to the change in transparency, and not merely to changes in market conditions that influence these variables (Bortoli, Frino, Jarnecic and Johnstone (2006)). We estimate Equation (3) to test the impact of changed pre-trade transparency on market depth, controlling for possible changes in known determinants:

$$DepthVal_{it} = \alpha_{it} + \beta_1 LogVol_{it} + \beta_2 Vola_{it} + \beta_3 Trend_{it} + \beta Dummy_{it} + \varepsilon_{it}, \quad (3)$$

where for each stock i at day t, Vol_{it} is daily volume; $Vola_{it}$ is high-low volatility; $Trend_{it}$ is the time variable; $Dummy_{it}$ is a dummy variable for broker ID opacity, taking the value 0 prior to the TSE design change and 1 after the event; and $DepthVal_{it}$ is the daily average of total depth and the best depth in yen.

5.3.2.1 Fixed effect OLS results

We estimate the model using OLS with stock fixed effect regression and, as for all of the above equations, we take the logarithm of all explanatory and dependent variables (except for the time trend variable). Table 8 reports the results of regression analysis of depth against the explanatory variables: volume, volatility, time trend and a dummy variable for the change in LOB transparency.

The results of the regression analysis can be used to determine the effects of the change in pre-trade transparency after controlling for changes in volume, volatility and daily trend.

<INSERT Table 8 here>

Consistent with O'Hara (1995) and Bortoli, *et al.* (2006), we find a positive and statistically significant association between the total depth in yen and the trading volume, and a negative and statistically significant relationship between the total depth in yen and volatility. Both measured depths reflect an uptrend over time, proved by positively significant coefficients of time trend for all regressions. The changes in market protocol in Tokyo have a positive impact on these market depths in the OLS specification, significant for both the log of best depth and the log of total depth. It is important to note that, concurrent with the move to opaque broker IDs, the TSE increased the transparency in the LOB from three best price levels to five best price levels. Hence, any changes in the depth in the estimation are impacted by two events.

5.3.2.2 Fixed effect 2SLS results

We estimate a two stage least-squares regression with stock fixed effect specification as expressed in Equation 3. Two determinants named volume and volatility are treated as endogenous variables, while the first lagged dependent variable, time trend, and logarithm of market capitalization are used as instruments. The results for the full sample are reported in the last two columns of Table 8. Our outcomes on the relationship between depths and log of volume as well volatility are consistent with O'Hara (1995) and Bortoli, *et al.* (2006), and in line with the OLS results. However, after controlling the endogeneity of explanatory variables, we find that only the coefficient of dummy variable in Log of the best depth model is significant and positive. This implies that the TSE market design change has a positive impact on the best depth, not on the total market depth.

Similar regressions are implemented for individual quintiles and are reported in Table 9. We document the positive association between the logarithm of depth in yen and that of trading volume and volatility at a significance of 0.1 per cent. Interestingly, in contrast to the OLS results, the variation of all the investigated depths is proved to decline over time after controlling for the instruments. Neither is the negative coefficient of the broker ID dummy in the total depth regression significant. This result implies that the change in total depth may be caused by determinants of volume and volatility, as well as the extension of the LOB in the TSE, and not by the market design change event. However, the coefficient of the logarithm of the best market depth in yen is positive and significant at 0.1 per cent, as in the 2SLS model.

<INSERT Table 9 here>

Our results show that there is an increase in the depth at the best bid and ask as a result of the combined effect of removal of broker identity and more visible LOB price levels, but the impact on the aggregate depth is weak. Our results for individual regressions are consistent with that of the full sample, showing significant evidence of a deeper best depth after the event, and no changes in the total depth in the post-period. This is in line with previous research that shows that there are more orders on the best levels in a market with opaque broker IDs, due to less aggressive order placement: see Duong, *et al.* (2009). Our results are in line with hypothesis 4.

5.4 Changes in volume

Finally, univariate and multivariate tests for the effect of volume are performed. Although largely ignored by the literature, the volume effects should be of utmost importance for any exchange considering design policy, as the volume of trading is not only a sign of a well-functioning market but also the main source of revenue for an exchange. We estimate the following equation:

$$Vol_{it} = \alpha_{it} + \beta_1 Vol_{i,t-1} + \beta_2 Spd_{it} + \beta_3 Vola_{it} + \beta_4 Mcap_{it} + \beta_5 Trend_{it} + \gamma TotalDepthVal_{it} + \beta Dummy_{it} + \varepsilon_{it}, \tag{4}$$

In the two stage least-squares regression, we drop the first lag variable Vol_{t-1} in the regression as we use three lags of volume as instruments. We also exclude the logarithm of market capitalization variable in the main equation in the 2SLS, as this variable is utilized as instrumental variable.

Table 10 presents trading volume prior- and post-event as well as any statistical changes following the introduction of opacity and higher LOB transparency for five quintiles and the full sample. All indicators are significantly positive, suggesting the number of shares traded rises in the post-period. Further, we find that this impact is the greatest for the smallest stocks.

<INSERT Table 10 here>

Our outcome for the OLS and 2SLS with fixed effect specification reported in Table 11 for the full sample is in line with the univariate analysis. The broker ID opacity dummy coefficient is 0.03 in the OLS, and 0.06 in the 2SLS estimation, significant at the 5 per cent and 0.1 per cent level, respectively, which confirms a significant increase in trading volume in the post-period.

<INSERT Table 11 here>

We do not find significant evidence for this upward direction of trading volume in regressions for individual quintiles. The dummy coefficients are not significant for individual size quintiles, implying that the volume results are quite sensitive to the chosen sample and that large stocks dominate in the full sample analysis; see Table 12. The combined effect of removal of broker identity and more visible LOB price levels increases trading volume in line with Hypothesis 5.

