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The Impact of Dark Pools on the Market and Market Quality

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Abstract (Summary)

Dark pools are services that developed primarily for institutional investors seeking to trade without revealing their trading intentions or to access liquidity outside lit venues. Meanwhile, dark pool execution services aimed at improving prices for retail investors, primarily through online brokerages, have also been expanding. Amid these developments, the share of trading value in dark pools for stock transactions and other activities has also gradually increased, and the potential for trading in dark pools to impact the overall market is growing.

This paper analyzes the use of dark pools based on their trading value ratio relative to the regular lit trading session (on-auction) of the Tokyo Stock Exchange, the impact of dark pool trading on market quality, and factors influencing execution prices and price improvement rates within dark pools.

We found that the dark pool ratio tends to decrease under conditions of high market volatility. Although the use of dark pools by individual investors is on the rise, institutional investors are still considered the primary users of dark pools at present. In highly volatile environments, the dark pool ratio is expected to decline as market participants refrain from using dark pools to avoid delays and related costs.

The impact of trading in dark pools on market quality varies depending on market conditions. At the current level of dark pool trading value share, we find that the impact of dark pool trading on market quality differs between low- and high-volatility environments.

We also find that both execution prices and price improvement rates in dark pools are influenced by order book conditions in the Tokyo Stock Exchange's on-auction market (micro-prices considering depth). Proprietary-execution in dark pools tends to have relatively poor price improvement rates. In particular, execution probability for proprietary trades increases when depth is high on the proprietary side and market volatility is low. However, because executions occur at prices that incorporate micro-price movements, the observed price improvement rates for proprietary trades tend to deteriorate.

† Senior Manager, Equities Department, Tokyo Stock Exchange, Inc., Chartered Financial Analyst. The content and opinions expressed in this paper belong solely to the author and do not represent the official views of the Japan Exchange Group, Inc., Tokyo Stock Exchange, Inc., or any other organization with which the author is affiliated. Furthermore, any errors that may exist are solely attributable to the author.

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1 Introduction

In Japan, the primary execution venues for stocks, etc. broadly include stock exchanges, proprietary trading systems (PTS), dark pools, and over-the-counter (OTC) trading. This paper focuses on analyzing dark pools. As the name implies, dark pools do not broadcast order book (bid–ask) information, meaning investors cannot grasp the status of orders placed within the dark pool. On the other hand, since investor orders are invisible to others, there are also benefits such as the concealment of trading intentions.

While the primary traders in dark pools are considered to be institutional investors, securities firms and others have recently begun offering Smart Order Routing (SOR) services to retail investors. Consequently, the number of cases where retail investor orders are executed in dark pools is also on the rise. Under these circumstances, trading value in dark pools increased approximately threefold, from around 100 billion yen per day in August 2020 to around 300 billion yen per day in October 2024[1].

Furthermore, in terms of market share of transaction volume in the Japanese market, it has risen from 2% in August 2020 to over 4% in October 2024[2], indicating a growing impact.

This paper analyzes the impact of dark pool trading on market quality and how execution prices are determined in dark pools, using data from the period after August 2020 when dark pool flags began to be assigned, enabling the identification of dark pool transactions. Since the impact may vary depending on market conditions, separate analyses are conducted for periods of high market volatility and periods of low volatility.

First, in Section 2, we will outline dark pools and discuss the situation following the introduction of the dark pool flag. Section 3 reviews prior research, and Section 4 details the analysis content. Section 5 presents the analysis results, and Section 6 concludes the discussion.

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[1] In November 2025, the level exceeded 600 billion yen per day.

[2] In November 2025, it was just under 6%.

2 Dark Pool Overview

2.1 What is a Dark Pool?

A dark pool is a system where a securities firm matches orders entrusted by clients (investors) not with exchange-traded orders, but with its own proprietary orders or with other client orders, executing trades without disclosing order book (bid–ask) information. As the name implies, this information is not publicly displayed. In contrast to a dark pool, a market where order book (bid–ask) information is publicly disclosed, like an exchange, is sometimes called a lit pool.

Dark pools are characterized by the non-disclosure of order book (bid–ask) information, meaning transactions within them rely on the trust relationship between customers and the dark pool operator. With order book (bid–ask) information not publicly disclosed, transaction prices in dark pools were determined based on rules set by the dark pool operator. However, it was difficult for customers to verify the fairness and appropriateness of those transaction prices on a case-by-case basis.

However, based on discussions held by the Financial System Council's "Market Working Group" in February and June 2019, the "Cabinet Office Order on Financial Instruments Business, etc." and the "Comprehensive Guidelines for Supervision of Financial Instruments Business Operators, etc." were amended on June 19, 2020, and the situation is also changing. The amendments include: (a) Explanation of dark pool routing conditions and operational information from a customer protection perspective[3]; (b) Recording and retention of information to ensure the effectiveness of price improvement[4]; and (c) Explanation of price improvement effects to customers. These legal revisions aim to enhance the transparency of dark pool trading.

Furthermore, based on discussions at the Financial System Council held in 2019, exchanges have amended their regulations effective August 2020. This amendment includes requiring trading participants to assign a dark pool flag when placing orders in the ToSTNeT (Tokyo Stock Exchange Trading NeTwork System) market via a dark pool, among other changes[5], to enhance transparency in dark pools.

2.1.1 Advantages of Using Dark Pools

The benefits for investors using dark pools include (1) concealing trading intentions (reducing market impact), (2) improving transaction prices, and (3) accessing liquidity.

For institutional investors handling large order quantities, exposing their own orders on an exchange's order book can move stock prices in a direction unfavorable to them. This leads to high execution costs, ultimately negatively impacting investment performance and other outcomes. Therefore, executing orders in dark pools where order book (bid–ask) information is not publicly disclosed is considered highly advantageous, as it allows them to conceal their trading intentions while also minimizing market impact.

Regarding (2) the improvement in transaction prices, as discussed later, most transactions in dark pools are executed within the BBO (Best Bid and Offer) of each security's primary market[6], with a significant portion settling at the midpoint. As will be explained later, in Japan, approximately 60% of transactions by value settle at the midpoint.

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[3] The amended Cabinet Office Order and Guidelines for Supervision of Financial Instruments Business Operators, etc. took effect on September 1, 2020, with point (a) applying from the same date.

[4] Points (b) and (c) applied from September 1, 2021.

[5] For an overview of these regulatory amendments, refer to the JPX website (https://www.jpx.co.jp/rules-participants/rules/revise/nlsgeu000004r93w-att/gaiyoTSE.pdf). Concerns regarding user protection and market fairness in margin trading via dark pools were raised at the Financial System Council. Consequently, clarification of the types of transactions permitted for margin trading in the ToSTNeT market (including prohibitions on margin trading via dark pools, etc.) was also implemented at the same time.

[6] In Japan's dark pools, there are no specific stipulations regarding which market is designated as the primary market; this is determined by the dark pool operator. Generally, it is considered that the Tokyo Stock Exchange's regular trading session (on-auction), which has the highest liquidity (the most trading activity), is often the primary market.

One advantage of accessing liquidity mentioned in (3) is the ability to access liquidity that does not appear on exchanges such as lit pool or PTS. While lit pools are accessible to investors with various attributes, dark pools are provided by securities firms, making them accessible only to specific investors who trade with those firms[7]. This restricted access to specific investors means some investors place large orders exclusively in dark pools. Consequently, some investors find advantage in accessing liquidity that is difficult for general investors to reach.

2.1.2 Disadvantages of Using Dark Pools

The disadvantages for investors using dark pools include (1) uncertainty in trade execution and (2) the potential leakage of trading intentions. Uncertainty in trade execution refers to the fact that it is uncertain whether orders placed by investors in dark pools will be executed according to their intentions. Unlike lit pools, dark pools are characterized by non-publication of order book information. Consequently, investors cannot view the order book within a dark pool and must trade while harboring uncertainty about the price and volume at which their orders will execute, or whether the trade will execute at all. Executing orders placed in dark pools may take longer than anticipated, potentially causing prices to move unfavorably during that time and incurring transaction costs (delay costs).

Regarding the potential leakage of trading intent in (2), while the advantage of using dark pools includes concealing trading intent, and it may seem that trading intent would not be leaked due to the non-publication of quotes, many dark pools rely on the small-sized liquidity supplied by HST[8]. Therefore, during the process of executing trades within dark pools, HST may detect the existence of large orders placed by investors using dark pools.

2.2 Characteristics of Dark Pools in Japan

2.2.1 Definition of Dark Pools

While other countries define dark pools as a distinct market type[9], focusing on the characteristics of dark pools as markets and the characteristics of transactions conducted within them, Japan does not directly define dark pools as markets. Instead, they are categorized as one type of operation conducted by securities firms.

Section IV-4-2-1(1) A of the Comprehensive Guidelines for Supervision of Financial Instruments Business Operators, etc., which stipulates points to note regarding approvals for PTS operations at securities firms[10], contains the following description:

> A. A system acting as an agent for transactions involving securities in the financial instruments exchange markets or the over-the-counter (OTC) securities markets, or acting as an agent for transactions involving securities for another Financial Instruments Business Operator shall not fall under the category of the PTS or financial instruments exchange market, etc.

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[7] Primarily online brokerages offer SOR (Smart Order Routing) functionality to retail investors and others as one of the services to execute trades at better prices; since dark pools may also be included in the execution markets, access by retail investors and others is gradually increasing.

[8] Abbreviation for High Speed-Trading. Also referred to as High Frequency Trading. In Japan, registration as a high-speed trader has been required since April 2018 to conduct high-speed trading activities.

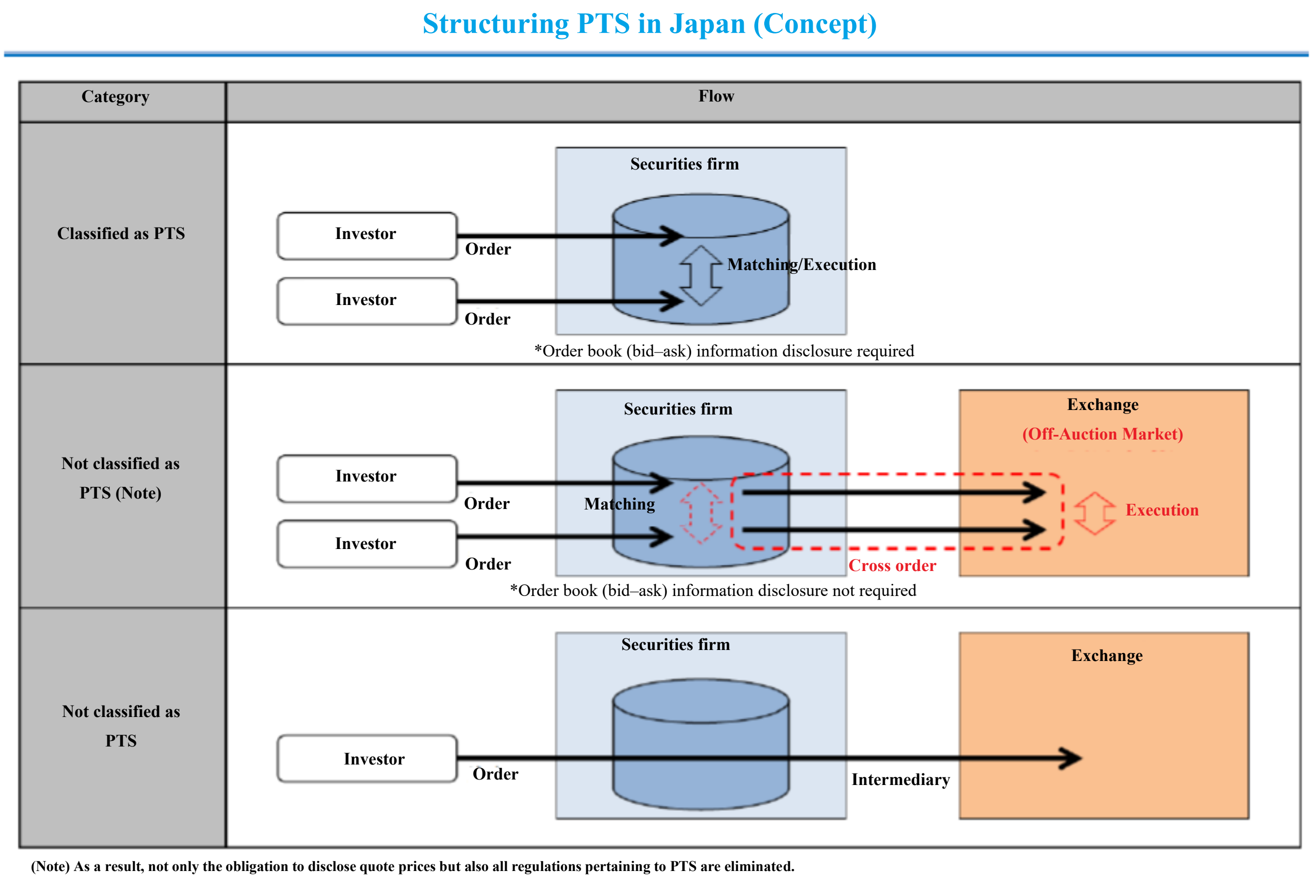
[9] For example, in the United States, dark pools are defined as a type of ATS (Alternative Trading Systems), and are subject to the regulations required for markets. In Australia, they are called Crossing Systems, and in Hong Kong, Alternative Liquidity Pools (ALPs). Each definition focuses on the market characteristics of dark pools. In Europe, while ensuring pre-trade transparency is the principle, exemptions are established based on transaction characteristics, and markets handling transactions that fall under these exemptions are generally referred to as dark pools.

[10] Securities firms (financial instruments business operators) are subject to a registration system. However, when a securities firm conducts PTS operations (Article 2, Paragraph 8, Item 10 of the Financial Instruments and Exchange Act), it must obtain approval from the Prime Minister (Article 30 of the Financial Instruments and Exchange Act).

(Note) For example, if the brokerage service is one prescribed in Article 70-2(7) of the FIB Cabinet Office Ordinance[11] that is provided by using a system that conducts determination of a price or any other transaction conditions or an act similar thereto prescribed in the same paragraph, the system shall, basically, not fall under the category of the PTS or financial instruments exchange markets, etc. On the other hand, even in the case of such brokerage service, if orders are integrated, offset or otherwise combined within the system, the system may fall under the category of the PTS or financial instruments exchange markets, etc.

In Japan, the first part of the above note, "For example, if the brokerage service is one prescribed in Article 70-2(7) of the FIB Cabinet Office Ordinance that is provided by using a system that conducts determination of a price or any other transaction conditions or an act similar thereto prescribed in the same paragraph" is recognized as a dark pool. Specifically, a dark pool is defined as a system within a securities firm that matches customer orders internally, with the actual execution taking place in an Off-auction trading facility operated by an exchange. (e.g., the ToSTNeT market on the Tokyo Stock Exchange[12]).

