

Introduction

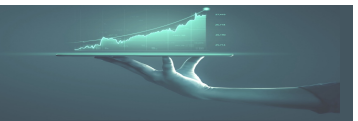
Japan Exchange Group (JPX), the parent company of the Tokyo Stock Exchange (TSE) implemented a significant upgrade to its electronic trading system on November 5th 2024, known as Arrowhead 4.0. Key changes, and the changes that this report will focus on, included extending the continuous trading hours and introducing a closing auction session.

At ExeQution Analytics we strive to transform data into insights, so using data provided by ICE Fixed Income and Data Services, we have ingested two months of tick data covering the period from October 5th to December 5th 2024. Our goal is to review and better understand the impact of these changes on trading behaviour.

Key objectives stated by the exchange were to maximize trading opportunities for investors, to improve the transparency of closing price formation, and to strengthen the price discovery functionality of Japan's stock market.

This report will evaluate the introduction of the closing auction session by measuring both the volatility and predictability of the closing auction price and volume. We note an increase in volatility between the continuous and auction periods, but a reduction in both the proportion of stocks exhibiting T+1 reversion and the extent of reversion, suggesting an improvement in price stability. Our analysis suggests that participants have greater confidence in executing in the closing auction, reducing the need for aggressive trading before the close and improving the predictability of the closing auction volume.

We study liquidity across both the continuous and auction periods and dive deep into the market microstructure characteristics to identify any changes in spread, order types or market depth during the extended hours. We conclude that trading participants were slow to change their behaviour following the extension of the trading hours - the intraday pattern of volume distribution remains largely unchanged - but this will likely adapt further as algorithmic trading strategies react to historical data.



What Did The Change Involve?

The Arrowhead 4.0 release was the first by the exchange since 2019 and covered a number of enhancements and improvements including technology upgrades to handle higher trading volumes with reduced latency, enhanced capabilities for disseminating real time data and refinements to circuit breaker mechanisms. This report will focus on the trading hours extension and the introduction of the closing auction session.

Before the upgrade, the exchange operated from 09:00 to 15:00 with a lunchbreak from 11:30 to 12:30. From November 5th, the continuous trading session (also known as Zaraba) has been extended for a further 25 minutes to finish at 15:25. This is now followed by a 5-minute order acceptance period followed by the Itayose closing auction at 15:30.

To increase the opportunities for closing price formation, the exchange introduced a new mechanism known as 'Special Execution' to determine the closing price. This mechanism is designed to increase the completion rate of orders when the predicted close price of a stock is trading at the upper or lower limits of the executable price range.

Focus of Analysis

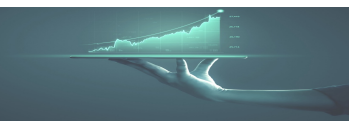
There are 4200 stocks trading on TSE. On an average day in October and November 2024, the TOPIX 100 universe accounts for 50% of total traded value across the entire exchange. The TOPIX 500 accounts for 80% of all trading and the top 1000 names (in terms of traded value) account for 97% of all activity.

Our analysis will focus on these liquidity groupings over a 2-month period from October 5th to December 5th to measure the success of the objectives as stated by the exchange : firstly, the efficiency of intraday price discovery and secondly the transparency and volatility of closing price formation and associated volume.

We are cognisant that this date-range includes some dates of significance including :