<INSERT Table 12 here>

5.5 Robustness check

Since the policy in this paper affects all stocks at the same time, the error terms in our regressions using Equations (1) – (4) may be contemporaneously correlated across stocks. To address this potential problem, we include separate dummy variables for each day of the Post-Period, as in Boehmer, Saar and Yu (2005). We also include a dummy variable for each stock to allow for stock-fixed effect, as in Foucault, *et al.* (2007) and we estimate the following equation of all proxies of volatility, effective and quoted spreads, depths and traded volume for all the stocks in our sample:

$$Mkt\_Quality_{it} = Intercept + \sum_{k=1}^{n} \beta_k Post - period_{it}^{k} + \sum_{j=1}^{m} \theta_j ControlVariable_{it}^{j} + \varepsilon_{it}, \quad (5)$$

where $Mkt\_Quality_{it}$ are the three measures of volatility - range-based volatility; realized volatility; and standard deviation of fifteen-minute mid-quote prices; the two relative spread metrics[10] – effective and quoted spreads; the two depth measurements – the daily average of total depth and the best depth in yen; and daily traded volume, respectively. The dummy variables $Post - period_{it}^{k}$ equal one for the k^{th} day in the *n*-day post-event period and is zero otherwise. This results in 63 coefficients of the daily post-period dummy variables. $ControlVariable_{it}^{j}$ is the same set of m control variables used in Equations (1), (2), (3) and (4) for analysis of volatility, spreads, depths and trading volume, respectively. We allow for the stock-fixed effect intercept. Table 13 reports the median of the coefficients of the post-period dummy variables ($\beta_k s$) and the $p - value$ (in parentheses) of the Wilcoxon signed rank test against the hypothesis of a zero median.

<INSERT Table 13 here>

Testing the median of the 63 post-period dummy variables against zero provides the robust tests for our findings in the above sections. Panel A of table 13 shows all of the three volatility proxies increase significantly after the TSE events as we found in the regression of Equation (1). Panel B of the table indicates that the policy change does not affect both of the average of effective and quote spread across the stocks, even when we take into account for the potential problem of cross-correlated residuals. Panel C displays evidence supporting one of the two of our results in the regression of Equation (3), which shows a significant increase in the best depth. Panel D presents the results of the trading volume analysis with the daily time-series specification in Equation (5).

[10] Since our sample includes a wide range of stocks, the relative measures of spreads would be more accurate than the absolute measures due to its comparability among stocks. Thus, we report the robustness tests for the two relative, not absolute measures of spreads.

Here, there is a highly significant increase in trading volume in the post-period. In summary, our findings on how volatility, spreads, best depth and traded volume are affected by the TSE market design change are robust to the potential cross-correlation across stocks.

6. Conclusions

We investigate the impact of a common change to pre-trade transparency on market quality. Many exchanges have recently ended disclosure of broker identification and, over time, increased the levels of price and volume displayed from the limit order book. Effectively this is the market structure that NYSE-Euronext, Nasdaq, Nasdaq-OMX, most European exchanges and Australia have moved to. We measure the effect of the introduction of this policy on volatility, transaction costs, LOB depth and traded volume in the Tokyo Stock Exchange (TSE). Foucault, *et al.* (2007) confirm that volatility co-moves with a variety of other variables, such as the number of trades, when opacity is introduced. Further, there were two conflicting events taking effect simultaneously in the TSE, which may cause ambiguous effects on liquidity and order aggressiveness. This is why we implement a two-stage least-squares model with fixed stock effects to examine the impact of the change in pre-trade transparency at the TSE.

We find that volatility increases after the TSE market design change which we attribute to a slower adjustment to new information when transaction counterparties are unknown. The depth of the limit order book increases at the best bid and ask prices while total depth is not significantly impacted. This supports earlier studies in the literature that predict an increase in depth as a result of more competitive order strategies in an opaque system. Our results also confirm findings in earlier studies that an increase in reported LOB depth is associated with a greater depth of the LOB. Accounting for the interaction between spreads, volatility and volume, we find that spreads are not affected by the TSE market design change, which is in contradiction to results in previous literature. We show this to be an expected result of the combined effect of the removal of broker identity and more visible LOB price and order size information. Previous literature largely ignores the volume impacts of transparency altering market design changes. We find that volume increases as a result of the TSE market design change, which is consistent with the higher volatility. Overall, we conclude that the TSE market design change increases the welfare of traders, as it promotes higher traded volume, the most important indicator of gains from trade within a trading system.

Interestingly, we find that the general combined effect of the removal of broker identity and more visible LOB price and order size information is greater for smaller stocks and close to neutral for larger stocks. As institutional traders that benefit most from anonymous broker IDs are active mainly in large stocks, it appears that the market design change has not affected large stocks negatively, while it has some positive effects on smaller stocks. Displaying more information about orders in the LOB, albeit anonymously, has previously been shown to improve liquidity (Boehmer, *et al.* (2005)). The good news is that while the search for counterparties becomes more costly when broker IDs are anonymous, in the Tokyo case, the benefits from a more transparent LOB appear to outweigh any negative effects.