[11] The operational control systems to be established by financial instruments business operators, etc. (limited to an operator conducting the purchase and sale of securities or market derivatives transactions on the financial instruments exchange market (limited to those conducted outside the trading session or through off-floor trading as prescribed in the operational rules of a financial instruments exchange operating the financial instruments exchange market) or a brokerage service for the entrustment of those transactions (excluding brokerage for the clearing of securities, etc.) in the course of trade by using an intra-company transaction system (meaning a system under which the financial instruments business operators, etc. or any other person determines the price of the purchase and sale of securities or market derivatives transactions or other transaction conditions or conducts similar acts by using electronic data processing systems with many persons as the other party or each party simultaneously, but excluding the proprietary trading system prescribed in Article 26-2-2, paragraph (7) of the Order; the same applies hereinafter in this paragraph and Article 158, paragraph (5))) pursuant to Article 35-3 of the Act must meet the following requirements, in addition to the requirements under paragraph (1):
(1) measures are taken to understand the operation status of the intra-company transaction system that the financial instruments business operator, etc. uses (excluding the system established by the financial instruments business operator, etc.); and
(2) measures are taken to provide appropriate explanation to customers concerning the intra-company transaction system that the financial instruments business operator, etc. uses on the following matters, in light of the customers' knowledge, experience, conditions of property, and purpose of conducting the purchase and sale of securities or market derivatives transactions:
(a) conditions in the case of using the intra-company transaction system; and
(b) a person establishing the intra-company transaction system, a person who can participate in making decisions on transaction conditions, methods of making decisions on transaction conditions, and other information related to operation of the intra-company transaction system.
[12] The Financial System Council's "Market System Working Group" stated in its second interim report: "While off-auction trading on the exchange (e.g., ToSTNeT) is exempt from the TOB 5% rule, similar PTS trading is subject to the TOB 5% rule. PTS trading that is similar to off-auction trading on the exchange should also be exempt from the TOB 5% rule, based on its similarity to off-auction trading on the exchange." It is stated. Based on this second interim summary, the amendment to Article 70-2, Paragraph 7 of the Cabinet Office Ordinance on Securities Business, etc. (adding PTSs similar to exchange-off-auction transactions as intermediaries for internal transaction systems, in addition to exchange-off-auction markets). This amendment took effect on December 1, 2024.



(Source) Excerpt from the secretariat's explanatory materials for the Financial System Council's "Market Working Group" (2nd meeting)

Figure 2.2.1 Overview of Dark Pools in Japan[13]

2.2.2 Off-auction market

As described earlier, transactions executed through matching orders in dark pools must be conducted in the off-auction market, and the trade data (execution details) is published as part of the off-auction trading on the exchange. Prior to August 16, 2020, it was difficult to accurately identify dark pool transactions included in off-auction trading because they were not assigned a dark pool flag. However, since August 17, 2020, dark pool flags have been assigned, enabling the identification of dark pool transactions included in exchange over-the-counter transactions.

Off-auction trading on the exchange is categorized by trading type. For example, the Tokyo Stock Exchange has (1) single-stock transactions[14], (2) basket transactions[15], (3) closing price transactions[16], and (4) off-auction own share repurchase transactions[17]. Among these, single-stock transactions (ToSTNeT-1) are used for dark pool executions.

[13] The category "Not classified as PTS" in the middle part of the figure corresponds to dark pools in Japan.

[14] Single-stock transactions also include guaranteed VWAP executions and VWAP target executions based on VWAP (Volume Weighted Average Price), in addition to transactions based on the most recent execution price.

[15] Basket transactions are used when executing transactions for multiple stocks (15 or more stocks with a total trading value of 100 million yen or more), such as index constituents, in a single batch.

[16] Closing price transactions are used when executing transactions at specific point-in-time prices, such as the previous day's closing price, the morning session closing price, or the afternoon session closing price.

[17] Off-auction own share repurchase transactions are used for pre-announced share repurchases by listed companies. Additionally, there exists a transaction called an over-the-counter block sale, which is the opposite of an over-the-counter buyback transaction. However, under Tokyo Stock Exchange rules, block sales are not classified as ToSTNeT transactions. Off-auction share distributions are classified as transactions conducted outside regular trading sessions, and transactions conducted outside regular trading sessions constitute a broader category that also includes ToSTNeT trading (ToSTNeT trading ⊆ trading conducted outside regular trading sessions).

While other ToSTNeT trading types are, in principle, available for dark pool transactions, in practice, from the perspectives of trading methods, trading hours, and pricing, the available trading method is limited to single-stock transaction[18].

Table 2.2.1 ToSTNeT Market Overview

	ToSTNeT-1		ToSTNeT-2	ToSTNeT-3
	Single-stock transactions (*1)	Basket transactions price transactions	Closing	Off-auction own share repurchase transactions
Primary uses	Large-volume transactions of individual stocks	Bulk transactions of multiple stocks	Transactions at specific point in time prices	Pre-announced share repurchases
Transaction methods	Cross transactions, Counterparty	Cross transactions, designated transactions	Individual auction (Time Priority (Cross transactions have highest priority))	Itayose (Call auction) (*2)
Trading hours	8:20-17:30 (8:20-18:00) (*3, 4)	8:20-17:30 (8:20-18:00) (*3, 4)	8:20-8:45, 11:30-12:15, 15:00-16:00 (15:30-16:30) (*4)	8:45
Transaction price	Within ±7% of the most recent execution price	Within ±5% of the reference value (*5) 15 or more stocks and	Previous day's closing price, morning session closing price, afternoon session closing price	Previous day's closing price
Trading unit	Available from minimum unit	Total trading value of 100 million yen or more	Available from minimum unit	Available from minimum unit

＊1 Single-stock transactions include guaranteed VWAP executions, but only those based on the most recent execution price are included here.

＊2 This method allocates the minimum unit to the trading participant with the largest sell order quantity. It then matches quantities calculated by multiplying the remaining quantity by the pro rata ratio (remaining buy quantity / total remaining sell quantity) (with amounts below the minimum unit rounded down). Finally, it allocates the minimum unit to the participant with the largest round-down quantity.

＊3 However, transactions for settlement on the second day must be completed by 12:30.

＊4 Starting November 5, 2024, trading hours on the Tokyo Stock Exchange's on-auction market have been extended by 30 minutes. Consequently, trading hours on the ToSTNeT market have also been adjusted. Times in parentheses indicate the new hours.

＊5 The reference price in basket trading refers to the total trading value calculated based on the most recent transaction prices of each security comprising the basket in its respective trading market.

[18] In single-stock transactions, (1) cross transactions between the same trading participants are possible, (2) trading hours are from 8:20 a.m. to 6:00 p.m. starting November 5, 2024, and (3) transaction prices are permissible within ±7% of the most recent transaction price. Therefore, there are virtually no constraints when conducting dark pool executions.

2.3 Trading Data, etc., Following the Introduction of Dark Pool Flags

As stated earlier, to improve the transparency of dark pools, the assignment of dark pool flags began in August 2020, enabling the accurate identification of dark pool trading. From August 2020 to November 2024[19], the trading value and share of dark pools[20] are as follows. The average daily trading value in dark pools over the entire period was 189.2 billion yen, with a trading value share of 3.6%. As shown in Figure 2.3.1, this indicates that transactions in dark pools have been gradually expanding.

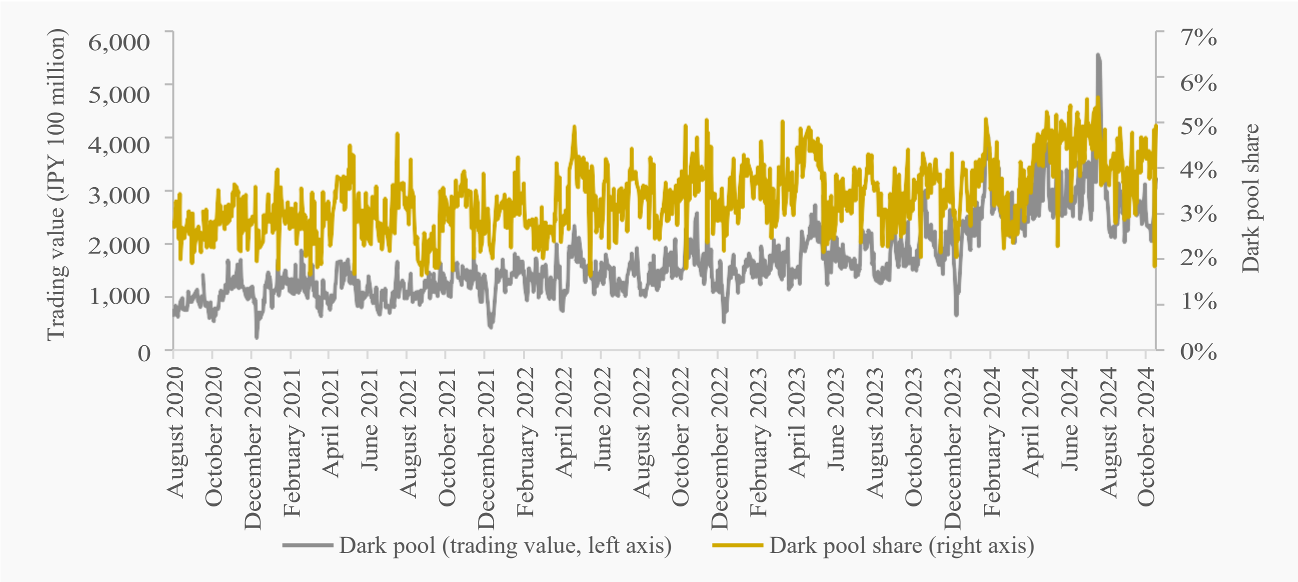


Figure 2.3.1 Trends in dark pool trading value and share

Additionally, data by stock category and index category is as follows. To compare relative liquidity in dark pools, we have included the ratio of trading value between dark pools and the Tokyo Stock Exchange on-auction market. Most instruments traded in dark pools are stocks, and Table 2.3.2 indicates that among stocks, trading in TOPIX Mid400 constituents is relatively active. One reason for the active trading of Mid400 constituents in dark pools is the inclusion of periods where tick size was relatively large compared to liquidity[21], allowing for easier price improvement in dark pool trading. Investment securities (especially REITs) are also actively traded through dark pools.

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[19] Data used is up to the business day prior to the launch date of the Tokyo Stock Exchange's cash equity trading system "arrowhead4.0" (November 1, 2024).
[20] Calculated from execution data bearing a dark pool flag. Calculated from transaction data published by the Japan Securities Dealers Association for off-exchange trading data (Off-Exchange Information Network, PTS Information Network) and transaction data from exchanges (Sapporo Securities Exchange, Tokyo Stock Exchange, Nagoya Stock Exchange, Fukuoka Stock Exchange).
[21] The tick size for TOPIX Mid400 constituent stocks has been optimized since June 5, 2023.

Table 2.3.1 Trading value in dark pools by stock category, etc.

	Average daily trading value (JPY)	Ratio	Ratio of dark pool trading to Tokyo Stock Exchange's on-auction trading
Prime/Tokyo Stock Exchange 1st Section[22]	180,415,184,433	95.36%	5.51%
Standard/Tokyo Stock Exchange 2nd Section, JQ Standard[23]	2,430,367,687	1.28%	2.40%
Growth/Mothers, JQ Growth[24]	2,328,127,038	1.23%	1.54%
Investment trust beneficiary certificates[25]	255,665,974	0.14%	0.09%
Investment securities[26]	3,767,312,245	1.99%	8.22%
Preferred securities	33,826	0.00%	0.06%
Total	189,196,691,204	100.00%	

Table 2.3.2 Trading value in dark pools by index category

	Average daily trading value (JPY)	Ratio	Ratio of dark pool trading to Tokyo Stock Exchange's on-auction trading
Core30	38,602,673,369	20.40%	4.36%
Large70	41,050,986,948	21.70%	4.38%
Mid400	82,716,204,983	43.72%	7.80%
Small	18,332,970,885	9.69%	4.39%
Other	8,493,855,018	4.48%	1.56%
Total	189,196,691,204	100.00%	

Dark pools mostly execute trades at prices within the BBO of each stock's primary market (see Figure 2.3.4), and dark pool trading is believed to occur during exchange trading hours. Figure 2.3.2 shows the volume curve, which indicates the proportion of the daily trading volume per minute in dark pools during the data collection period. Dark pool trading occurs most frequently during the opening periods of the morning and afternoon sessions, followed by the period immediately before the close. Comparing this to Tokyo Stock Exchange's on-auction trading (Figure 2.3.3), it is evident that Tokyo Stock Exchange's on-auction trading is concentrated at the close, as well as the opening periods of the morning and afternoon sessions.

Furthermore, while 99.76% of dark pool trades are executed during the Tokyo Stock Exchange's regular trading hours, some dark pool trading also occurs outside regular trading hours[27]. The most frequent time is 15:01, after the close of the afternoon session, accounting for approximately 0.22% of daily transactions. It is presumed that dark pool trading post-afternoon session primarily involves transactions at the day's VWAP, etc.

[22] Data prior to April 1, 2022 includes stocks listed on the Tokyo Stock Exchange 1st Section.
[23] Data prior to April 1, 2022 includes stocks listed on the Tokyo Stock Exchange 2nd Section and JASDAQ Standard.
[24] Data prior to April 1, 2022 includes stocks listed on Mothers and JASDAQ Growth.
[25] Includes ETFs and ETNs.
[26] Includes REITs and infrastructure funds.
[27] Dark pool trades do occur before the morning session opens and during the lunch break (11:30 a.m. to 12:30 p.m.), but trades during these periods account for only 0.01% of all dark pool trading.