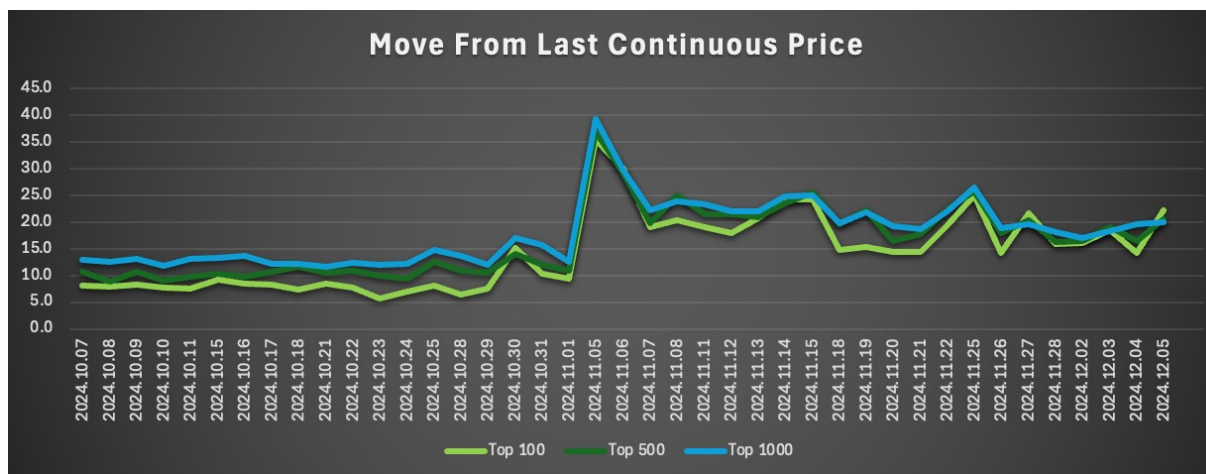
- October 30th : TOPIX rebalance
- November 5th : The day of the change coincided with the date of the US election
- November 25th : MSCI rebalance

Unless otherwise stated, these event dates are excluded from any averages represented in tables and figures to avoid skewing the conclusions of this report.



Closing Auction Price Formation

We start with an evaluation of the efficacy of the closing auction price formation by measuring how much the close prices move from the continuous session. Figure 1 shows a comparison between the basis point move from last continuous traded price across the period before and after the closing auction session was introduced.



Data Source: ICE Fixed Income & Data Services

Figure 1 : Basis Point Move Between Last Continuous Price And Close

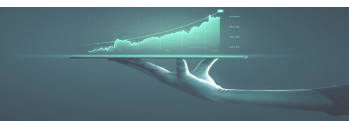
The chart shows a clear spike on the day of the change, which quickly reverts but it remains at a level that is much higher than the previous average move. Intuitively, this makes sense, as participants have more time to react in the newly introduced closing auction session - where previously the auction book overlapped with the continuous session, since November 5th, there is a dedicated 5-minute window for participants to enter closing auction orders.

What is potentially less intuitive, is that the relative impact of the introduction of the closing auction session appears to be most pronounced for the top 100 most liquid names. To verify this, we pull out the average move for each liquidity grouping, excluding the index rebalance and the date of the introduction itself and compare the ratio of the average moves before and after the change. The results are displayed in Table 1.

Liquidity Grouping	Before	After	Ratio
Top 100	8.2	19.6	238%
Top 500	10.6	21.4	201%
Top 1000	12.9	22.1	171%

Data Source: ICE Fixed Income & Data Services

Table 1 : Average Moves From Last Continuous Price



Closing Auction Price Formation

While this heightened volatility may initially seem at odds with the exchange’s objectives, we hesitate to attribute it solely to the market structure change, given the broader rise in global volatility at the time.

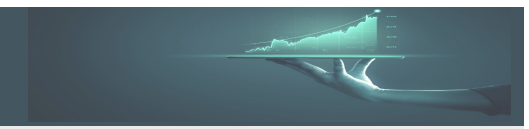
To better understand the shift from the last continuous price and the impact of the dedicated closing auction session, we compare the move from last continuous price to two alternative metrics : the difference between the closing price and the VWAP over the final 1-minute and 5-minute intervals of continuous trading. Figure 2 presents these calculations across each of our liquidity groupings and includes the overnight move, calculated as the basis point movement between the closing price and the next day open.

Following the introduction of the closing auction, price movements increase across all three metrics and liquidity segments. However, the relative increase between the moves from VWAP are noticeably smaller. This prompts us to explore volatility and other intraday orderbook metrics to further understand how the introduction of the closing auction session impacts the end of continuous trading.