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Table 1: Univariate Analysis for Volatility

The table reports a summary of changes in median volatility for the full sample and five market capitalization quintile sub-samples. The Pre-Period is March 1, 2003 to May 31, 2003 and the Post-Period is July 1, 2003 to September 30, 2003. 'Difference' rows report the change from the pre-period to post-period in three volatility metrics: Ln_hi_lo, which is range-based volatility; realized volatility; and standard deviation of fifteen-minute mid-quote prices. A signed-rank Wilcoxon test examines whether medians change significantly after the removal of broker IDs and extension of the LOB. *, **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Ln_hi_lo	**Realized Volatility**	**Standard deviation 15 mins**
Quintile 1 (smallest)			
Pre-Period	0.02	38.357	8.408
Post-Period	0.021	42.614	11.617
Difference	0.001***	4.257***	3.209***
Quintile 2			
Pre-Period	0.01777	43.717	15.416
Post-Period	0.01828	47.004	20.321
Difference	0.001	3.287***	4.905***
Quintile 3			
Pre Period	0.01687	46.507	17.019
Post-Period	0.01713	49.116	21.593
Difference	0.00026	2.609***	4.574*
Quintile 4			
Pre-Period	0.01662	50.224	17.846
Post-Period	0.01685	53.201	23.265
Difference	0.00023	2.977***	5.419**
Quintile 5 (largest)			
Pre-Period	0.01472	58.806	28.02
Post-Period	0.01528	61.663	37.337
Difference	0.001	2.857***	9.317**
Full Sample			
Pre-Period	0.017	47.548	20.055
Post-Period	0.018	50.751	22.772
Difference	0.001**	3.203***	2.717***

Table 2: Multivariate Analysis for Volatility: Full Sample

This table reports the results of regressions of the form:

$$Vola_{it} = \alpha_{it} + \beta_1 Num\_Trade_{it} + \beta_2 Trend_{it} + \gamma TotalDepthVal_{it} + \beta Dummy_{it} + \varepsilon_{it}, \quad (1)$$

where for each stock i at day t, $Vola_{it}$ represents three measurements of volatility including range-based volatility, realized volatility and standard deviation of mid-quote prices every fifteen minutes; $Dummy_{it}$ is a dummy variable for broker ID opacity, taking the value 0 prior to the TSE design change and 1 after the event; $Trend_{it}$ is the time variable; Num_trade_{it} is daily number of trade; and $TotalDepthVal_{it}$ is the daily average of total depth in yen. The table contains the stock fixed effect results of OLS and 2SLS regression for the full sample with t-statistics in parentheses. In fixed effect 2SLS, the number of trades and total depth in yen are treated as endogenous variables, while the first and second lagged dependent variables, trend and log of market capitalization, are used as instruments. **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Fixed effect OLS regression			**Fixed effect 2SLS regression**		
	Ln_hi_lo	Log of Realized Volatility	Log of Standard deviation 15'	Ln_hi_lo	Log of Realized Volatility	Log of Standard deviation 15'
Log of Number of trades	0.0122	0.0444	0.5973	0.0164	0.4192	2.518
	(56.82)***	(2.48)*	(36.79)***	(19.00)***	(4.34)***	(21.97)***
Log of Total Depth in Yen	-0.0052	0.0082	-0.0718	-0.004	0.0513	-0.6899
	(30.07)***	-0.57	(5.56)***	(16.38)***	-1.87	(21.21)***
Trend	-0.000042	0.0002	-0.0027	-0.0001	-0.0007	-0.0053
	(10.85)***	-0.76	(9.15)***	(14.41)***	(2.04)*	(11.55)***
Dummy	0.0018	0.0927	0.268	0.0022	0.0857	0.2136
	(5.25)***	(3.21)**	(10.25)***	(6.13)***	(2.90)**	(5.49)***
Adj R-squared	0.368477	0.224003	0.781756	0.8389	0.97207	0.87243

Table 3: Multivariate Analysis for Volatility: Individual Quintiles

This table reports the results of regressions of the form:

$$Vola_{it} = \alpha_{it} + \beta_1 Num\_Trade_{it} + \beta_2 Trend_{it} + \gamma TotalDepthVal_{it} + \beta Dummy_{it} + \varepsilon_{it}, \quad (1)$$