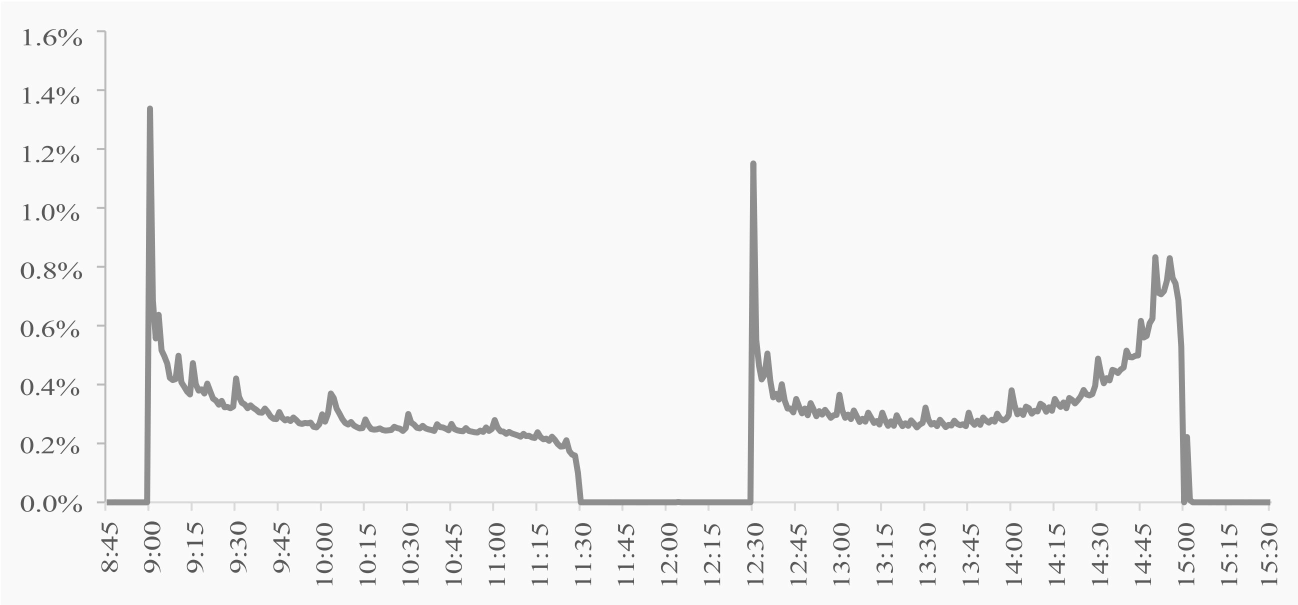

Figure 2.3.2 Average volume curve for dark pools

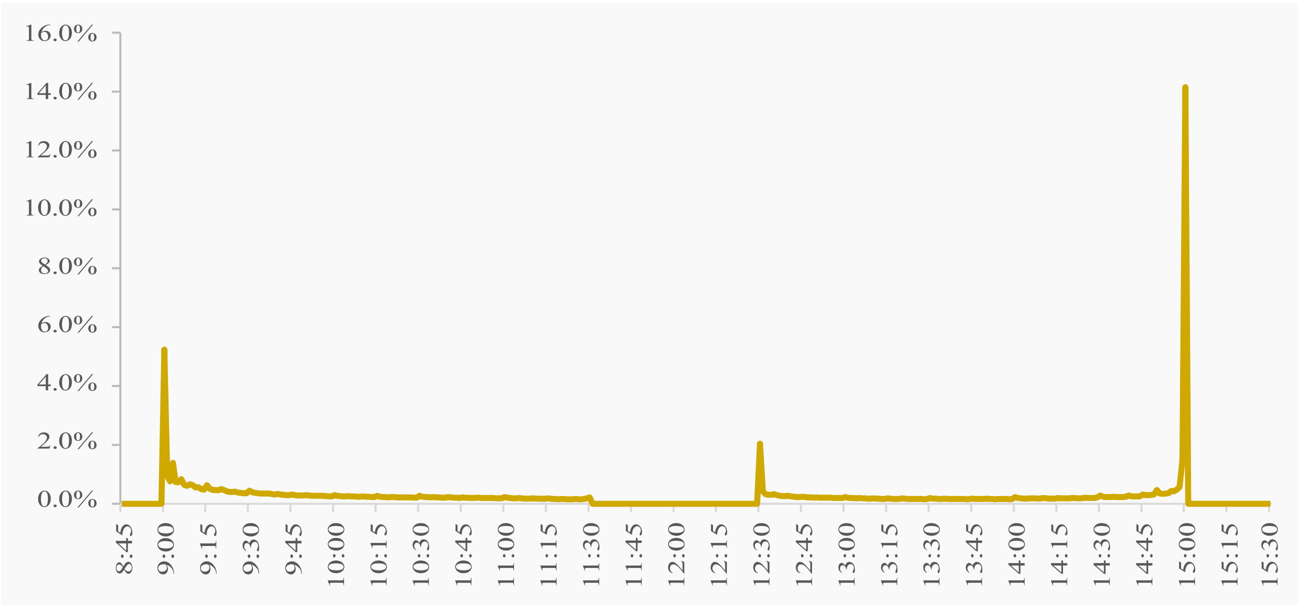

Figure 2.3.3 Average volume curve for Tokyo Stock Exchange's on-auction trading

Figure 2.3.4 shows the distribution of execution prices in dark pools based on trading value[28], using the midpoint of the Tokyo Stock Exchange's BBO at the time of execution[29] as the reference (0%). The Tokyo Stock Exchange's Best Bid Price is set at -100% and the Best Ask price at +100%. This distribution applies to executions occurring during the Tokyo Stock Exchange's regular trading hours.

Approximately 60% of trading value in dark pools is executed near the midpoint price. The second-highest trading value occurs in the price range near the best bid/ask prices (-105% to -95%, 95% to 105%), accounting for just under 20% of the total.

[28] Data for the entire period (August 2020 to November 2024) was aggregated.

[29] As shown in Figure 2.2.1, the process involves matching orders within the securities firm's dark pool, then placing a cross order on the Tokyo Stock Exchange's ToSTNeT-1 to execute the trade. Therefore, while the quoted prices may have changed from the Tokyo Stock Exchange's BBO at the time of matching within the securities firm's dark pool to the Tokyo Stock Exchange's BBO at the time of execution on ToSTNeT-1, we use the Tokyo Stock Exchange's BBO at the time of execution on ToSTNeT-1 for our calculations.

Third is the price range outside the Tokyo Stock Exchange's best bid and ask prices (-105% or less, 105% or more), For one side of the transaction, the price has been settled without improvement (worsened). Fourth is the price range between the midpoint and half of the best bid/best ask prices (-55% to -45%, 45% to 55%), accounting for about 6%.

This indicates that the execution prices in dark pools are based on the Tokyo Stock Exchange's BBO and midpoint prices. Furthermore, it shows that the majority of execution prices in dark pools fall within the range between the Tokyo Stock Exchange's best bid and best ask prices.

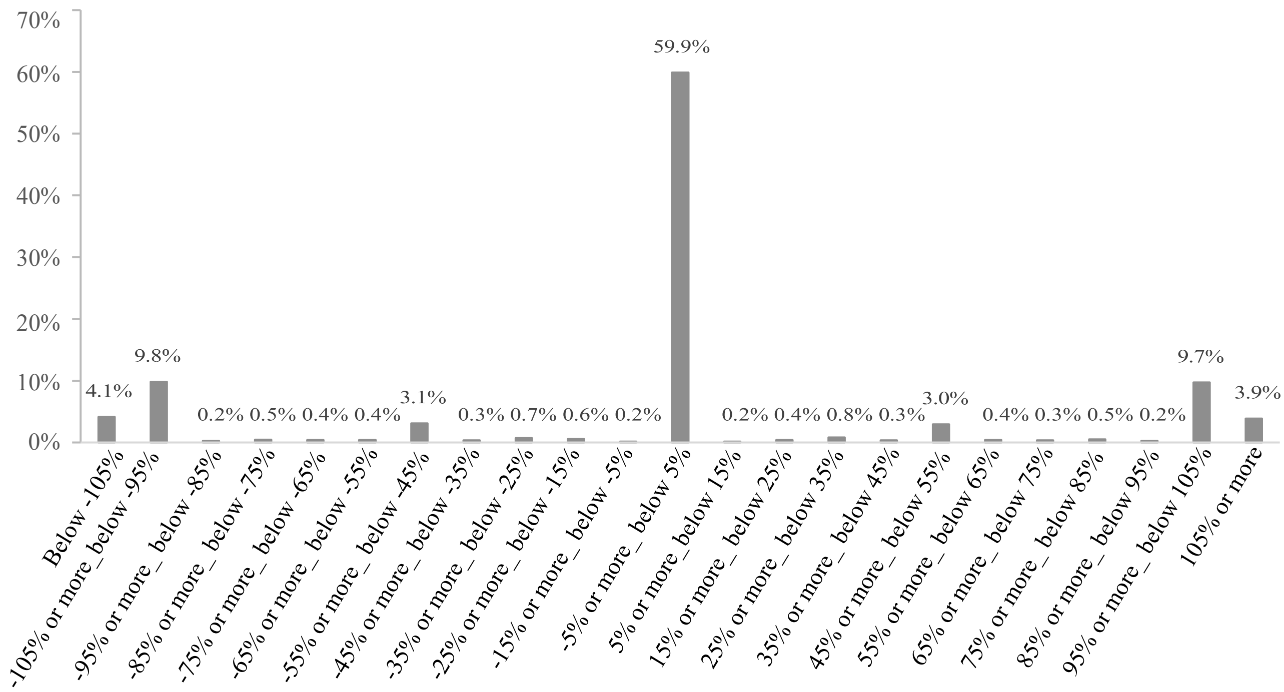

Figure 2.3.4 Distribution of execution prices in dark pools
(based on trading value, normalized by the Tokyo Stock Exchange midpoint)

Figure 2.3.4 shows that a certain amount of trading occurs outside the Tokyo Stock Exchange's best bid and ask prices, so we examine during which time periods such transactions are likely to occur. Figures 2.3.5 to 2.3.7 show the volume curve for trading during the Tokyo Stock Exchange's regular trading hours, broken down by outside the best bid and ask prices("outside"), at the best bid and ask prices ("at"), and inside the best bid and ask prices ("inside").

Executions outside the best bid and ask prices are concentrated during the volatile opening periods of the morning and afternoon sessions[30]. Furthermore, as shown in Figure 2.3.8, the average execution volume per trade for "inside," "at," and "outside" during the 9:00 minute is approximately 440 shares for "inside," 569 shares for "at," and 1,079 shares for "outside," indicating relatively larger execution volumes for "outside." Large-scale transactions in dark pools during the opening period, including that of the afternoon session, tend to be executed at prices outside the Tokyo Stock Exchange's best bid and ask prices.

Additionally, regarding trades executed in dark pools during the 14:59 minute immediately before the market close, it is also interesting to note that while the volume curves for "inside" and "outside" are declining, the curve for "at" is rising.

[30] The volume curve for "outside" during the 9:00 minute shows 2.9%, more than double that of "at" (1.4%) and "inside" (1.1%). Similarly, the volume curve for "outside" during the 12:30 minute shows 2.0%, roughly double that of "at" (0.5%) and "inside" (1.1%).

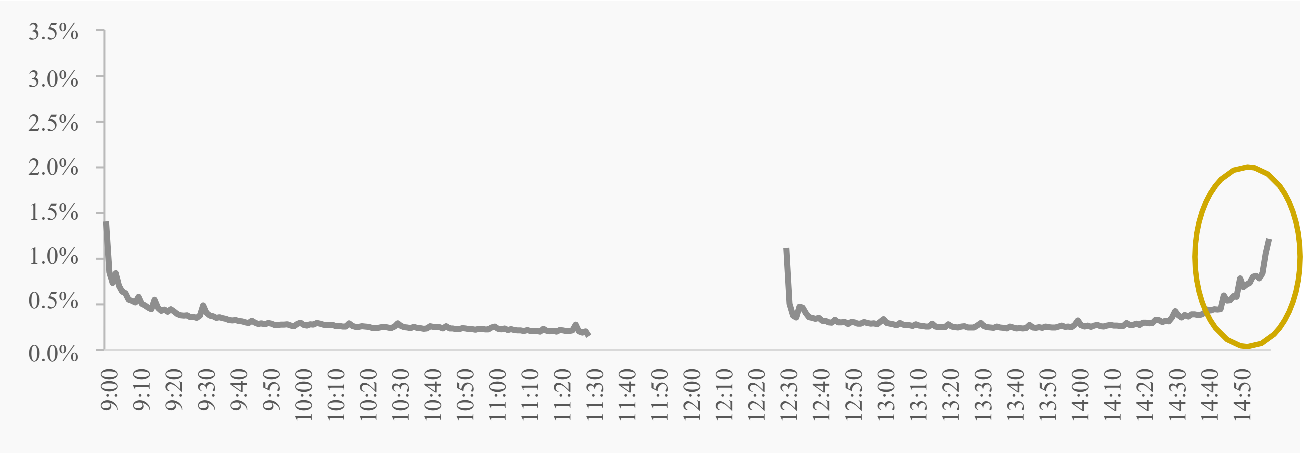

Figure 2.3.5 Volume curve in dark pools (at)

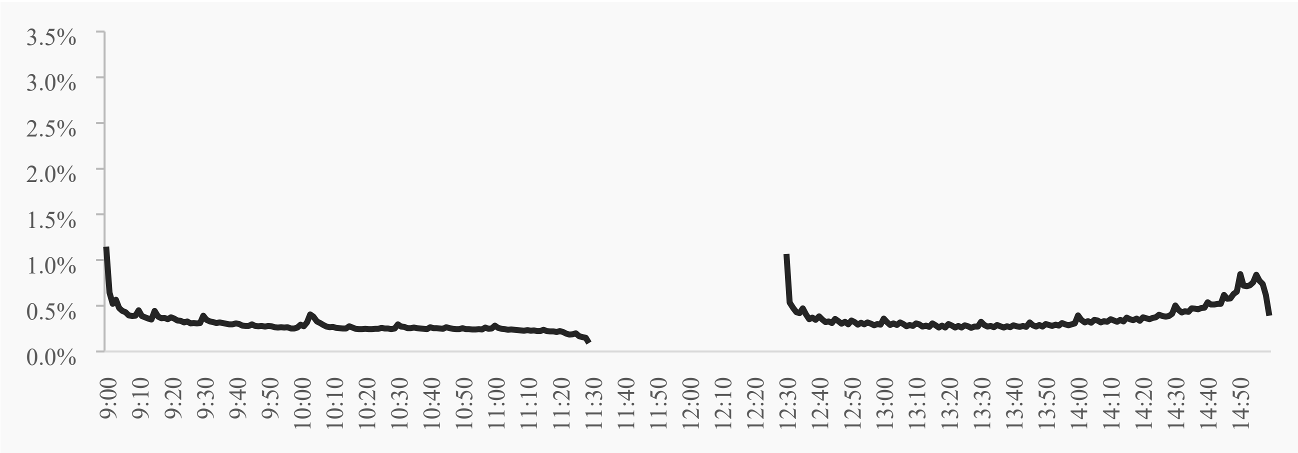

Figure 2.3.6 Volume curve in dark pools (inside)

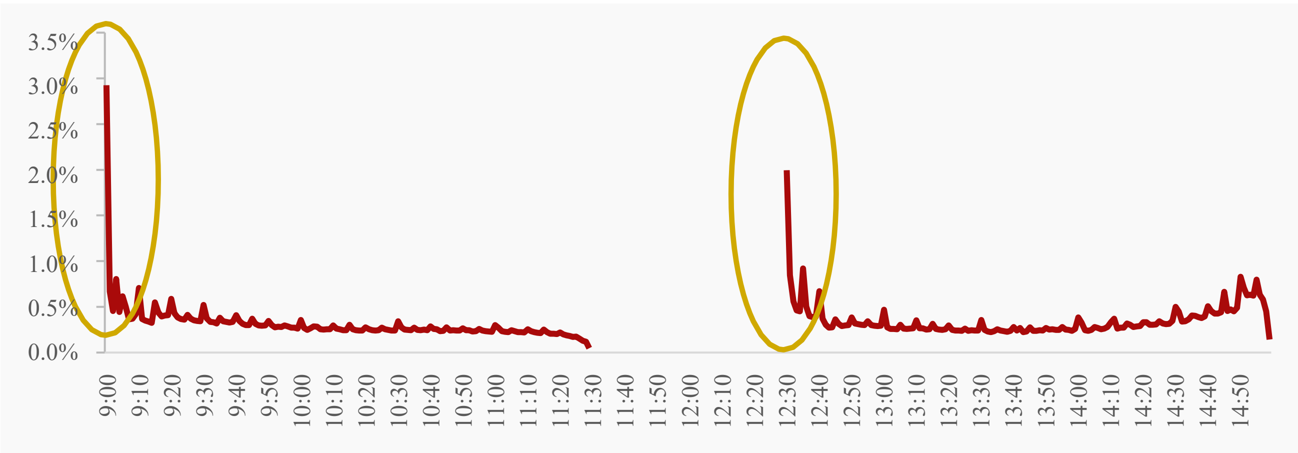

Figure 2.3.7 Volume curve in dark pools (outside)