Examining overnight price movements provides further context on the closing auction price formation. While this overnight move is significantly larger than any intraday movement, it is notably lower for the most liquid stocks post-upgrade compared to the earlier period. This observation leads us to explore T+1 reversion. A reduction in the number of stocks exhibiting reversion or a decrease in the extent of reversion could indicate that the enhanced closing auction mechanism has contributed to a more stable and robust price formation process.



Data Source: ICE Fixed Income & Data Services
Figure 2 : Basis Point Moves Around The Close Price



Intraday Volatility & Trade Metrics

Figure 3 shows the change in volatility during the trading day for the 1000 most liquid names on the exchange before and after the event where volatility is measured as the basis point move between the minimum and maximum price in 5-minute bins throughout the day.

The volatility profile remains consistent before and after the event, with increased volatility when the market first opens and reacts to overnight news, decreasing throughout the day with a second peak at the start of the afternoon session and increasing again towards the end of the day.

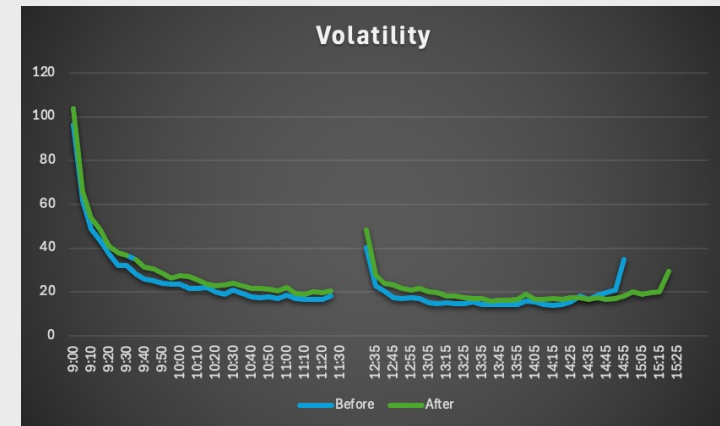
Whilst volatility is on average marginally higher throughout the continuous session after the change, this was true across most venues in November 2024 due to the US election results, so we cannot attribute this to the event itself. What we find interesting about Figure 3 is that although overall volatility is higher throughout the day, the volatility in the last five minutes of the extended trading session is less than that of the five minutes prior to the extension.

Figure 4 charts the average trade size (excluding auction trades) throughout the day. Before the extension of trading hours, we expected the average trade size to increase towards the end of the day as participants prioritise completion of their orders but as highlighted in Table 2, this no longer occurs with the introduction of a dedicated closing auction session.

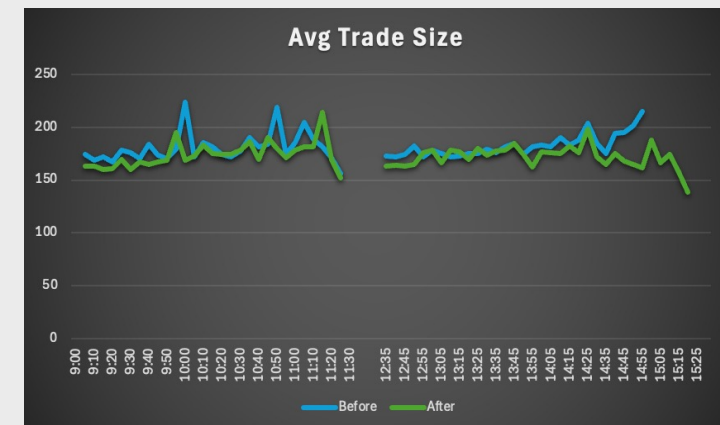
Top 1000 Stocks	Before	After	Decrease
Average Trade Size	215.8	138.3	36%

Data Source: ICE Fixed Income & Data Services
Table 2 : Average Trade Sizes in the Last 5 Minutes of Continuous Trading

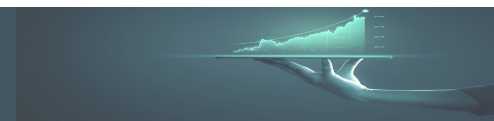
The combination of these features suggest that participants have greater confidence in executing in the closing auction, reducing the need for aggressive trading before the close.