where for each stock i at day t, $Vola_{it}$ represents three measurements of volatility including range-based volatility, realized volatility and standard deviation of mid-quote prices every fifteen minute; $Dummy_{it}$ is dummy variable for broker ID opacity taking the value 0 prior to the TSE design change and 1 after the event; $Trend_{it}$ is the time variable; Num_trade_{it} is daily number of trade; and $TotalDepthVal_{it}$ is the daily average of total depth in yen. The table contains the stock fixed effect results of OLS and 2SLS regression for the full sample with t-statistics in parentheses. In fixed effect 2SLS, the number of trades and total depth in yen are treated as endogenous variables while the first and second lagged dependent variables, trend and log of market capitalization, are used as instruments. **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Quintiles				
	1 (Smallest)	2	3	4	5 (Largest)
Panel 1: Log of High-Low Volatility					
Log of Number of Trades	0.012	0.0128	0.0222	0.0207	0.0175
	(5.89)***	(7.06)***	(11.38)***	(10.28)***	(6.75)***
Log of Total Depth in Yen	-0.0019	-0.003	-0.0061	-0.0054	-0.0044
	(-3.47)**	(-4.93)***	(-9.39)***	(-9.39)***	(-5.95)***
Trend	-0.0001	-0.0001	-0.0001	-0.0001	-0.00004
	(-9.12)***	(-6.6)***	(-5.75)***	(-5.77)***	(-4.18)***
Dummy	0.0054	0.003	0.0011	0.001	0.0005
	(5.52)***	(3.86)***	(1.34)	(1.41)	(0.69)
Adj R-squared	0.8474	0.8318	0.8117	0.8367	0.8335
Panel 2: Log of Realized Volatility					
Log of Number of Trades	0.3763	0.1804	0.3801	0.587	0.3846
	(1.56)	(1.0)	(1.74)	(4.38)***	(0.6)
Log of Total Depth in Yen	0.1195	0.1727	0.1402	0.0664	0.0616
	(1.89)	(2.87)*	(1.92)	(1.73)	(0.34)
Trend	-0.001	-0.0002	-0.0012	-0.0008	-0.0009
	(-0.82)	(-0.27)	(-1.54)	(-2.12)*	(-0.72)
Dummy	0.1516	0.1018	0.0794	0.0089	0.0928
	(1.62)	(1.7)	(-1.34)	(0.29)	(1.03)
Adj R-squared	0.9429	0.97	0.9749	0.9939	0.9668
Panel 3: Log of Standard Deviation of Fifteen-Minute Mid-Quote Prices					
Log of Number of Trades	1.5801	1.8047	3.069	3.1298	2.6895
	(8.37)***	(10.13)***	(10.00)***	(9.74)***	(6.84)***
Log of Total Depth in Yen	-0.2928	-0.4384	-0.7329	-0.7912	-0.7383
	(-5.91)***	(-7.39)***	(-7.14)***	(-8.58)***	(-6.6)***
Trend	-0.0065	-0.0032	-0.0065	-0.0058	-0.005
	(-7.32)***	(-4.25)***	(-5.26)***	(-5.34)***	(-4.51)***
Dummy	0.4297	0.236	0.1171	0.2192	0.138
	(5.97)***	(3.61)**	(1.18)	(2.31)*	(1.43)
Adj R-squared	0.8483	0.9044	0.8336	0.8696	0.9078

Table 4: Univariate Analysis for Spreads

The table reports changes in median effective spread and quoted spread for the full stock sample and for five size quintiles. The pre-period and post-period are defined as March 1, 2003 to May 31, 2003, and July 1, 2003 to September 1, 2003, respectively. 'Difference' measures changes of absolute and relative spreads from the pre-period to the post-period. Each panel presents the analysis for the full sample and for individual quintiles. The signed-rank Wilcoxon test examines whether medians change after the broker IDs became anonymous and the LOB display was extended to three levels. *, **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Quintiles					
	1 (smallest)	**2**	**3**	**4**	**5 (largest)**	**Full sample**
Panel 1: Closing Quoted Spread (%)						
Pre-Period	0.00504	0.00368	0.00305	0.00283	0.00238	0.00339
Post-Period	0.00407	0.00333	0.00288	0.00254	0.00236	0.00303
Difference	-0.00097***	-0.00035**	-0.00017*	-0.00029**	-2.00E-05	-0.00036***
Panel 2: Equally-Weighted Quoted Spread (%)						
Pre-Period	0.00408	0.00277	0.00233	0.00209	0.00187	0.00262
Post-Period	0.00324	0.00233	0.00208	0.00177	0.00176	0.00223
Difference	-0.00084***	-0.00044***	-0.00025***	-0.00032***	-0.00011**	-0.00039***
Panel 3: Time-Weighted Quoted Spread (in percentage)						
Pre-Period	0.01011	0.0073	0.00614	0.00552	0.0048	0.00675
Post-Period	0.00816	0.00623	0.0054	0.00459	0.00444	0.00574
Difference	-0.00195***	-0.00107***	-0.00074***	-0.00093***	-0.00036**	-0.00101***
Panel 4: Trade Value-Weighted Effective Spread						
Pre-Period	1.005	1.738	1.381	1.802	2.785	1.736
Post-Period	1.293	2.013	1.603	1.908	3.113	1.981
Difference	0.288***	0.275***	0.222	0.106***	0.328***	0.245***
Panel 5: Trade Value-Weighted Effective Spread (in percentage)						
Pre-Period	0.00197	0.00132	0.00112	0.00101	0.00092	0.0013
Post-Period	0.00157	0.00112	0.001	0.00085	0.00086	0.0011
Difference	-0.0004***	-0.0002***	-0.00012***	-0.00016***	-0.00006**	-0.0002***

Table 5: Fixed Effect Regression Model for Spreads: Full Sample

This table reports the results of regressions of the form:

$$Spd_{it} = \alpha_{it} + \beta_1 Vol_{it} + \beta_2 Vola_{it} + \beta_3 Trend_{it} + \gamma TotalDepthVal_{it} + \beta Dummy_{it} + \varepsilon_{it}, \qquad (2)$$