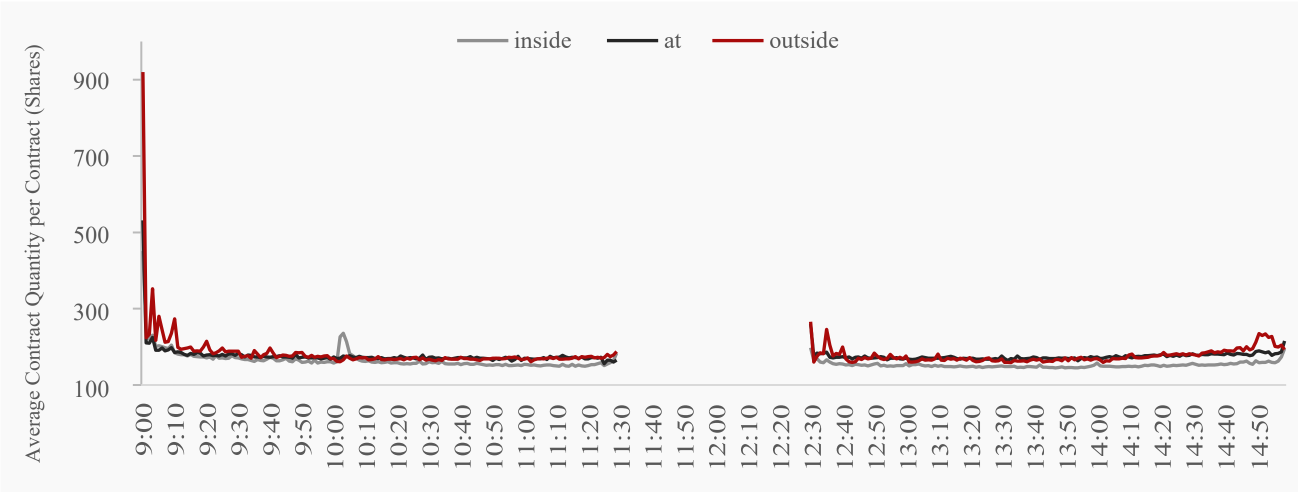

Figure 2.3.8 Average execution volume per trade by time slot

Next, we examine the trend in price improvement rates within dark pools. The price improvement rate is defined as follows:

Price Improvement Ratio (Seller Side) = (Execution Price - Best Bid Price at Execution Time (TSE)) / Midpoint
Price Improvement Ratio (Buyer Side) = (Best Ask Price at Execution Time (TSE) - Execution Price) / Midpoint

Figure 2.3.9 calculates the price improvement rate for each trade in dark pools and computes the average price improvement rate on a monthly basis. Both the seller-side and buyer-side price improvement rates are calculated and are nearly identical. While the price improvement rate appears to show a slight downward trend, it depends on factors such as the quoted spread and the stock price of the executed shares. Therefore, it cannot be concluded from this data that the price improvement rate in dark pools is deteriorating. The decline in the improvement rate in June 2023 is likely attributable to the impact of the optimization of the tick size for TOPIX Mid400 constituent stocks and the subsequent narrowing of the Tokyo Stock Exchange's quoted spread. Furthermore, the increase in the improvement rate in August 2024 is thought to be influenced by the sharp stock price decline in early August, followed by elevated volatility and a widening of the quoted spread.

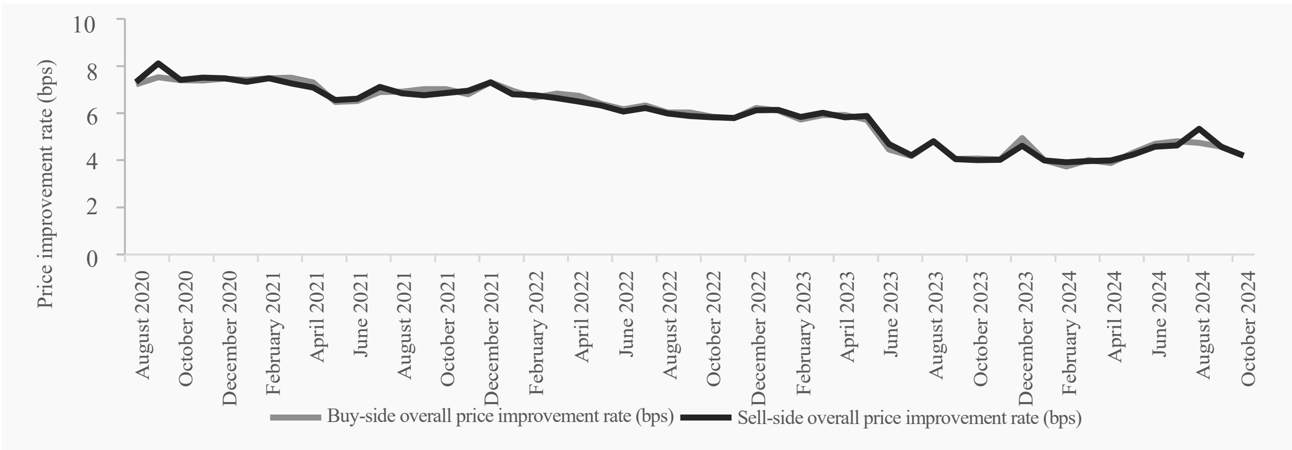

Figure 2.3.9 Trends in price improvement rate in dark pools

3 Prior research

3.1 Prior research

According to Xinkai Huang (2020), the bid-ask spread does not affect dark pool trading volume. Regarding volatility, a negative correlation was observed in dark pools provided by the Australian Securities Exchange (ASX), while a positive correlation was observed in dark pools provided by brokers. It was recognized that when the depth of the CLOB (Central Limit Order Book) is large, the market share of dark pools increases. This aligns with the notion that investors prefer dark pools because they recognize the uncertainty surrounding trade execution.

According to Ibikunle and Rzayev (2020), during the period heavily impacted by COVID-19, informed traders shift their trading from lit pools to dark pools when market volatility surges, while traders without information move from dark pools to lit pools, wary of adverse selection risk. Taking both impacts into account (net effect), they conclude that trading in lit pools increases.

According to Zhu (2014), an analysis of the impact of dark pools was conducted using a theoretical model. Under normal market conditions, even with the addition of dark pool markets, informed traders are expected to concentrate (prefer) trading on exchanges, thereby enhancing the price discovery function of exchanges. Furthermore, regarding the impact of dark pools on price discovery, it states that their price discovery function deteriorates under conditions such as reduced liquidity on exchanges, significant delay costs for liquidity-providing traders (transaction costs arising from orders not being executed immediately), and prolonged time to information disclosure (longer time for the market to price in information). It also states that imbalances in orders may adversely affect price discovery.

Comerton-Fode and Putnins (2015) argue that trades in dark pools contain less information compared to those in lit pools. They further state that when trading volume in dark pools becomes extremely high, informed traders become overly concentrated in lit pools, thereby increasing adverse selection costs and diminishing price discovery function.

Bartlett and McCrary (2015) state that queue-jumping in dark pools significantly reduces liquidity (order quantity and depth on the order book) in exchanges, but this impact stems from HST, and there may be a negative correlation between HST trading volume and dark pool trading volume. They also suggest that Regulation NMS Rule 612 (regulating minimum tick size), which facilitates queue-jumping, may not adversely affect market quality as much as previously feared.

Brogaard (2021) states that trading in dark pools is linked to information acquisition. Specifically, it states that trading and settlement information in dark pools are related and have a strong correlation with current returns and future earnings.

Buti, Rindi, and Werner (2022) conducted an analysis using U.S. dark pool data from 2009 and 2020. They state that in the 2009 sample, for trades in large-cap stocks, dark pools were used for queue jumping when order volume was very high in the public market. In the 2020 sample, dark pools were used to avoid bearing the associated execution costs for stocks experiencing widening spreads. Furthermore, for stocks with high dark pool shares, the 2009 sample showed narrow spreads that did not affect short-term volatility, while the 2020 sample indicated that stocks with large market capitalizations and high dark pool shares exhibited widening spreads and increased short-term volatility.

Ye (2016) states that adding dark pools in addition to exchanges creates an amplification effect on price discovery. When information accuracy is high (information risk is low), informed traders trading on exchanges enhance price discovery. Conversely, when information accuracy is low (information risk is high), informed traders trading in dark pools diminish price discovery.

Lin et al.(1995) analyzed the relationship between the adverse selection component and trade size in stock trading, and found that the adverse selection component increases as trade size increases. They also found that the adverse selection component varies by trading time, being highest immediately after the opening of trading and lowest just before the close of trading.

4 Analysis Content

4.1 Data Used

To analyze trading activities in dark pools under high-volatility conditions, we referenced the historical Nikkei Volatility Index and identified periods of low volatility[31] and periods of high volatility[32] during the timeframe from August 17, 2020, to November 1, 2024. each comprising 20 trading days (totaling 40 trading days), as the detailed analysis period. Analysis targets TOPIX 500 index constituents, which account for over 80% of trading value in dark pools.

There are two types of analytical data for the target period: one is data by stock and trading day, and the second is more granular data for each stock showing every single trade executed in dark pools. We use both data types depending on the specific purpose of the analysis.

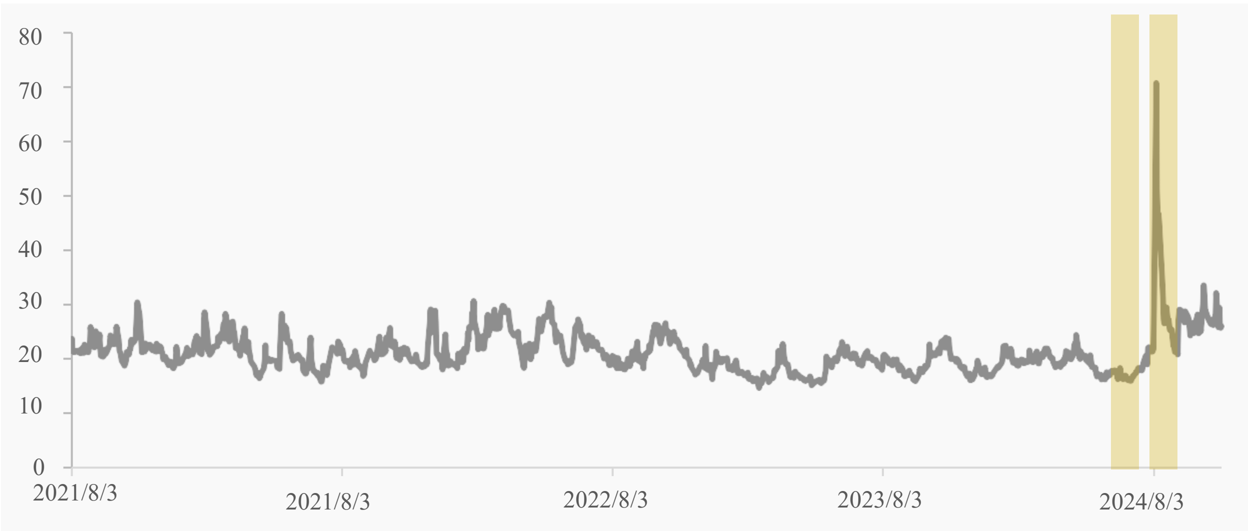

Figure 4.1.1 Trends in the Nikkei average volatility index

4.2 Analytical Methods

First, we analyze the characteristics of dark pools and perform clustering for each dark pool. Next, we analyze how dark pools are used. In this analysis, we use data such as the depth[33] of the Tokyo Stock Exchange on-auction market at the time of execution in dark pools and quoted spreads[34],etc. to identify the conditions under which dark pools are more likely to be used. In addition, we analyze how execution prices are determined within dark pools. Additionally, we will analyze how the increasing proportion of trading value in dark pools (relative to the TSE on-auction market) affects market quality.

[31] From June 12, 2024 to July 9, 2024

[32] From August 1, 2024 to August 29, 2024

[33] The order volume registered at each bid–ask quote

[34] The spread between bid and ask prices displayed on the order book

Quoted (half) spread

This refers to the bid–ask spread displayed in the order book. For stocks with high liquidity, the spread is typically one tick wide.

After trading commences, each time the best bid and ask prices change (where the number of quoted price changes per trading day is denoted as i = 1, 2, 3,...,n), compute the difference between the best ask price $P^i_{best\ ask}$ and the best bid price $P^i_{best\ bid}$, divide it by 2, and then divide this value by the mid-quote price P^i_{mid}. Multiply the result by the duration Δt^i for which the quote remains in effect.

Perform this calculation for all n quoted price changes, sum the results, and obtain the time-weighted average by dividing by the total trading time ($\sum_{i=1}^{n} \Delta t^i$)[35]

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

Intraday volatility and variance ratio

Intraday volatility indicates the standard deviation of stock price fluctuations on a given day and is used to confirm whether effects such as suppressed price volatility exist. Furthermore, the variance ratio is calculated by adjusting the variance values of two stock price fluctuations measured at different time intervals to a single time interval (here, to match 10-minute volatility, the squared value of 1-minute volatility is multiplied by 10) and taking their ratio. A variance ratio approaching 1 indicates that long-term price fluctuations are an extension of short-term price fluctuations, meaning stock prices exhibit behavior closer to Brownian motion. This is used to assess market efficiency.

For intraday volatility, we calculate the variance value $(\sigma^d_{1,10})^2$ for the given trading day d. This is determined by taking the natural logarithm of the ratio of fluctuation in the midpoint P^t_{mid} of the best bid-ask spread at time t (t=1, 2,・・・,N[36]) relative to the time t-1, calculated at 1-minute and 10-minute intervals following the opening price determination. Here, we define the 1-minute volatility as σ^d_1 and the 10-minute volatility as σ^d_{10}.

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

$$(\sigma^d)^2 = \frac{1}{N}\sum_{t=1}^{N}(logP^t_{mid} - logP^{t-1}_{mid} - \mu^d)^2 \tag{3}$$

Additionally, the variance ratio vr^d is calculated for each trading day d from the 1-minute volatility σ^d_1 and the 10-minute volatility σ^d_{10}.

$$vr^d = \frac{(\sigma^d_{10})^2}{10 \times (\sigma^d_1)^2} \tag{4}$$

High-Low volatility

One method for capturing stock price fluctuations on a trading day d is to evaluate the difference between the high and low prices, normalized by the closing price on that day. Depending on the analysis, we will use the above intraday volatility appropriately.