Data Source: ICE Fixed Income & Data Services
Figure 3 : Volatility Profiles for the 1000 most liquid stocks



Data Source: ICE Fixed Income & Data Services
Figure 4 : Trade Size Profiles for the 1000 most liquid stocks



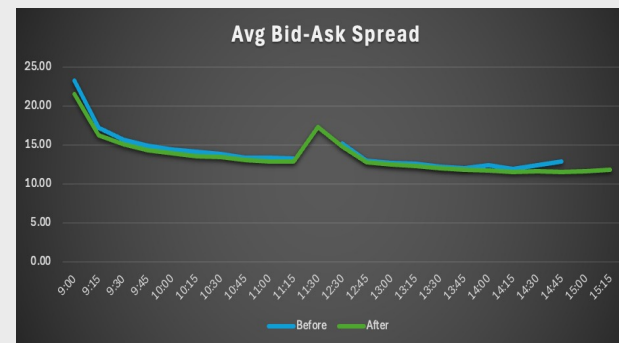
Intraday Orderbook Metrics

As is widely documented, many orderbook metrics follow consistent intraday patterns. To explore the impact of the extra 25 minutes of continuous trading on these dynamics, we focus on three metrics that capture a broad view of orderbook activity and chart their behaviour in 15-minute intervals for the top 1,000 stocks trading on the exchange.

Figure 5 illustrates the average bid-ask spread in basis points, a widely used proxy for execution costs. As expected, spreads are widest at the start of the trading day and gradually narrow as liquidity improves. The familiar midday spike around the lunchbreak remains, mirroring the volatility trends observed in Figure 3.

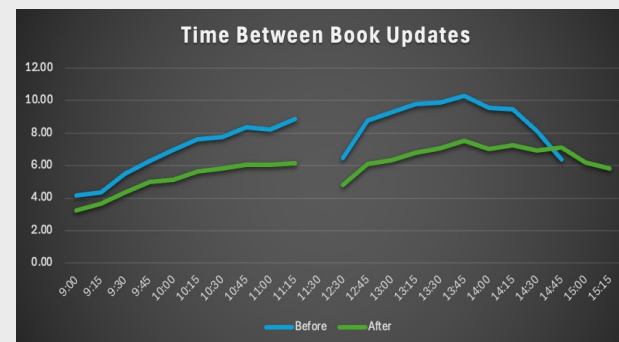
Figure 6 displays the average time (in seconds) between updates triggered by changes in the bid or offer price – an indicator of orderbook stability and market speed. Given the observed increase in volatility post November 5th, it is unsurprising that the average time between book updates has decreased, reflecting a more reactive market. While the overall intraday pattern remains largely unchanged, the acceleration of updates into the close appears less pronounced after the trading hours extension.

Figure 7 presents the average number of shares available on either side of the orderbook. To enable a more representative comparison across stocks and time periods, we normalise the number of shares by the trade size within each 15-minute interval (excluding auction trades). While the ratio of book volume to traded volume has decreased following the trading hours extension, the overall intraday pattern remains consistent with pre-change behaviour.