where for each stock i at day t, Spd_{it} is either the quoted spread or the effective spread in percentage and local currency; Vol_{it} is daily volume; $Vola_{it}$ is high-low volatility; $Trend_{it}$ is the time variable; $Dummy_{it}$ is a dummy variable for broker ID opacity, taking the value 0 prior to the TSE design change and 1 after the event; and $TotalDepthVal_{it}$ is the daily average of total depth in yen. The table contains the stock fixed effect results of OLS and 2SLS regression for the full sample with t-statistics in parentheses. In fixed effect 2SLS, volume, volatility and total depth in yen are treated as endogenous variables, while the first and second lagged dependent variables, time trend, log of market capitalization and relative tick size are used as instruments. *, **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Fixed effect OLS regression				**Fixed effect 2SLS regression**			
	Log of Trade Value-Weighted Effective Spread (Yen)	Log of Trade Value-Weighted Relative Effective Spread (%)	Log of Time-Weighted Quote Spread (Yen)	Log of Time-Weighted Quote Spread (%)	Log of Trade Value-Weighted Effective Spread (Yen)	Log of Trade Value-Weighted Relative Effective Spread (%)	Log of Time-Weighted Quote Spread (Yen)	Log of Time-Weighted Quote Spread (%)
Log(Volume)	-0.0728	-0.0906	-0.073	-0.0898	-0.0653	-2.0255	-0.0108	-1.5072
	(3.64)***	(19.12)***	(13.12)***	(15.74)***	(-1.11)	(10.92)***	-0.18	(10.97)***
Ln_hi_lo	9.0514	8.6603	5.436	5.0408	30.734	20.4908	24.6588	5.3522
	(16.09)***	(37.98)***	(20.30)***	(18.37)***	(17.09)***	(3.86)***	(11.89)***	-1.18
Log of Total Depth in Yen	0.0298	0.0348	-0.0476	-0.0423	-0.0031	1.2431	0.0346	0.9242
	(41.58)***	(6.77)***	(7.88)***	(6.84)***	(0.07)	(8.64)***	(0.76)	(8.68)***
Trend	0.0007	-0.001	0.0009	0.0001	0.0008	0.0011	0.0006	0.0005
	(7.12)***	(10.37)***	(7.49)***	(6.90)***	(5.37)***	(2.64)**	(3.68)***	(1.49)
Dummy	0.0106	-0.0289	0.0136	0.0104	0.0194	0.0121	0.0147	0.003
	(1.28)	(3.33)***	(1.34)	(2.48)*	(1.61)	(0.34)	(1.12)	(0.1)
Adj-R-squared	0.9602	0.8843	0.9428	0.8063	0.9193	0.9875	0.9764	0.9858

Table 6: Fixed Effect Regression Model for Spreads: Individual Quintiles

This table reports the results of regressions of the form:

$$Spd_{it} = \alpha_{it} + \beta_1 Vol_{it} + \beta_2 Vola_{it} + \beta_3 Trend_{it} + \gamma TotalDepthVal_{it} + \beta Dummy_{it} + \varepsilon_{it}, \qquad (2)$$

where for each stock i at day t, Spd_{it} is either the quoted spread or the effective spread in percentage and local currency; Vol_{it} is daily volume; $Vola_{it}$ is high-low volatility; $Trend_{it}$ is the time variable; $Dummy_{it}$ is a dummy variable for broker ID opacity, taking the value 0 prior to the TSE design change and 1 after the event; and $TotalDepthVal_{it}$ is the daily average of total depth in yen. The table contains the stock fixed effect results of OLS and 2SLS regression for the full sample with t-statistics in parentheses. In fixed effect 2SLS, volume, volatility and total depth in yen are treated as endogenous variables, while the first and second lagged dependent variables, time trend, log of market capitalization and relative tick size are used as instruments. *, **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Quintiles				
	1 (Smallest)	2	3	4	5 (Largest)
Panel 1: Log of Trade Value-Weighted Effective Spread (in Yen)					
Log(Volume)	0.1263	0.5213	-1.0597	-0.8092	-1.4029
	(2.57)*	(2.76)**	(-7.67)***	(-0.69)	(-0.57)
Ln_hi_lo	13.3941	14.49	31.3985	63.0442	119.7778
	(5.78)***	(4.1)***	(8.68)***	(2.05)*	(1.96)
Log of Total Depth in Yen	-0.1331	-0.4297	0.7567	0.517	0.992
	(-3.58)**	(-2.91)**	(8.63)***	(0.64)	(0.51)
Trend	0.0001	-0.0002	0.002	0.0018	0.0025
	(0.25)	(-0.44)	(4.32)***	(2.01)*	(2.06)*
Dummy	0.06	0.0576	0.0129	-0.0354	-0.0358
	(2.57)*	(1.85)	(0.34)	(-0.82)	(-0.46)
Adj-R-squared	0.9084	0.8962	0.8136	0.8064	0.7264
Panel 2: Log of Trade Value-Weighted Relative Effective Spread (%)					
Log(Volume)	-0.6026	-1.6432	-1.9625	1.6311	8.2222
	(-7.64)***	(-3.63)***	(-7.73)***	(1.17)	(0.84)
Ln_hi_lo	2.2653	-11.1318	11.7016	-81.8092	-31.9802
	(0.68)	(-1.45)	(1.63)	(-1.69)	(-0.11)
Log of Total Depth in Yen	0.0466	0.8522	0.7898	-1.5762	-6.7425
	(0.79)	(2.42)*	(4.89)***	(-1.63)	(-0.87)
Trend	-0.0003	-0.0008	0.0032	-0.0012	-0.0022
	(-0.75)	(-0.94)	(3.42)***	(-0.83)	(-0.35)
Dummy	0.0507	0.0582	0.0097	-0.0694	-0.0293
	(1.42)	(0.77)	(0.13)	(-0.95)	(-0.07)
Adj-R-squared	0.8062	0.8771	0.8471	0.8676	0.8415