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[35] $\sum_{i=1}^{n} \Delta t^i$ represents the time excluding periods of special quote. When no special quote occurs, this amounts to approximately 18,000 seconds (5 hours).

[36] N differs between the 1-minute and 10-minute intervals. Since the daily trading hours are 5 hours, per trading day, N is approximately 300 for the 1-minute interval and N becomes 30 for 10-minute interval.

$$Volatility^d_{high\_Low} = \frac{\left(P^d_{high} - P^d_{Low}\right)}{P^d_{Last}} \tag{5}$$

STR (Spread to Tick Ratio)

STR is an indicator showing how many times the nominal spread exceeds the tick size. Its minimum value is 1, and values closer to 1 indicate a state where the tick size is too coarse (where the spread is constrained by the tick size).

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

$$STR^d = \frac{\sum_{k=1}^{n}\left(\left(P^i_{best\ ask} - P^i_{best\ bid}\right) \times \Delta t^i\right)}{\sum_{k=1}^{n} \Delta t^i} \Big/ TS \tag{6}$$

Depth

We perform calculations each time the order volume registered at the best bid and ask prices (QQ_{ask}, QQ_{bid}) is calculated each time it changes, and the time-weighted average for that business day is determined. For each order volume (time-weighted average) within a single trading day, we take the average of the bid and ask prices and designate this as the lth depth. Furthermore, when using only one-side depth as an explanatory variable, the values of QQ_{ask} and QQ_{bid} are to be used.

$$QQ_{ask} = \frac{\sum_{p=1}^{n}\left(QQ_{ask} \times \Delta t^p\right)}{\sum_{p=1}^{n} \Delta t^p} \tag{7}$$

$$QQ_{bid} = \frac{\sum_{q=1}^{n}\left(QQ_{bid} \times \Delta t^q\right)}{\sum_{q=1}^{n} \Delta t^q} \tag{8}$$

$$depth = \frac{QQ_{ask} + QQ_{bid}}{2} \tag{9}$$

Dark pool execution price (relative value)

Regarding execution prices in dark pools, as we have confirmed, trades generally execute at prices between the best bid and ask prices on the Tokyo Stock Exchange’s on-auction market. Approximately 60% of the trading value in dark pools is executed at the midpoint, but depending on the order book situation on the Tokyo Stock Exchange, the execution price in the dark pool may differ. Therefore, we calculate the relative value of the execution price in dark pools by setting the midpoint price to 0, the best bid price on the Tokyo Stock Exchange to -1, and the best ask price to +1.

$$Dark\ Price_{relative\ price} = \frac{(Dark\ Price_{execution} - Mid\ Price_{TSE})}{\left\{\left(P_{TSE,best\ ask} - P_{TSE,best\ bid}\right)/2\right\}} \tag{10}$$

Micro price

The execution price in dark pools may also be affected by the micro price on the Tokyo Stock Exchange[37]. For example, when the order volume displayed as bids significantly exceeds the order volume displayed as asks, the micro price rises, potentially causing execution prices in dark pools to increase as well.

[37] This is a price weighted by the order volume presented at the best bid and ask prices. In dark pools, where order book (bid–ask) information is not disclosed, the micro price cannot be calculated.

$$Micro\ Price = \frac{\left(P_{TSE,best\ bid} \times QQ^1_{ask} + P_{TSE,best\ ask} \times QQ^1_{bid}\right)}{\left(QQ^1_{ask} + QQ^1_{bid}\right)} \tag{11}$$

Micro price (relative value)

For analysis purposes, since stock price levels vary across individual stocks, making comparison difficult, we define a relative value with the midpoint set to zero[38], similar to the dark pool execution price (relative value), and use this for analysis.

$$Micro\ Price_{relative\ price} = \frac{(Micro\ Price - Mid\ Price_{TSE})}{\left\{\left(P_{TSE,best\ ask} - P_{TSE,best\ bid}\right)/2\right\}} \tag{12}$$

Autocorrelation

The calculation method for the autocorrelation on a given trading day d is as follows. Here, we calculate the autocorrelation at 10-second, 30-second, and 60-second intervals. In the formula below, t indicates the calculation point at the midpoint of each interval, while t-1 represents the midpoint 10, 30, or 60 seconds prior. Furthermore, $\overline{Mid\ Price}^d$ is the average value of the midpoint on trading day d.

$$autocorrelation^d = \frac{\sum_{t=2}^{n}\left(Mid\ Price^d_t - \overline{Mid\ Price}^d\right)\left(Mid\ Price^d_{t-1} - \overline{Mid\ Price}^d\right)}{\sum_{t=1}^{n}\left(Mid\ Price^d_t - \overline{Mid\ Price}^d\right)^2} \tag{13}$$

[38] The micro price (relative value) ranges from -1 to +1.

5 Analysis Results

5.1 Market Environment, etc., During the Analysis Period

In this analysis, since investment behavior and its impact on the market differ due to varying market environments, we fundamentally conduct separate analyses for two distinct periods: low-volatility periods and high-volatility periods.

First, the market environment during the analysis periods and on August 5, 2024, when stock prices plummeted (data covers TOPIX 500 constituents). Below are the relative spreads[39] and depth calculated every 15 minutes by dividing the quoted spread by the stock price. Looking at the relative spread, it is evident that during periods of high volatility, the relative spread is elevated across all trading sessions. Furthermore, on August 5, 2024, unlike usual patterns, the relative spread rose significantly toward the close of the afternoon session. On August 5, 2024, the rapid appreciation of the yen towards the close of the afternoon session caused stock prices to plummet, likely elevating the relative spread. Regarding depth, it significantly decreased during high-volatility periods (showing an inverse correlation with volatility).

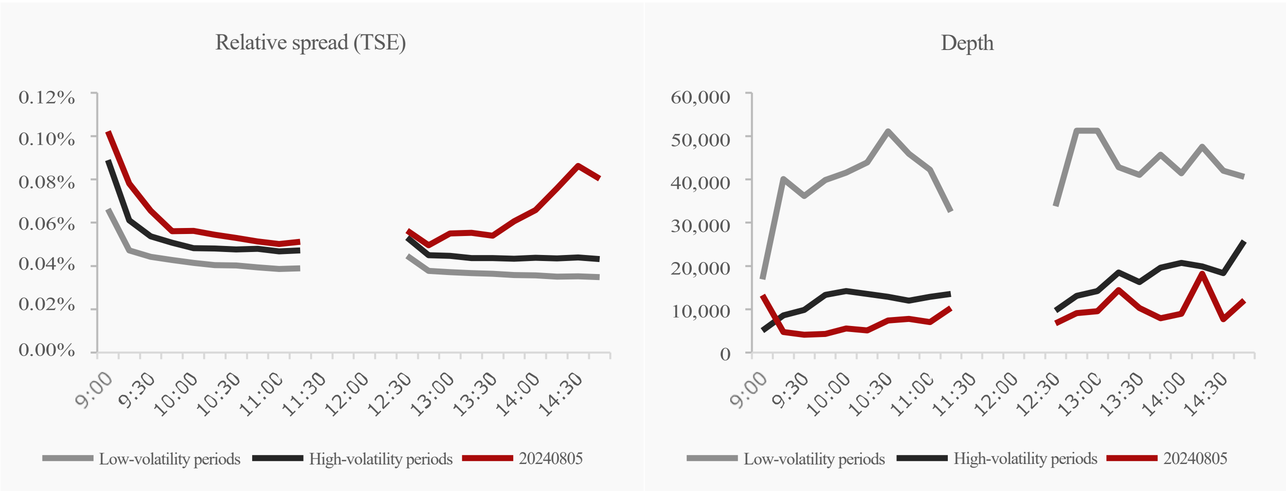


Figure 5.1.1 Changes in relative spreads and depth by time slot

Next, we examine the trading value (volume curve) in dark pools. While the average trading value over both periods remains largely unchanged, a significant increase in trading value is evident on August 5, 2024. However, when comparing with the Tokyo Stock Exchange market (the ratio of dark pools to TSE's on-auction trading), as discussed in the next section, the dark pool ratio tends to decrease during periods of high volatility.

[39] In calculating the relative spread, the quoted spread on the Tokyo Stock Exchange market at the time of execution in the dark pool is calculated and then divided by the mid-price at that time. Calculations for other indicators were also performed each time an execution occurred in a dark pool.

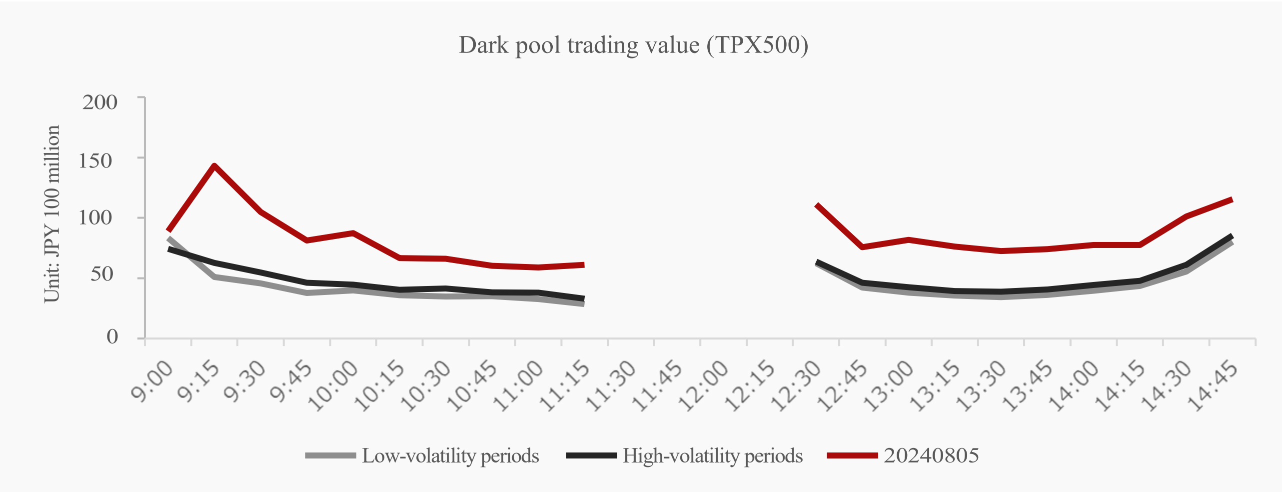
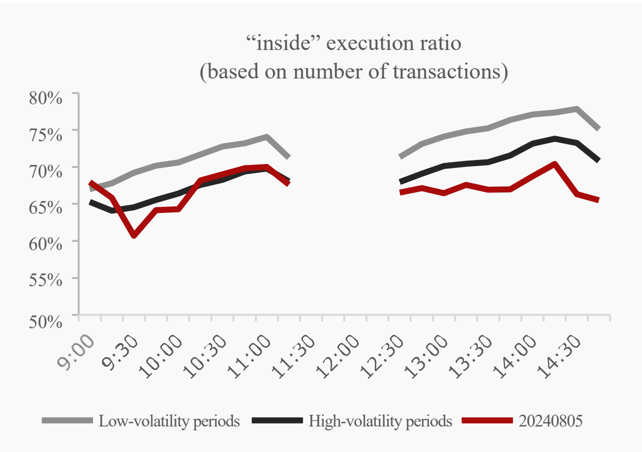
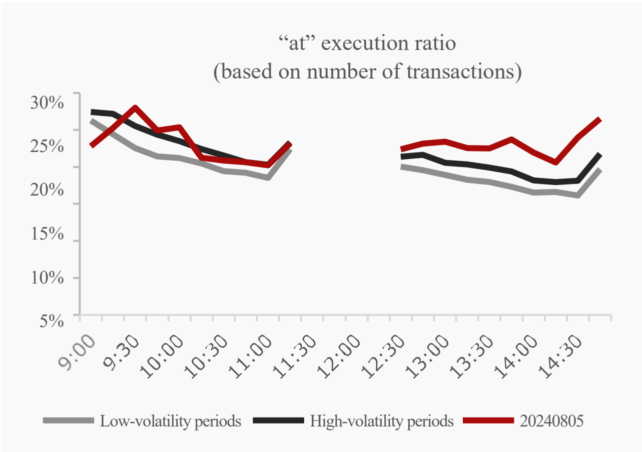


Figure 5.1.2 Changes in dark pool trading value by time slot

The following figures show the execution ratio (based on number of transactions) for Tokyo Stock Exchange's on-auction market outside the best bid and ask prices ("outside"), at the best bid and ask prices ("at"), and inside the best bid and ask prices ("inside"), broken down by time slot. Compared to low-volatility periods, high-volatility periods show a tendency for the execution ratio "inside" to decrease and the execution ratio "outside" to increase. Additionally, the execution ratio "at" also tends to increase during high-volatility periods.





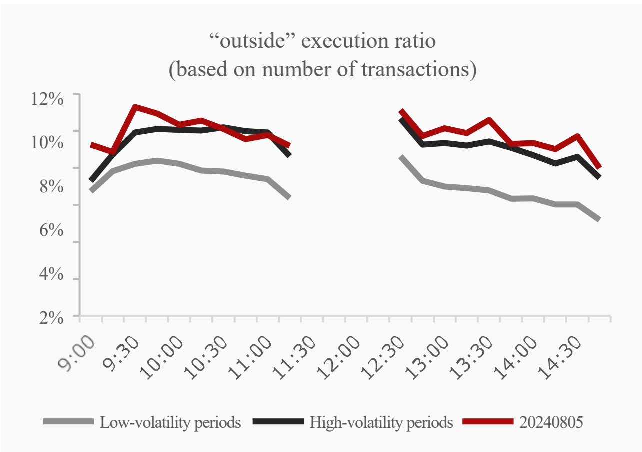


Figure 5.1.3 Changes in "inside," "outside," and "at" execution ratio (based on number of transactions) by time slot

The results of similarly verifying the proprietary trading ratio are as follows. While the proprietary trading ratio appears to show no significant difference between both periods, it tends to be lower during high-volatility periods.