Data Source: ICE Fixed Income & Data Services

Figure 5 : Average Intraday Spread - 1000 most liquid stocks



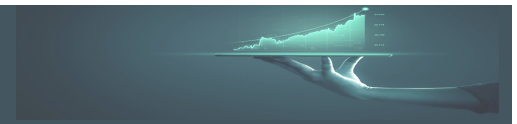
Data Source: ICE Fixed Income & Data Services

Figure 6 : Frequency of Book Updates - 1000 most liquid stocks



Data Source: ICE Fixed Income & Data Services

Figure 7 : Ratio of Bid Offer Volumes - 1000 most liquid stocks



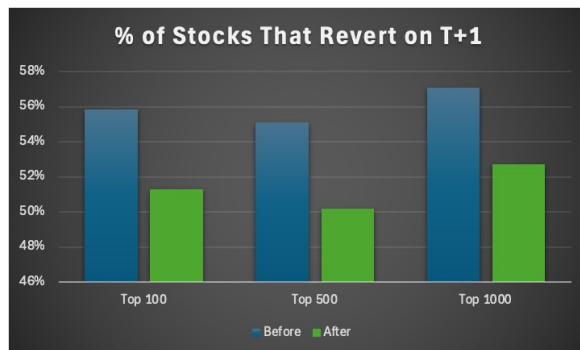
Measuring T+1 Reversion

The concept of T+1 reversion refers to the idea that price movements observed in a stock on a trading day (T) tend to reverse direction on the day following the move (T+1). Reversion is often used as a measure of the efficacy of a price formation process – if stocks exhibit less “correction “ on the day following a movement, participants can have more confidence that the original move more accurately represents the fundamental value of the stock.

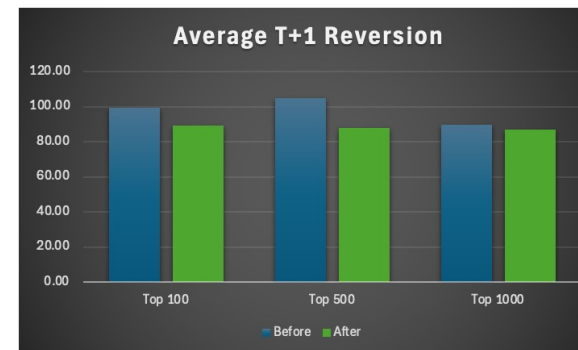
For the purpose of this report, we will define reversion quite simply : we compare the direction of the move between the last continuous price and the close price to the direction of the move between the close price and the next day open price. If the moves are in opposite directions, we will consider that an example of reversion.

Figure 8 shows the proportion of stocks that exhibit reversion characteristics before and after the introduction of the closing auction session and highlights a clear decrease in the number of stocks that revert across each of our liquidity groupings.

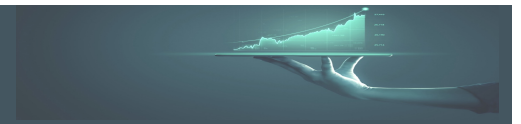
Figure 9 highlights the average overnight move for stocks that exhibit T+1 reversion and demonstrates that not only have the proportion of stocks exhibiting T+1 reversion reduced, the extent of that reversion has also decreased. These combined features suggest greater price stability and efficiency of the closing auction mechanism.



Data Source: ICE Fixed Income & Data Services
Figure 8 : Percentage of Stocks Exhibiting T+1 Reversion



Data Source: ICE Fixed Income & Data Services
Figure 9 : Average Overnight Move (bps) : Stocks Exhibiting T+1 Reversion



T+1 Reversion : Large Price Moves

To further interrogate the characteristics of stocks that revert, we will focus on stocks that exhibit a large price move between the end of the continuous session and the closing auction. We define a large move as a move that exceeds 2% (or 200 basis points) between last continuous price and the closing price. This is a relatively rare occurrence as Table 3 shows. In our date-range, it does not occur across the most liquid 100 stocks on the exchange, who typically exhibit more stable price characteristics than less liquid stocks. Over the full exchange, it impacts on average 20-40 stocks per date (excluding special dates like index rebalance dates) or 0.5 – 1% of all stocks across the full exchange.