	Quintiles				
	1 (Smallest)	2	3	4	5 (Largest)
Panel 3: Log of Time-Weighted Quote Spread (in Yen)					
Log(Volume)	0.1546	0.0992	-0.9928	-1.2892	-3.9536
	(3.00)**	(0.82)	(-6.87)***	(-1.95)	(-0.63)
Ln_hi_lo	6.9773	6.3045	31.3582	74.5239	71.6524
	(2.71)**	(2.43)*	(7.75)***	(4.36)***	(0.52)
Log of Total Depth in Yen	-0.0272	0.0116	0.8209	0.9535	3.0918
	(-0.7)	(0.12)	(9.01)***	(2.07)*	(0.62)
Trend	-0.0007	-0.0002	0.0018	0.0019	0.0028
	(-2.41)*	(-0.55)	(3.57)***	(2.49)*	(1.03)
Dummy	0.0887	0.0806	-0.0131	-0.0325	-0.0724
	(3.7)***	(3.26)**	(-0.32)	(-0.56)	(-0.42)
Adj-R-squared	0.9718	0.9807	0.9475	0.917	0.7121
Panel 4: Log of Time-Weighted Quote Spread (%)					
Log(Volume)	-0.5621	-1.256	-1.3061	-8.1185	7.4677
	(6.93)***	(-3.92)***	(-7.58)***	(-1.12)	(0.44)
Ln_hi_lo	-5.5688	-19.1109	7.1816	169.6662	-86.9049
	(-1.51)	(-2.87)**	(1.40)	(0.91)	(-0.31)
Log of Total Depth in Yen	0.1452	0.6667	0.4854	5.3082	-6.0433
	(2.39)**	(2.66)**	(4.47)***	(1.05)	(-0.46)
Trend	-0.001	-0.0011	0.002	0.005	-0.0024
	(-2.4)*	(-1.56)	(3.20)**	(0.90)	(-0.39)
Dummy	0.0733	0.0592	-0.0138	-0.0376	-0.0776
	(2.01)*	(0.93)	(-0.27)	(-0.14)	(-0.23)
Adj-R-squared	0.9951	0.9824	0.9602	0.7941	0.8037

Table 7: Univariate Analysis for Market Depth

The table reports the changes in median eight depth measurements for the full stocks and five size quintiles. The pre-period and post-period are defined as March 1, 2003 to May 31, 2003, and July 1, 2003 to September 1, 2003, respectively. 'Difference' measures the change of eight market depth proxies from the pre-period to the post-period. Each panel presents the analysis for the full sample and the top, middle and bottom individual quintiles. The signed-rank Wilcoxon test examines whether medians change after the concealment of broker identity and extension of the LOB. *, **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Group			
	1 (smallest)	**2**	**3 (largest)**	**All Stocks**
Panel 1: Best Depth by Size				
Pre-Period	385541.228	40094.11	50245.309	158626.882
Post-Period	297889.828	41107.276	59709.452	129977.615
Difference	-87651.4*	1013.166	9464.143	-28649.267
Panel 2: Total Depth by Size				
Pre-Period	1076687.394	125272.387	153797.262	451919.015
Post-Period	977401.383	124506.625	182593.799	418522.112
Difference	-99286.011	-765.762	28796.537	-33396.903
Panel 3: Ratio Bid Depth by Size				
Pre-Period	0.309	0.318	0.314	0.314
Post-Period	0.303	0.313	0.31	0.308
Difference	-0.006	-0.005*	-0.004	-0.006*
Panel 4: Ratio Ask Depth by Size				
Pre-Period	0.315	0.323	0.319	0.319
Post-Period	0.307	0.32	0.322	0.317
Difference	-0.008	-0.003	0.003	-0.002
Panel 5: Best Depth by Value				
Pre-Period	40,603,214.64	20,731,463.15	58,276,894.22	39,870,524
Post-Period	44,413,817.66	25,424,450.87	77,906,801.80	48,997,167.11
Difference	3,810,603.023*	4,692,987.719***	19629907.58**	9126643.109**
Panel 6: Total Depth by Value				
Pre-Period	112,858,693.70	62,957,019.58	178,889,813.10	118,235,175.50
Post-Period	142,868,938.30	75,712,913.36	237,294,220.50	151,106,436.10
Difference	30,010,244.62*	12,755,893.78***	58,404,407.46**	32,871,260.61**
Panel 7: Ratio Bid Depth by Value				
Pre-Period	0.31	0.319	0.315	0.314
Post-Period	0.303	0.313	0.31	0.309
Difference	-0.007	-0.006*	-0.005	-0.005*
Panel 8: Ratio Ask Depth by Value				
Pre-Period	0.314	0.323	0.319	0.318
Post-Period	0.306	0.32	0.322	0.316
Difference	-0.008	-0.003	0.003	-0.002

Table 8: Regression Model for Depth: Full Sample

This table reports the results of regressions of the form:

$$DepthVal_{it} = \alpha_{it} + \beta_1 LogVol_{it} + \beta_2 Vola_{it} + \beta_3 Trend_{it} + \beta Dummy_{it} + \varepsilon_{it}, \quad (3)$$

where for each stock i at day t, Vol_{it} is daily volume; $Vola_{it}$ is high-low volatility; $Trend_{it}$ is the time variable; $Dummy_{it}$ is a dummy variable for broker ID opacity, taking the value 0 prior to the TSE design change and 1 after the event; and $DepthVal_{it}$ is the daily average of total depth and the best depth in yen. The table presents the OLS and 2SLS regression results with fixed effect approach for the full sample, with t-statistics in parentheses. In fixed effect 2SLS, the volume and volatility are treated as endogenous variables while the first lagged dependent variable, logarithm of market capitalization and time trend are used as instruments. *, **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Fixed effect OLS regression		**Fixed effect 2SLS regression**	
	Log of Total Depth in Yen	Log of Best Depth in Yen	Log of Total Depth in Yen	Log of Best Depth in Yen
Log of Volume	0.5441	0.5652	1.3354	1.2471
	(80.33)***	(67.74)***	(179.25)***	(175.89)***
Ln_hi_lo	-16.072	-14.7819	-74.7673	-55.0283
	(42.71)***	(31.89)***	(8.41)***	(6.53)***
Trend	0.0013	0.0006	-0.0017	-0.0018
	(7.31)***	(2.99)**	(5.06)***	(6.02)***
Dummy	-0.033	0.1464	-0.007	0.1688
	(2.15)*	(7.74)***	(-0.25)	(6.49)***
Adj R-squared	0.8818	0.8271	0.9988	0.9989