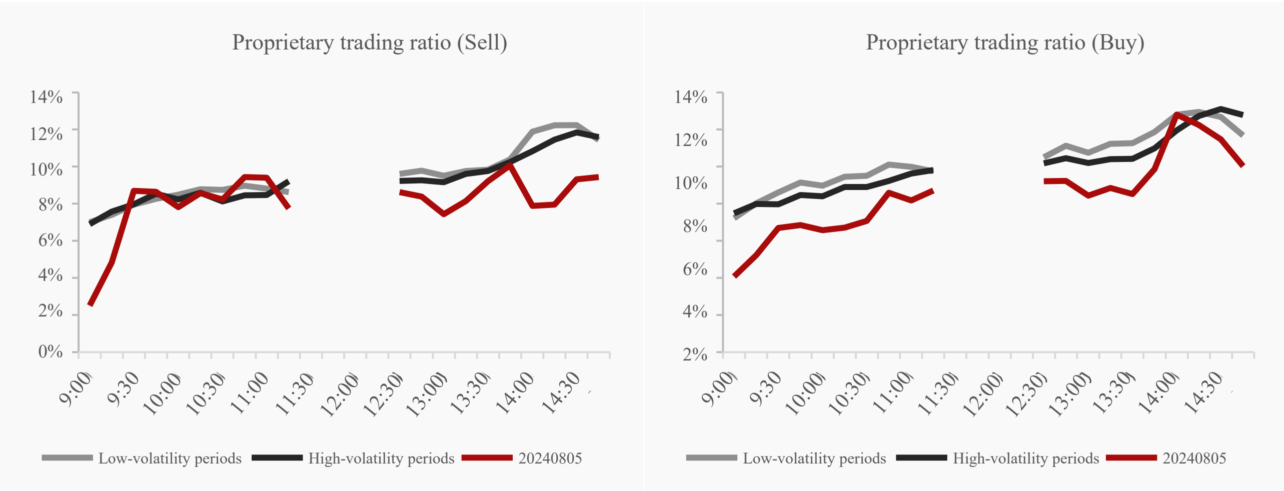
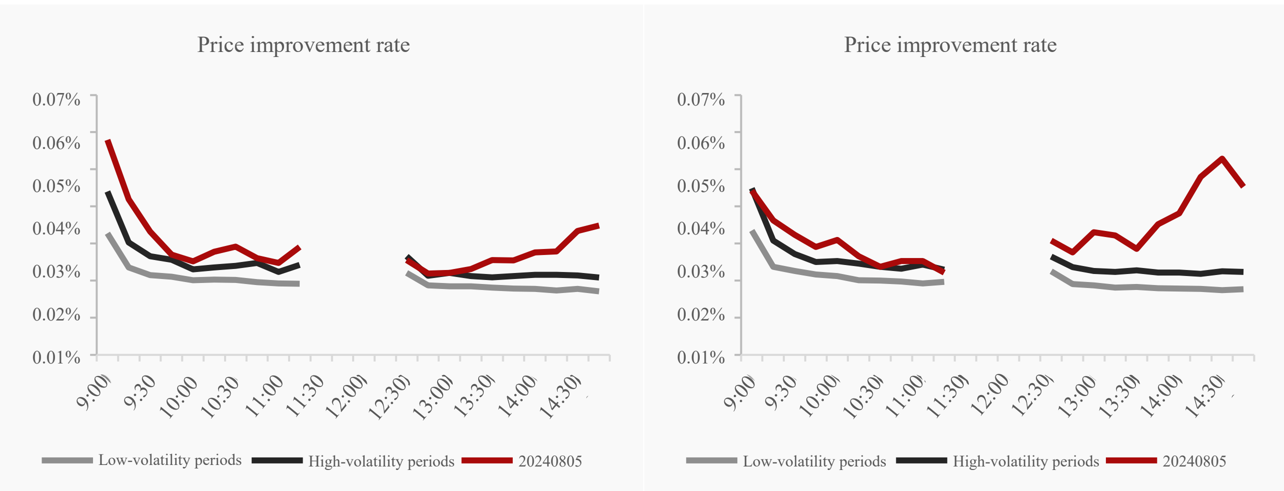


Figure 5.1.4 Changes in proprietary trading ratio by time slot

Next, we examine the price improvement rate for both sellers and buyers. Since the price improvement rate depends on the spread on the Tokyo Stock Exchange, it tends to increase in environments with high volatility as a result of widening spreads.



5.2 Impact on Dark Pool Ratio

Changes in the dark pool ratio relative to the Tokyo Stock Exchange's on-auction market during the analysis period and the average dark pool ratio by period are as follows. Even when examined by index category, it is evident that the dark pool ratio tends to decrease during high-volatility periods.

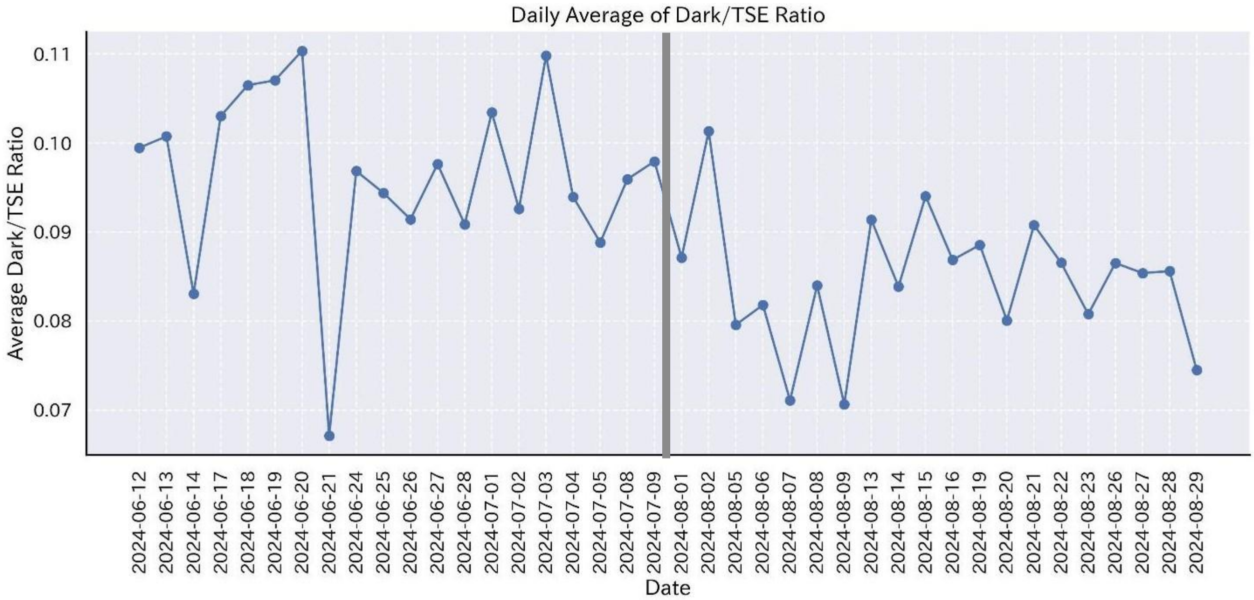


Figure 5.2.1 Trend in Dark Pool Ratio During the Analysis Period

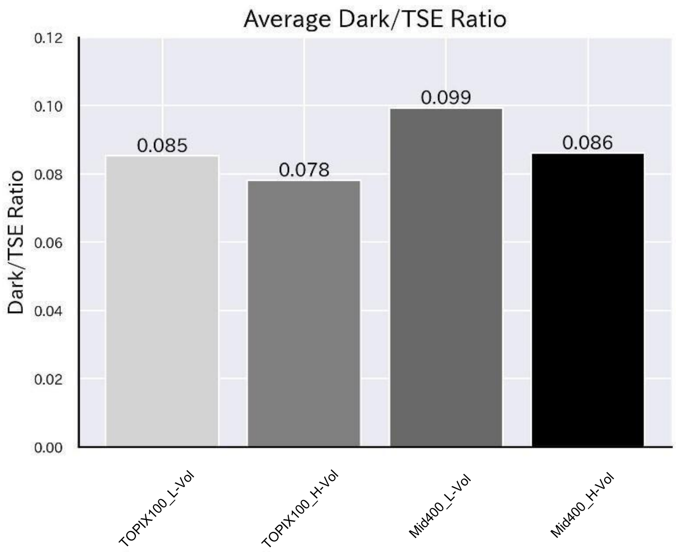


Figure 5.2.2 Average dark pool ratio by period and index category

Here, we analyze the variables affecting the dark pool ratio and examine how investors and others use dark pools. To analyze the impact under high-volatility conditions as well, we conduct separate analyses using data from low-volatility[40] and high-volatility periods. To address concern regarding multicollinearity among variables[41] and outliers (same applies below), we employed a fixed-effects model to eliminate stock- and date-specific impacts. The results are as follows.

As shown in the graph above, during both periods, high volatility resulted in a lower dark pool ratio, consistent with the findings of prior research (Ibikunle and Rzayev). As for depth, a positive correlation was observed during low-volatility periods, while both order volume and market order ratio[42] showed negative correlations. When depth is low, order volume is high, and market order ratio is high, i.e., under conditions where the order book is relatively thin and order volume and market orders are high, the dark pool ratio tends to decrease. Previous research (Xinkai Huang) pointed out that in so-called lit markets, when queues are long (depth is high), traders may use dark pools due to execution uncertainty. However, while depth was not significant in high-volatility environments, it was positively significant in low-volatility environments, suggesting dark pools may be preferred in such long-queue situations.

Furthermore, while the mid ratio[43], the execution volume per trade in dark pools, and the dark pool ratio exhibit a positive correlation, the characteristics of a high mid ratio and a large execution volume per trade in dark pools suggest heavy dark pool usage by institutional investors[44]. In such cases, it is reasonable to assume that the dark pool ratio increases (as one would expect).

Additionally, an interesting finding is the negative correlation between the dark pool ratio and the proprietary trading ratio[45] within dark pools. This indicates that when the dark pool ratio is low, the proprietary trading ratio tends to be relatively higher, suggesting a structure where, when flow into dark pools from institutional investors (natural flow) decreases, there is an increase in cases where the proprietary trading desk acts as the counterparty, taking the other side of the trade.

Based on these results, it can be inferred that during low-volatility periods, institutional investors use dark pools to access liquidity outside the Tokyo Stock Exchange market for stocks exhibiting high depth and tick weight, relatively low market order ratios and order volumes, and stable price movements.

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[40] As shown in Figure 4.1.1, normal market conditions are considered to be close to low-volatility periods.

[41] Regarding multicollinearity, the variance inflation factor is calculated to assess whether it falls within an acceptable range, etc.

[42] This is calculated by dividing the order volume of market orders by the total order volume.

[43] This value represents the ratio of the trading value in dark pools for a given stock, where the executed price in dark pools falls within -5% to +5% of the Tokyo Stock Exchange's BBO midpoint (used as the reference point at 0%), to the total trading value in dark pools for that stock. The Tokyo Stock Exchange's Best Bid Price is set at -100% and the Best Ask price at +100% relative to the BBO midpoint.

[44] Regarding dark pools for retail investors, examining the mechanism suggests that rather than retail flows matching with each other within dark pools, they are more likely matching with market makers providing liquidity in the dark pool. This mechanism implies little incentive for matching at the mid-price.

[45] Regarding the proprietary trading ratio, it is calculated by dividing the trading value executed in the operator's proprietary account by the total trading value, including agency accounts, for each stock.

Table 5.2.1 Analysis results for dark pool ratio

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Depth	2.00×10^{-3}***	0.00	5.93	1.00×10^{-3}	0.46	0.74
Volatility (per 1-minute)	-3.00×10^{-3}***	0.00	-4.16	-1.50×10^{-3}***	0.00	-3.79
Tick weight[46]	4.50×10^{-3}**	0.02	2.30	1.60×10^{-3}	0.25	1.16
HST ratio	9.00×10^{-4}	0.12	1.54	1.00×10^{-3}*	0.09	1.70
Buyer-side proprietary trading ratio	-4.80×10^{-3}***	0.00	-7.83	-3.20×10^{-3}***	0.00	-6.89
Seller-side proprietary trading ratio	-4.50×10^{-3}***	0.00	-8.15	-3.30×10^{-3}***	0.00	-8.00
Mid ratio	1.10×10^{-2}***	0.00	15.12	1.28×10^{-2}***	0.00	20.52
outside ratio	3.70×10^{-3}***	0.00	5.57	5.70×10^{-3}***	0.00	11.22
Dark pool execution volume/execution count	1.89×10^{-2}***	0.00	4.10	1.03×10^{-2}**	0.03	2.23
Market order ratio (based on order volume)	-2.30×10^{-3}***	0.00	-3.90	-1.40×10^{-3}**	0.02	-2.28
Stock prices	2.00×10^{-4}	0.97	0.03	-8.60×10^{-3}*	0.05	-1.93
Order count	-4.70×10^{-3}***	0.00	-5.01	-1.60×10^{-3}**	0.03	-2.23
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	9,758			9,737		
R-squared (Within)	0.20			0.18		

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

[46] Tick weight is calculated as the tick size divided by the stock price, indicating the relative size of a tick at a given stock price.

5.3 Impact of Dark Pools on Market Quality

As analyzed in prior research, increased trading in dark pools may affect market quality (e.g., market efficiency). We analyze the relationship between the ratio of trading value in the TSE's on-auction market versus dark pools (dark pool ratio) for each security—viewed as an indicator of dark pool influence—and market quality. Since the impact of each variable on market quality may differ under low-volatility and high-volatility environments, we conduct the same analysis under each environment.

5.3.1 Volatility

The following figures show volatility (standard deviation of stock price fluctuations over 1 minute and 10 minutes) calculated daily for each stock, then divided into 10 groups based on dark pool ratio (1 = low dark pool ratio, 10 = high dark pool ratio), with the average calculated for each group. The figures suggest a tendency for volatility to decrease as the dark pool ratio increases, though other variables may also affect this relationship.

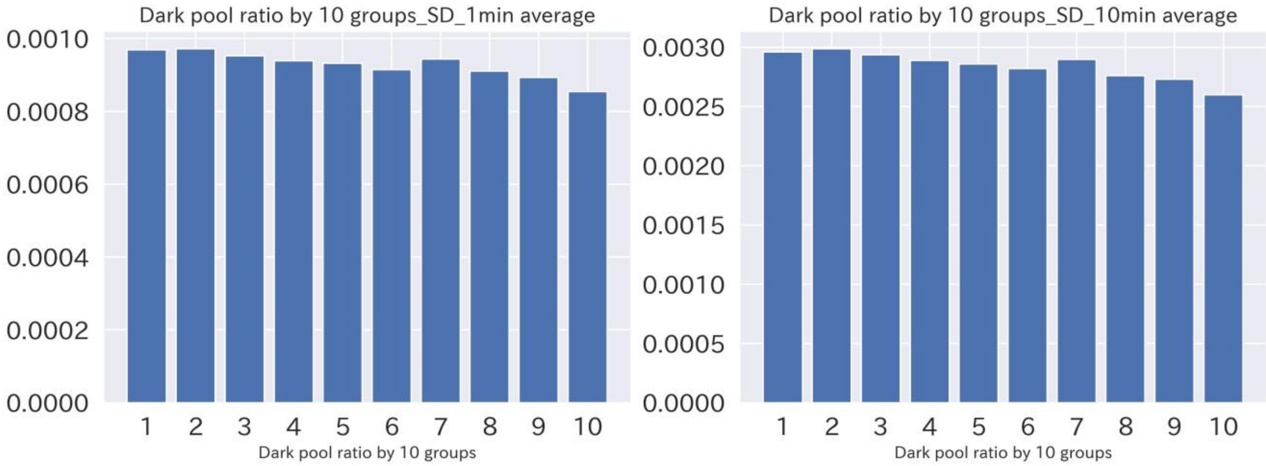

Figure 5.3.1 Volatility by dark pool ratio

The results of the analysis using a fixed-effects model, including variables affecting volatility, etc. are as follows. During low-volatility periods, the fixed-effects model analysis for 1-minute volatility and 10-minute volatility shows that the coefficient for the dark pool ratio is negative in both cases, indicating a negative correlation between the dark pool ratio and volatility. On the other hand, when performing the same analysis during high-volatility periods, the dark pool ratio was not significant. This suggests that while the dark pool ratio and volatility exhibit a negative correlation under normal conditions (where low-volatility periods are considered closer to normal market environments) this relationship disappears under high-volatility market environments.