Move > 200 bps	Top 500	Top 1000	Full Exch
Before	0.19%	0.18%	0.71%
After	0.25%	0.27%	1.00%

Data Source: ICE Fixed Income & Data Services

Table 3 : Percentage of Stocks With Large Price Moves Between Last Cns & Close

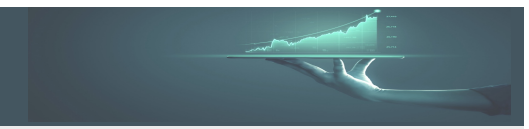
Figure 9 (previous page) displayed the average reversion across all stocks (between 50 – 56% depending on the liquidity grouping). We expect the stocks that experience large moves to have higher rates of reversion on the following day and this holds true before and after the introduction of the closing auction. Table 4 shows the proportion of large-move events that exhibit reversion and the extent of that reversion on T+1. There is a slight reduction in the number of stocks exhibiting reversion, but the most dramatic change is the extent of the reversion which is less than 50% of the value before the event.

Date-Range	% of Stocks that Revert	Avg Move of Stocks That Revert
Before	82%	361.13
After	75%	150.84

Data Source: ICE Fixed Income & Data Services

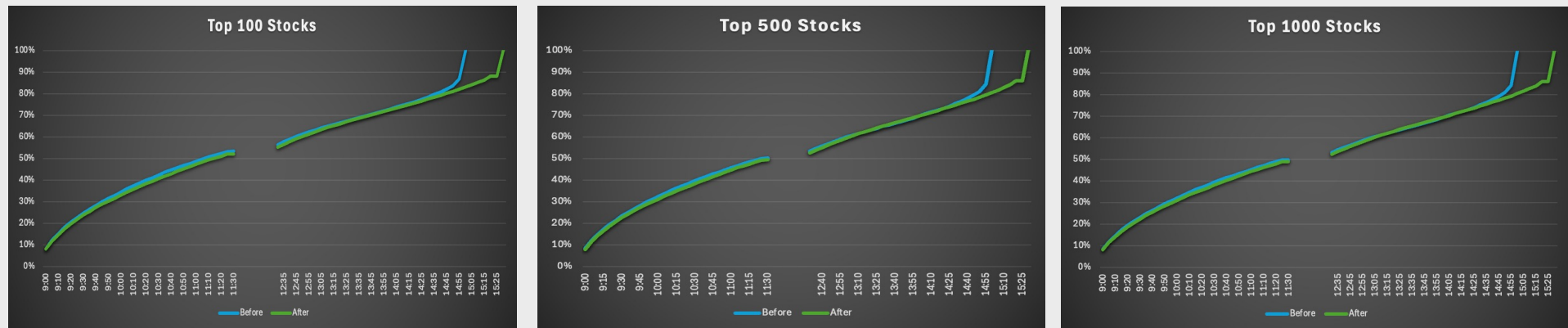
Table 4 : Reversion Characteristics of Stocks With Large Price Moves Between Last Cns & Close

These results suggest that the introduction of the closing auction session had an immediate impact on the stability of the price formation process for the stocks that experience extreme price movements with a significant reduction in reversion.



Distribution of Intraday Volume

Finally, we look into how volumes are impacted by looking at both intraday volume (across each classification grouping) and the predictability of the closing auction volume. Figure 1 displays the average volume distribution for each grouping before and after the November 5th change. We can see that not only is the distribution of intraday volume remarkably similar regardless of the liquidity classification, the impact of the change is localised to the last hour of the afternoon session.



Data Source: ICE Fixed Income & Data Services

Figure 10 : Distribution of Intraday Traded Volumes Across Varying Liquidity Classifications

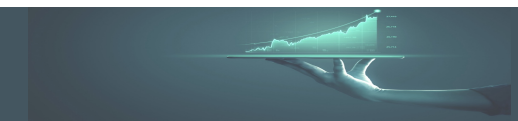
If we snapshot the proportion of volume traded by 14:00 before and after the change, it is largely unchanged by the extension of trading hours. The proportion of volume that trades after 14:00 has stayed the same, but it is now distributed across 90 minutes instead of across 60 minutes with a lower proportion trading in the closing auction. This suggests participants are slow to change to the new trading hours.