Table 9: Regression Model for Depth: Individual Quintiles

This table reports the results of regressions of the form:

$$DepthVal_{it} = \alpha_{it} + \beta_1 LogVol_{it} + \beta_2 Vola_{it} + \beta_3 Trend_{it} + \beta Dummy_{it} + \varepsilon_{it}, \quad (3)$$

where for each stock i at day t, Vol_{it} is daily volume; $Vola_{it}$ is high-low volatility; $Trend_{it}$ is the time variable; $Dummy_{it}$ is a dummy variable for broker ID opacity, taking the value 0 prior to the TSE design change and 1 after the event; and $DepthVal_{it}$ is the daily average of total depth and the best depth in yen. The table presents the OLS and 2SLS regression results with fixed effect approach for the full sample, with t-statistics in parentheses. In fixed effect 2SLS, the volume and volatility are treated as endogenous variables while the first lagged dependent, logarithm of market capitalization and trend are used as instruments. *, **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Quintiles				
	1 (Smallest)	2	3	4	5 (Largest)
Panel1: Log of Total Depth in Yen					
Log of Volume	1.6557	1.3142	1.6337	1.4361	1.387
	(10.48)***	(52.26)***	(65.63)***	(154.79)***	(31.07)***
Ln_hi_lo	-206.76	-15.241	-28.3606	-36.8877	-144.415
	(-2.10)*	(-0.97)	(-2.32)*	(-3.0)**	(-2.42)*
Trend	-0.0047	-0.0008	-0.0033	-0.0004	-0.0029
	(-1.6)	(-1.54)	(-4.92)***	(-0.76)	(-2.21)*
Dummy	-0.141	-0.0192	0.0741	-0.0523	0.0677
	(-0.71)	(-0.41)	(1.26)	(-1.07)	(0.71)
Adj R-squared	0.8219	0.8882	0.8533	0.8766	0.8452
Panel 2: Log of Best Depth in Yen					
Log of Volume	1.5885	1.258	1.4696	1.3162	1.2123
	(10.31)***	(44.52)***	(51.31)***	(122.71)***	(45.81)***
Ln_hi_lo	-216.985	-29.6659	4.488	-5.9094	-10.4412
	(-2.26)*	(-1.6)	(0.32)	(-0.41)	(-0.29)
Trend	-0.0047	-0.0015	-0.0028	-0.0001	-0.0015
	(-1.57)	(-2.53)*	(-3.91)***	(-0.15)	(-1.84)
Dummy	-0.0455	0.1745	0.2237	0.107	0.2373
	(-0.22)	(3.6)**	(3.5)**	(1.97)*	(3.98)***
Adj R-squared	0.8063	0.8782	0.8484	0.8695	0.8422

Table 10: Univariate Analysis for Trading Volume

The table reports the changes in median trading volume for the full stocks and five size quintiles. The pre-period and post-period are defined as March 1, 2003 to May 31, 2003, and July 1, 2003 to September 1, 2003, respectively. Difference measures changes of volume from the pre-period to the post-period. Each row presents the analysis for the full sample and the top, middle and bottom individual quintiles. The signed-rank Wilcoxon test examines whether medians change after the concealment of broker ID and extension of the LOB. *, **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Pre-Period	**Post-Period**	**Difference**
Group 1	1291747	2744450	1452703***
Group 2	1311706	1972201	660494.9***
Group 3	1377484	2191674	814189.98***
Group 4	2329665	3208162	878497.16***
Group 5	2825095	3714367	889272.02***
Full sample	1817764	2752081	934317.52***

Table 11: Regression Model for Trading Volume: Full Sample

This table reports the results of regressions of the form:

$$Vol_{it} = \alpha_{it} + \beta_1 Vol_{i,t-1} + \beta_2 Spd_{it} + \beta_3 Vola_{it} + \beta_4 Mcap_{it} + \beta_5 Trend_{it} + \gamma TotalDepthVal_{it} + \beta Dummy_{it} + \varepsilon_{it}, \quad (4)$$

where all variables are defined in the previous tables; the table presents the OLS and 2SLS regression results with fixed effect approach for the individual quintiles with t-statistics in parentheses. In fixed effect 2SLS, the volume and volatility are treated as endogenous variables while the first lagged dependent, logarithm of market capitalization and trend are used as instruments. *, **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Fixed Effect OLS regression	**Fixed Effect 2SLS regression**
	Log of Trade Volume	
Lag of Log(Volume)	0.2815	
	(43.69)***	
Log of Relative Effective Spread	-0.2693	-0.0304
	(16.09)***	(1.52)
Ln_hi_lo	22.1524	50.8503
	(58.42)***	(5.02)***
Log of MCap	-0.035	
	(1.09)	
Log of Total Depth in Yen	0.5431	0.629
	(71.45)***	(10.35)***
Trend	0.0002	0.0005
	(0.94)	(1.84)
Dummy	0.0303	0.0613
	(1.98)*	(3.15)**
Adj R-squared	0.93	0.99