Regarding the HST ratio, it is interesting to note that during high-volatility periods, the coefficient of the HST ratio becomes negatively significant, indicating that higher HST trading value ratios during such periods lead to reduced volatility (see Section 5.3.5 below for the impact of HST on the market).

Table 5.3.1 Analysis results for volatility (per 1-minute)

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Dark pool ratio	-1.67×10^{-5}***	0.00	-7.35	2.09×10^{-6}	0.67	0.42
Execution count	1.00×10^{-4}***	0.00	5.78	3.00×10^{-4}***	0.00	8.34
STR	2.45×10^{-5}*	0.06	1.87	5.50×10^{-5}***	0.01	2.60
HST ratio	3.18×10^{-5}***	0.00	12.74	-1.52×10^{-5}**	0.02	-2.33
Dark pool execution volume/execution count	1.88×10^{-5}***	0.00	7.51	1.45×10^{-5}*	0.10	1.65
Market order ratio (based on order volume)	2.48×10^{-6}	0.22	1.22	3.15×10^{-5}**	0.02	2.26
Proprietary trading ratio	-4.13×10^{-6}***	0.00	-2.82	5.52×10^{-6}*	0.09	1.71
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	9,758			9,737		
R-squared (Within)	0.17			0.25		

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

Table 5.3.2 Analysis results for volatility (per 10-minute)

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Dark pool ratio	-4.47×10^{-5}***	0.00	-4.47	6.80×10^{-6}	0.71	0.37
Execution count	4.00×10^{-4}***	0.00	4.90	8.00×10^{-4}***	0.00	8.15
STR	7.31×10^{-5}**	0.02	2.34	1.00×10^{-4}**	0.02	2.26
HST ratio	1.00×10^{-4}***	0.00	13.21	-4.43×10^{-5}**	0.04	-2.09
Dark pool execution volume/execution count	5.38×10^{-5}***	0.00	4.64	5.36×10^{-5}*	0.08	1.74
Market order ratio (based on order volume)	3.30×10^{-6}	0.73	0.34	5.28×10^{-5}	0.19	1.32
Proprietary trading ratio	-2.23×10^{-5}***	0.00	-3.53	1.97×10^{-5}*	0.09	1.71
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	9,758			9,737		
R-squared (Within)	0.11			0.20		

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

The analysis results above indicate a negative correlation between dark pool ratio and volatility during low-volatility periods. This could also be explained by investors refraining from using dark pools under high-volatility conditions, leading to a decline in the dark pool ratio (volatility affects the dark pool ratio).

To estimate the direction of causality, we used volatility and dark pool ratio as explained variables and conducted a fixed-effects model with lag variables and Granger causality tests, including data on dark pool ratio and volatility from the previous trading day. The results are shown in Tables 5.3.3 to 5.3.7.

The Granger causality test, as shown below, assumes that variable Y in period t is explained by variable Y in period t-1 (fixed at one trading day prior in this analysis[47]). It further adds variable X from period t-1 and tests whether the coefficient of the added lagged variable is statistically non-zero.

[47] Since it is generally considered to be most strongly affected by the previous trading day, the lag is fixed at 1.

This time, in addition to the unconditional Granger causality test, we included fixed effects for stocks and trading days[48] in the Granger causality analysis, and conducted the test using the Wald test[49].

$$Y_t = a_0 + \sum_{i=1}^{n} b_i Y_{t-1} + \sum_{i=1}^{n} c_i X_{t-1} + \epsilon_t$$

In the unconditional Granger causality test, only the negative relationship between the dark pool ratio and volatility (per 10-minute) was significant during low-volatility periods. No Granger causality was confirmed in either direction during high-volatility periods. This indicates that during low-volatility periods, an increase in the dark pool ratio contributes to a decrease in volatility (market stabilization), while the reversed direction (volatility changes affecting the dark pool ratio) was not supported by the results.

The fixed-effects model with lags summarizes the results in Table 5.3.8. During low-volatility periods, the dark pool ratio and volatility (per 10-minute) were found to affect each other bidirectionally. However, the impact from the dark pool ratio to volatility (per 10-minute) was negatively significant, while the impact from volatility (per 10-minute) to the dark pool ratio was positively significant. These results suggest that in low-volatility environments, an increase in the dark pool ratio reduces price impact in the lit market, thereby acting to lower volatility. Conversely, when volatility in the lit market rises, it appears that trading tends to shift toward execution in dark pools. Taking the results in Table 5.3.3 into account as well, it is highly likely that the dark pool ratio affects volatility.

During high-volatility periods, unlike low-volatility periods, the results show a one-way rather than two-way impact (dark pool ratio affects volatility). Interestingly, the impacts of volatility (per 1-minute, per 10-minute) to dark pool ratio are both positively significant, with the coefficient signs reversed compared to the results from low-volatility periods. This implies that, contrary to low-volatility periods, an increase in the dark pool ratio leads to higher volatility (market instability). This can be explained by the fact that, in high-volatility environments, an increase in the dark pool ratio reduces price discovery functionality in the lit market, ultimately contributing to increased volatility.

Table 5.3.3 Granger causality test results

Period	Explained variable (t period)	Explanatory variables (t-1 period)	Lag	Coefficient	Test statistic	p-value
Low-volatility periods	Volatility (per 1-minute)	Dark pool ratio	1	-2.33×10^{-5}	χ^2=1.1913	0.28
	Volatility (per 10-minute)	Dark pool ratio	1	-2.00×10^{-4}**	χ^2=4.1031	0.04
	Dark pool ratio	Volatility (per 10-minute)	1	7.06×10^{-1}	χ^2=0.7564	0.38
High-volatility periods	Volatility (per 1-minute)	Dark pool ratio	1	-5.00×10^{-4}	χ^2=0.0656	0.80
	Volatility (per 10-minute)	Dark pool ratio	1	3.37×10^{-5}	χ^2=0.0002	0.99
	Dark pool ratio	Volatility (per 10-minute)	1	8.28×10^{-2}	χ^2=0.1159	0.73

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

[48] Note that the Granger causality test does not reveal structural causality; it merely confirms changes in predictive power.

[49] Since this analysis includes fixed effects for stocks and trading days, we performed the Wald test based on cluster-robust covariance rather than an F-test.

Table 5.3.4 Fixed-effects model analysis results with lagged volatility (per 1-minute)

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Execution count	1.00×10^{-4}***	0.00	5.62	3.00×10^{-4}***	0.00	8.35
STR	2.48×10^{-5}**	0.05	1.98	5.70×10^{-5}***	0.01	2.68
HST ratio	3.03×10^{-5}***	0.00	12.62	-1.35×10^{-5}**	0.04	-2.01
Dark pool execution volume/execution count	3.65×10^{-6}**	0.01	2.53	1.24×10^{-5}*	0.05	1.93
Market order ratio (based on order volume)	3.24×10^{-6}	0.11	1.62	2.74×10^{-5}**	0.05	1.96
Proprietary trading ratio	-2.67×10^{-6}*	0.06	-1.92	6.94×10^{-6}**	0.03	2.13
t-1_dark pool ratio	-1.20×10^{-6}	0.41	-0.83	1.04×10^{-5}***	0.00	2.94
t-1_volatility (per 1-minute)	3.16×10^{-5}***	0.00	9.36	3.33×10^{-5}***	0.00	5.29
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	9,270			9,250		
R-squared (Within)	0.21			0.27		

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

Table 5.3.5 Fixed-effects model analysis results with lagged volatility (per 10-minute)

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Execution count	5.00×10^{-4}***	0.00	4.92	8.00×10^{-4}***	0.00	8.80
STR	7.76×10^{-5}**	0.01	2.53	1.00×10^{-4}**	0.02	2.43
HST ratio	1.00×10^{-4}***	0.00	12.83	-4.04×10^{-5}*	0.06	-1.87
Dark pool execution volume/execution count	1.40×10^{-5}**	0.03	2.21	4.60×10^{-5}*	0.07	1.83
Market order ratio (based on order volume)	6.11×10^{-6}	0.55	0.60	4.65×10^{-5}	0.26	1.14
Proprietary trading ratio	-1.91×10^{-5}***	0.00	-2.99	2.01×10^{-5}*	0.08	1.77
t-1_dark pool ratio	-9.94×10^{-6}**	0.03	-2.13	4.11×10^{-5}***	0.00	3.05
t-1_volatility (per 10-minute)	3.45×10^{-5}***	0.00	3.15	1.00×10^{-4}***	0.00	4.81
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	9,270			9,250		
R-squared (Within)	0.12			0.22		

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

Table 5.3.6 Results of fixed-effects model analysis with lagged variables for dark pool ratio (using volatility per 1-minute as an explanatory variable)

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Execution count	-7.30×10^{-3}***	0.00	-3.98	-2.20×10^{-3}**	0.02	-2.35
STR	-4.50×10^{-3}***	0.00	-3.01	-7.00×10^{-4}	0.54	-0.62
HST ratio	-4.01×10^{-5}	0.95	-0.06	4.00×10^{-4}	0.54	0.61
Dark pool execution volume/execution count	2.06×10^{-2}***	0.00	4.08	1.09×10^{-2}**	0.03	2.19
Market order ratio (based on order volume)	-2.40×10^{-3}***	0.00	-3.64	-2.30×10^{-3}***	0.00	-3.14
Proprietary trading ratio	-6.80×10^{-3}***	0.00	-11.01	-5.30×10^{-3}***	0.00	-10.57
t-1_volatility (per 1-minute)	9.00×10^{-4}	0.22	1.23	3.00×10^{-4}	0.30	1.03
t-1_dark pool ratio	2.70×10^{-3}*	0.05	1.93	3.50×10^{-3}***	0.00	4.50
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	9,270			9,250		
R-squared (Within)	0.15			0.09		

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

Table 5.3.7 Results of fixed-effects model analysis with lagged variables for dark pool ratio (using volatility per 10-minute as an explanatory variable)

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Execution count	-7.40×10^{-3}***	0.00	-4.00	-2.20×10^{-3}**	0.02	-2.36
STR	-4.60×10^{-3}***	0.00	-3.06	-7.00×10^{-4}	0.53	-0.62
HST ratio	-3.26×10^{-5}	0.96	-0.05	4.00×10^{-4}	0.54	0.62
Dark pool execution volume/execution count	2.06×10^{-2}***	0.00	4.08	1.09×10^{-2}**	0.03	2.19
Market order ratio (based on order volume)	-2.40×10^{-3}***	0.00	-3.66	-2.30×10^{-3}***	0.00	-3.14
Proprietary trading ratio	-6.80×10^{-3}***	0.00	-11.00	-5.30×10^{-3}***	0.00	-10.58
t-1_volatility (per 10-minute)	1.40×10^{-3}**	0.02	2.28	3.00×10^{-4}	0.31	1.02
t-1_dark pool ratio	2.70×10^{-3}*	0.05	1.93	3.50×10^{-3}***	0.00	4.50
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	9,270			9,250		
R-squared (Within)	0.15			0.09		

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

Table 5.3.8 Summary of analysis results for fixed-effects models with lagged variables

Period	Test direction	Key results	Interpretation
Low-volatility periods	Dark pool ratio →Volatility (per 1-minute)	Not significant	No statistically significant impact of dark pool ratio on volatility
	Dark pool ratio → Volatility (per 10-minute)	Negatively significant	Increased dark pool ratio suppresses volatility (Market stabilization)
	Volatility (per 1-minute) → Dark pool ratio	Not significant	No statistically significant impact of volatility on dark pool ratio
	Volatility (per 10-minute) → Dark pool ratio	Positively significant	Increased volatility raises dark pool ratio (Investors prefer dark pools to avoid the impact of volatility)
High-volatility periods	Dark pool ratio →Volatility (per 1-minute)	Positively significant	Rising dark pool ratio amplifies volatility (Market instability)
	Dark pool ratio → Volatility (per 10-minute)	Positively significant	Rising dark pool ratio amplifies volatility (Market instability)
	Volatility (per 1-minute) → Dark pool ratio	Not significant	No statistically significant impact of volatility on dark pool ratio
	Volatility (per 10-minute) → Dark pool ratio	Not significant	No statistically significant impact of volatility on dark pool ratio

5.3.2 Variance Ratio

Regarding the variance ratio, no significant changes were observed when comparing across dark pool ratio groups, as shown in Figure 5.3.2. Furthermore, Figure 5.3.3 compares the variance ratio distribution density functions between the group with the highest dark pool ratio and the group with the lowest dark pool ratio. The distribution density functions for both groups remained largely unchanged. A t-test was performed on the mean values for both groups, revealing no significant difference.

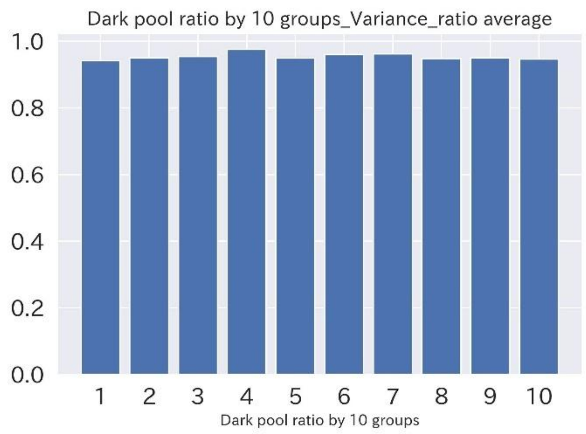

Figure 5.3.2 Variance ratio by dark pool group

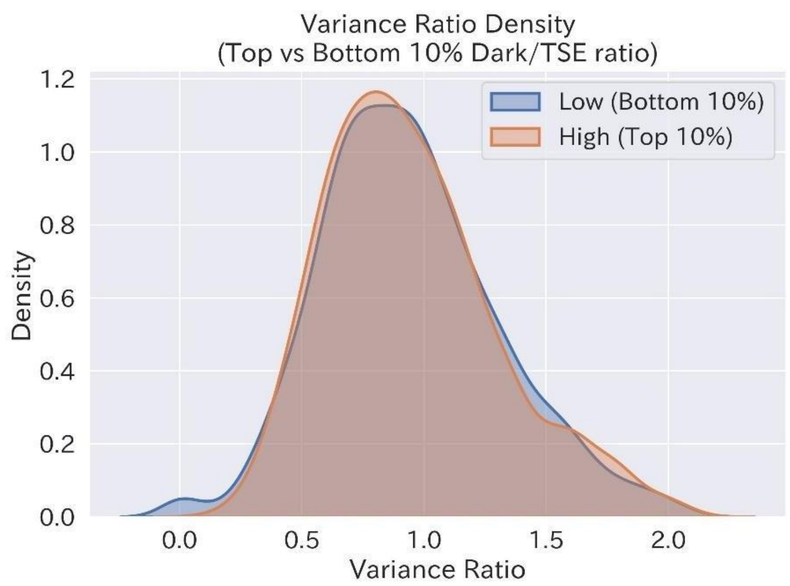

Figure 5.3.3 Comparison of variance ratio distribution density functions

5.3.3 Autocorrelation

Regarding autocorrelation, calculations were performed every 10 seconds, 30 seconds, and 60 seconds for each stock and trading day, Divided into 10 groups, the average values calculated for each group are as follows.