% Of Volume Traded by 14:00	Top 100	Top 500	Top 1000
Before	72.7%	69.7%	69.5%
After	73.0%	69.8%	69.6%

Data Source: ICE Fixed Income & Data Services
Table 5 : Snapshot of Accumulated % Volume Traded by 14:00

% Volume Traded in Closing Auction	Top 100	Top 500	Top 1000
Before	13.2%	15.6%	15.7%
After	11.8%	14.0%	14.0%

Data Source: ICE Fixed Income & Data Services
Table 6 : % Volume Traded in Closing Auction

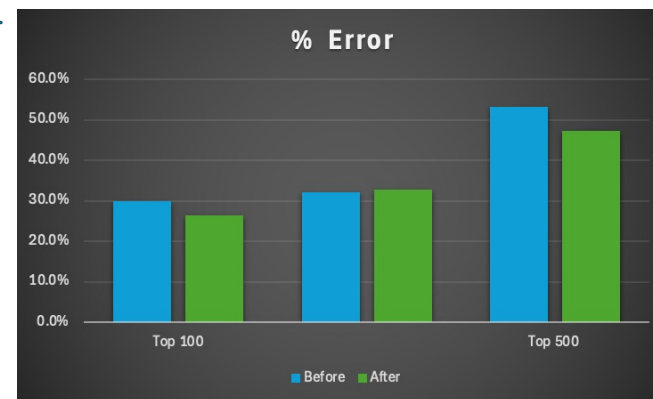


Closing Auction Volumes

The closing auction is one of the most significant volume events of the trading day and being able to accurately estimate the predicted closing auction volume is critical to a range of trading strategies. By improving their prediction of the closing auction volume, trading participants can plan order execution to better manage market impact and slippage. Many brokers invest significant effort in predictive models, but we will use a simple estimate to determine whether the closing auction volume has become easier to predict following the introduction of the new closing auction session.

Method : Calculate the rolling 5-day historical average percentage closing auction volume and apply it to the intraday volume on T to predict the close volume on T

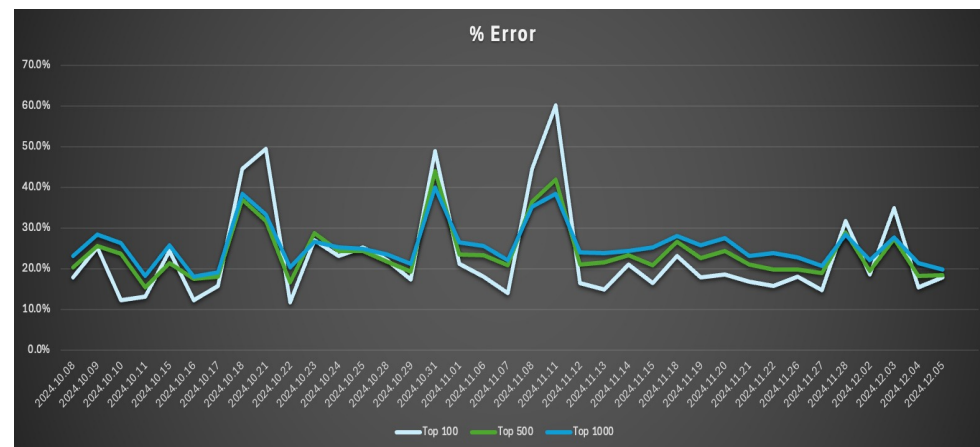
We measure the percentage error by comparing our prediction to the actual closing auction volume on the day. Figure 11 presents the average percentage error across each liquidity grouping. On average, the prediction error appears to be slightly decreased after the introduction of the closing auction session.



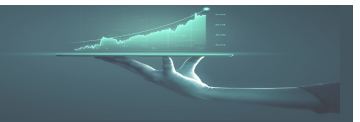
Data Source: ICE Fixed Income & Data Services
Figure 11 : Percentage Error of Close Volume Prediction

Figure 12 charts the daily average percentage error for each group of stocks. Although we're excluding the index rebalance dates from our dataset, it's clear to see the impact of these events is not limited to just the date of the rebalance.