Table 12: Regression Model for Trading Volume: Individual Quintiles

This table reports the results of regressions of the form:

$$Vol_{it} = \alpha_{it} + \beta_1 Vol_{i,t-1} + \beta_2 Spd_{it} + \beta_3 Vola_{it} + \beta_4 Mcap_{it} + \beta_5 Trend_{it} + \gamma TotalDepthVal_{it} + \beta Dummy_{it} + \varepsilon_{it}, \quad (4)$$

where all variables are defined in the previous tables; the table presents the OLS and 2SLS regression results with fixed effect approach for the individual quintiles with t-statistics in parentheses. In fixed effect 2SLS, the volume and volatility are treated as endogenous variables while the first lagged dependent, logarithm of market capitalization and trend are used as instruments. *, **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Quintiles				
	1 (Smallest)	2	3	4	5 (Largest)
Log of Relative Effective Spread	3.2904	2.7634	22.4658	1.4853	-2.703
	(1.47)	(0.40)	(0.21)	(1.29)	(-0.25)
Ln_hi_lo	67.379	18.5121	266.7126	35.5743	48.0802
	(2.35)*	(0.16)	(0.29)	(1.19)	(0.66)
Log of Total Depth in Yen	1.3772	1.1516	8.0259	0.9886	0.0683
	(1.79)	(1.09)	(-0.24)	(-0.28)*	(0.03)
Trend	0.0005	-0.001	-0.0088	0.000023	0.0011
	(0.33)	(-0.26)	(-0.18)	(4.26)***	(0.16)
Dummy	0.0679	0.0815	0.0401	0.0115	0.09
	(0.65)	(1.23)	(0.06)	(0.03)	(1.51)
Adj R-squared	0.9954	0.9973	0.8096	0.9988	0.9988

Table 13: Robustness Checks using Daily Post-period Dummy variables

This table reports the robustness checks results for volatility, spreads, depths and trading volume in the following form:

$$Mkt\_Quality_{it} = Intercept + \sum_{k=1}^{n} \beta_k Post-period_{it}^{k} + \sum_{j=1}^{m} \theta_j ControlVariable_{it}^{j} + \varepsilon_{it}, \quad (5)$$

where $Mkt\_Quality_{it}$ are the three measures of volatility - range-based volatility; realized volatility; and standard deviation of fifteen-minute mid-quote prices; the two relative spread metrics – effective and quoted spreads; the two depth measurement – the daily average of total depth and the best depth in yen; and daily trading volume, respectively. We control for cross-correlation by introducing n dummy variables $Post-period_{it}^{k}$, which equal one for the k^{th} day in the n-day post-event period and is zero otherwise. $ControlVariable_{it}^{j}$ is the same set of m control variables used in Equations (1), (2), (3) and (4) for analysis of volatility, spreads, depths and trading volume, respectively. We allow for stock-fixed effect intercept. We report the median of the dummy variables' coefficients ($\beta_k s$) and the $p-value$ (in parentheses) of the Wilcoxon signed rank test against the hypothesis of a zero median. *, **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

	Median (n = 63)	**p-Value of Wilcoxon Test**
Panel A: Analysis of Volatility Estimated from Multivariate Regressions using Daily Post-period Dummy variables		
Ln_hi_lo	0.0020***	(0.0000)
Log of Realized Volatility	0.0069***	(0.0000)
Log of Standard deviation 15'	0.2855***	(0.0000)
Panel B: Analysis of Spreads Estimated from Multivariate Regressions using Daily Post-period Dummy variables		
Log of Trade Value-Weighted Relative Effective Spread (%)	0.0031	(0.8870)
Log of Time-Weighted Quote Spread (%)	-0.0066	(0.7659)
Panel C: Analysis of Depths Estimated from Multivariate Regressions using Daily Post-period Dummy variables		
Log of Total Depth in Yen	-0.0010***	(0.0000)
Log of Best Depth in Yen	0.0100***	(0.0000)
Panel D: Analysis of Volume Estimated from Multivariate Regressions using Daily Post-period Dummy variables		
Log of Trade Volume	0.0540***	(0.0006)

Appendix: Unit root tests

We implement Im, Pesaran and Shin (2003) unit root tests including and excluding time trend for our unbalanced panel datasets to examine whether our series contains unit roots. The null hypothesis is that all panels contain unit roots and the alternative is that some panels are stationary. The test involves fitting an augmented Dickey–Fuller regression for each panel; we requested that the number of lags to include be selected based on the AIC with at most 8 lags. The test results are presented in the following table. **, and *** denote significance at the 5%, 1% and 0.1% levels, respectively.

Number of panels	Average number of periods	Variables	Statistics	
			With trend	Without trend
99	122.74	High-low volatility	-84.5655***	-78.9300***
99	122.73	Logarithm of realized volatility	-29.2548***	-31.0323***
99	122.55	Logarithm of standard deviation of fifteen-minute mid-quote prices	-75.6872 ***	-64.8614***
99	122.74	Logarithm of Volume	-50.5913***	-42.7786***
99	122.74	Logarithm of traded value weighted relative effective spreads	-43.4631***	-39.7691***
99	122.74	Logarithm of traded value weighted effective spreads	-78.2894***	-75.3358***
99	122.54	Logarithm of time weighted quoted spreads	-80.5986***	-72.0409***
99	122.54	Logarithm of time weighted relative quoted spreads	-52.7918***	-45.7925***
99	122.74	Logarithm of total depth value	-48.8805***	-40.2526***
99	122.74	Logarithm of best depth value	-59.2071***	-41.2434***
99	122.74	Logarithm of trade size	-69.2538***	-60.8810***
99	122.74	Logarithm of market capitalization	-5.5449***	-9.0776***
99	122.74	Logarithm of relative tick size	-50.7876***	-46.3972***
99	122.74	Relative tick size	-53.8848***	-46.2257***

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