We have three distinct peaks in the graph where the closing auction did not match predictions. These three peaks correlate with external events : the first coincides with the date of a speech from the chief of Bank of Japan, the second is the TOPIX rebalance date, and the third and largest peak is directly after the closing auction session is introduced. This settles down quickly and the MSCI rebalance has much less impact on the predictability of volume in the closing auction.



Data Source: ICE Fixed Income & Data Services
Figure 12 : Percentage Error of Close Volume Prediction By Date



Closing Auction – Special Execution

The changes on November 5th also included the introduction of a special execution method in the closing auction. Traditionally, during the closing auction, orders are matched within a predefined executable price range – the close price must lie within a range of the last continuous price which is twice the renewal price interval. The renewal price limit table is published by TSE, quoted in yen and is directly proportional to the trading price of each stock.

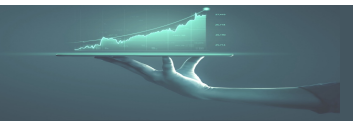
The Special Execution method addresses stocks which do not meet the standard matching conditions in the closing auction session, by allowing executions at the upper or lower limits of this price range when standard conditions are not met. The priority of orders in the special execution is determined based on the time at which orders were placed, regardless of price or execution conditions. This approach is intended to ensure that more orders are executed during the closing auction.

Table 7 presents a summary of the stocks hitting the upper or lower limits of this price range in the 20 days before and after the introduction of the Special Execution. Having already noted an increase in volatility, it is unsurprising to also note an increase in the frequency of stocks hitting these limits in the closing auction session. We calculate the closing auction volume as a percentage of total daily volume to enable a better comparison across stocks and can observe a consistent increase in the volume of orders executed for stocks hitting renewal price limits.

Date-Range	Frequency	% Closing Auction Volume
Before	43	15%
After	67	19%

Data Source: ICE Fixed Income & Data Services

Table 7 : Stocks Hitting Renewal Price Limits in Close Auction



Conclusions

The ArrowHead 4.0 upgrade on November 5th has had several notable impacts on market microstructure, providing valuable insights into trading behaviour and market efficiency.

While volatility has increased post-implementation, this appears to be driven by external geo-political factors rather than the structural changes introduced by JPX. Therefore, attributing the observed volatility changes directly to the exchange's adjustments would be premature.

We observed an increase in the price differential between the end of the continuous trading period and the closing auction and believe this is likely correlated with the general increase in volatility. The reduction in both the proportion of stocks exhibiting T+1 reversion and the extent of reversion suggests that price stability may have been improved by the introduction of the closing auction session.

There are some signs that the closing auction has become easier to predict, a trend which we expect to continue as models react to historical data, which is beneficial for institutional investors and passive funds that rely heavily on end-of-day price formation. This improvement may indicate enhanced transparency or better alignment of participant expectations in the auction process.

In terms of volume distribution, the intraday pattern remains largely unchanged at the start of the day. However, the extension of trading hours from 15:00 to 15:30 has redistributed activity within this period, with a slightly reduced proportion of volume occurring in the closing auction. This redistribution could reflect a natural adjustment by market participants to the extended trading session and its impact on liquidity timing.

We analysed the intraday patterns of several metrics including spread, volatility, frequency of book updates and the ratio of bid-offer volume to traded volume. Whilst patterns remained largely unchanged by this event, we noted a decrease in spread, an increase in market speed and a slower rate of acceleration in orderbook activity over the extended continuous trading time. An observed reduction in volatility in the final five minutes combined with a decrease in average trade sizes in this window suggest that participants have greater confidence in executing in the closing auction, reducing the need for aggressive trading before the close.

Overall, while the changes have produced some measurable shifts in market dynamics on the day of the release, particularly around the closing auction and price stability, the results suggest that the new structure is being absorbed by market participants without significant disruption to intraday trading behaviour.

EXEQUTION

Analytics



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