For 10-second and 30-second intervals, autocorrelation tends to increase as the dark pool ratio rises, but this trend is not observed for 60-second interval.

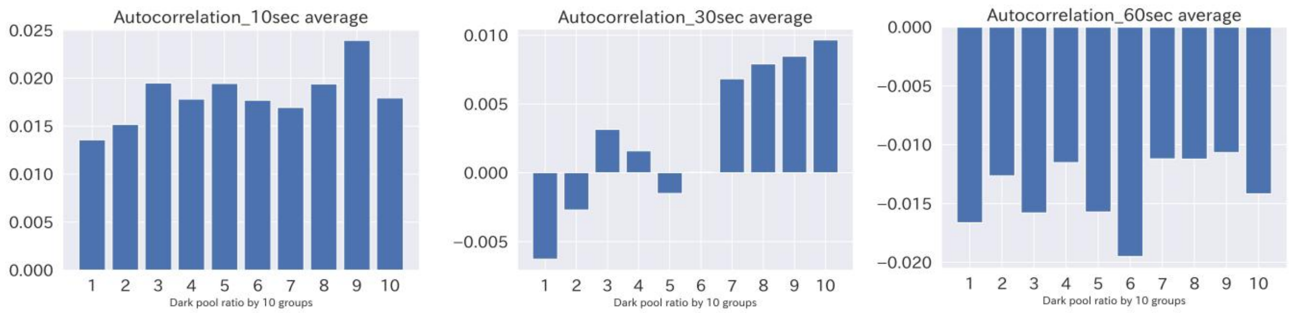

Figure 5.3.4 Autocorrelation by dark pool ratio group

As shown in the figures above, since autocorrelation exhibits positive and negative values depending on the calculation period, we analyze the absolute values of autocorrelation by trading day and by stock. We can interpret that further the absolute value of autocorrelation deviates from zero, the lower the market efficiency.

The results of analyzing the absolute value of autocorrelation using a fixed-effects model, as previously done, are as follows. For the dark pool ratio, it is only positively significant during high-volatility periods for both 10-second and 30-second intervals. In low-volatility environments, the dark pool ratio is not significant. This suggests that an increase in the dark pool ratio during high-volatility environments could negatively impact market quality.

Regarding the HST ratio, this analysis also shows a sign reversal between low-volatility periods (10 sec, 30 sec) and high-volatility periods. In low-volatility environments, an increase in the HST ratio tends to raise the absolute value of autocorrelation (negatively impacting market quality). Conversely, in high-volatility environments, it has the opposite impact (positively impacting market quality). Similar to the volatility analysis results, this indicates that the impact varies depending on the market environment.

Table 5.3.9 Analysis results for the absolute value of autocorrelation (low-volatility period)

	10 sec		30 sec		60 sec	
	Unstandardized coefficient	t-value	Unstandardized coefficient	t-value	Unstandardized coefficient	t-value
Depth	-5.70×10^{-3}*	-1.68	4.23×10^{-5}	0.06	-2.10×10^{-3}***	-5.42
High-Low volatility	1.90×10^{-3}***	3.36	2.50×10^{-3}***	3.43	1.50×10^{-3}	1.51
STR	-2.10×10^{-3}	-1.00	1.70×10^{-3}	0.85	3.10×10^{-3}	1.40
Tick weight	-7.10×10^{-3}***	-3.84	6.00×10^{-4}	0.23	2.30×10^{-3}	0.67
Dark pool execution volume/execution count	-9.00×10^{-4}	-1.16	-9.00×10^{-4}	-1.02	1.10×10^{-3}	0.88
Dark pool ratio	5.00×10^{-4}	0.78	7.00×10^{-4}	0.87	-1.40×10^{-3}	-1.24
HST ratio	1.82×10^{-5}	0.03	1.50×10^{-5}	0.02	8.00×10^{-4}	0.81
Execution count	-6.00×10^{-4}	-0.77	1.30×10^{-3}	1.01	8.00×10^{-4}	0.46
Stock fixed effects	Yes		Yes		Yes	
Time fixed effects	Yes		Yes		Yes	
No. Observations	9,758		9,758		9,758	
R-squared (Within)	0.00		0.00		0.00	

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

Table 5.3.10 Analysis results for the absolute value of autocorrelation (low-volatility period)

	10 sec		30 sec		60 sec	
	Unstandardized coefficient	t-value	Unstandardized coefficient	t-value	Unstandardized coefficient	t-value
Depth	4.60×10^{-3}***	3.89	2.40×10^{-3}	0.99	3.50×10^{-3}	1.35
High-Low volatility	6.30×10^{-3}***	6.10	5.50×10^{-3}***	4.36	4.10×10^{-3}***	3.04
STR	-1.80×10^{-3}	-1.33	3.00×10^{-49}	0.14	2.40×10^{-3}	1.61
Tick weight	-3.60×10^{-3}**	-2.04	-3.30×10^{-3}	-1.24	5.00×10^{-4}	0.21
Dark pool execution volume/execution count	-2.00×10^{-3}***	-3.62	-1.60×10^{-3}**	-2.08	-4.00×10^{-4}	-0.39
Dark pool ratio	1.50×10^{-3}***	2.95	1.20×10^{-3}*	1.76	6.00×10^{-4}	0.68
HST ratio	-4.30×10^{-3}***	-6.83	-3.80×10^{-3}***	-4.86	-2.40×10^{-3}***	-2.33
Execution count	-3.10×10^{-3}***	-3.47	-5.40×10^{-3}***	-3.75	-1.50×10^{-3}	-1.13
Stock fixed effects	Yes		Yes		Yes	
Time fixed effects	Yes		Yes		Yes	
No. Observations	9,737		9,737		9,737	
R-squared (Within)	0.03		0.01		0.00	

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

5.3.4 Percentage deviation between the closing price on the day and the stock price at 10:00 a.m. on the next business day

Similarly to above, the data was divided into 10 groups based on dark pool ratio, and graph below shows the average deviation rate between the closing price on the day and the stock price at 10:00 a.m. on the next trading day[50]. The average value for the group with the highest dark pool ratio appears relatively low.

Figure 5.3.5 Deviation rate between the closing price on the day and the stock price at 10:00 a.m. on the next trading day by dark pool ratio group

Similarly, we conducted an analysis using a fixed-effects model including variables such as the dark pool ratio that affects the deviation rate from the stock price at 10:00 a.m. the next trading day. The results are as follows. The coefficient for the dark pool ratio was not significant during either low-volatility or high-volatility periods (it was negative at the 10% significance level during the low-volatility period). This indicates that the dark pool ratio does not affect this deviation rate.

[50] This is calculated as |closing price on the day - stock price at 10:00 a.m. on the next trading day| / closing price on the day. The reason for using the stock price at 10:00 a.m. on the next trading day is that volatility is high and stock prices are unstable near the start of trading on the Tokyo Stock Exchange. Therefore, the stock price at 10:00 a.m., when prices are relatively stable, is used.

Table 5.3.11 Analysis results for the deviation rate between the closing price on the day and the stock price at 10:00 a.m. on the next trading day

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Dark pool ratio	-1.00×10^{-4}*	0.08	-1.74	9.89×10^{-5}	0.59	0.54
High-Low volatility	1.00×10^{-4}	0.19	1.31	5.00×10^{-3}***	0.00	11.74
Market order ratio (based on order volume)	6.00×10^{-4}***	0.00	5.74	1.40×10^{-3}***	0.00	5.09
Order count	1.00×10^{-4}	0.72	0.36	1.10×10^{-3}**	0.01	2.54
Stock prices	-8.00×10^{-4}	0.44	-0.77	7.90×10^{-3}*	0.08	1.76
Tick size	-4.48×10^{-5}	0.79	-0.26	-1.20×10^{-3}**	0.01	-2.54
Depth	-1.00×10^{-4}***	0.00	-5.17	1.10×10^{-3}***	0.00	4.91
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	9,758			9,737		
R-squared (Within)	0.01			0.19		

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

5.3.5 (Supplement) HST Trading During Low-Volatility and High-Volatility Periods

The figure below shows the HST trading value ratio[51] calculated for both periods. We can see that the HST ratio tends to rise during high-volatility periods. Furthermore, the highest HST ratio occurred on August 7, 2024, two days after the stock price plummeted on August 5, 2024.

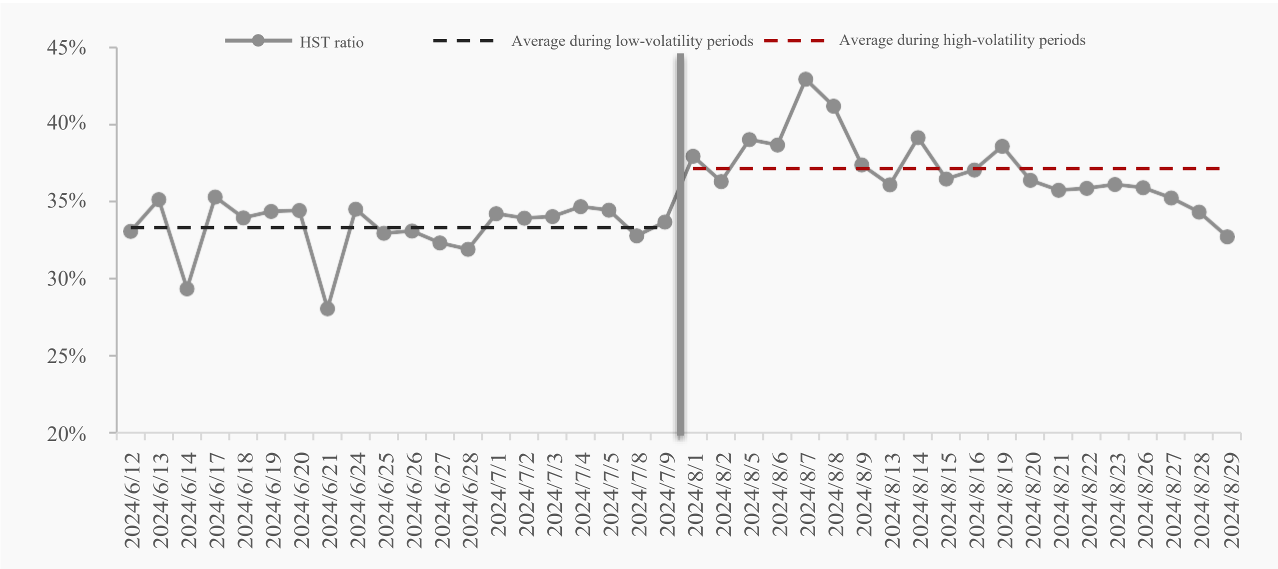

Figure 5.3.6 Changes in HST ratio

[51] Pursuant to the Tokyo Stock Exchange's rules concerning Bids and Offers, when submitting orders related to high-speed trading activities, it is necessary to explicitly state whether the order is based on a market-making strategy, arbitrage strategy, directional strategy, or other strategy. Transactions executed based on orders where such strategies are explicitly stated are referred to in this paper as HST-related trading volume. We did not restrict the target stocks; calculations were performed for all stocks listed on the Tokyo Stock Exchange market.

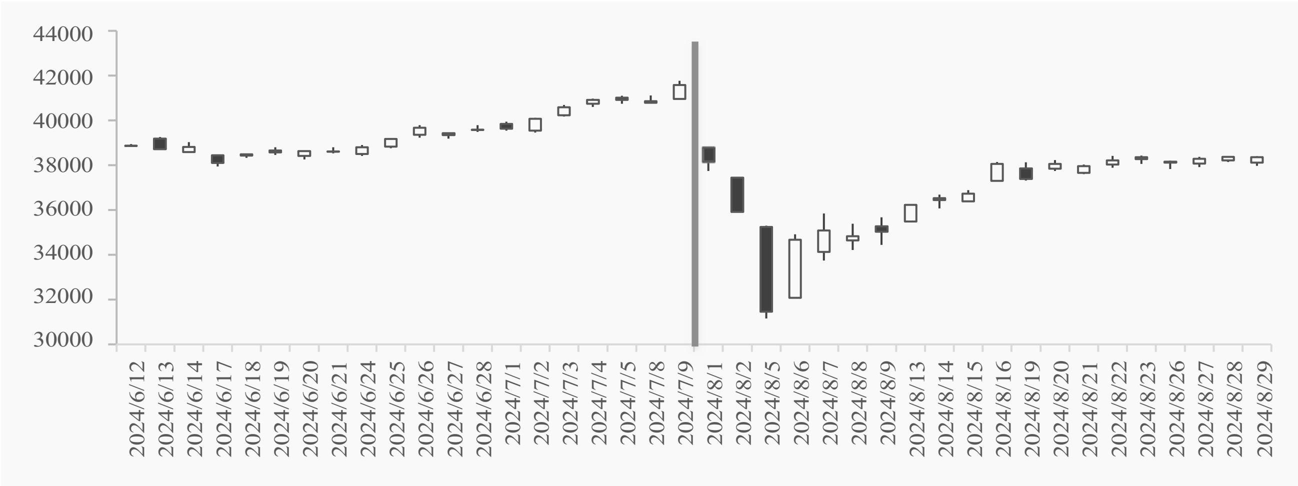

Figure 5.3.7 Changes in the Nikkei Stock Average Index

In our analysis thus far, during low-volatility periods, an increase in the HST ratio has been found to negatively impact market quality, such as volatility and autocorrelation. Conversely, during high-volatility periods, an increase in the HST ratio has been found to positively impact market quality.

Based on these results, it is possible that the nature of HST transactions (execution patterns) changed during both periods. Specifically, we examine whether HST executions on the Tokyo Stock Exchange involved taking orders already present on the order book (take orders) or whether HST orders already placed on the order book (make orders) were executed by other orders. This is because when the number of orders executed increases, it is likely to suppress stock price volatility and positively impact market quality.

We divide trading hours into 15-minute intervals, calculate the trading value for buy and sell orders placed from HST take/make orders during each interval, and then divide these trading values by the total trading value for that interval to determine the ratios of HST make buys, make sells, take buys, and take sells. Figure 5.3.8 shows this data for low-volatility periods, high-volatility periods, and the stock price plunge on August 5, 2024. The ratio of make buys to make sells in the upper segment increased during periods of high volatility. Specifically, on August 5, 2024, both make buys and make sells remained at elevated levels throughout all time periods. Furthermore, regarding take buys and take sells, while the high-volatility periods appear slightly higher when compared to low-volatility periods, the difference is not as clear as it is for make buys and make sells.

These data suggest that during high-volatility periods, the number of executions from HST make orders increased, and these executions likely exerted a suppressive impact on volatility and reduced the absolute value of autocorrelation.

Figure 5.3.8 Share of trading value from HST make and take orders

5.3.6 Summary of Analysis Results on Market Quality

We have conducted an analysis of market quality, and the results are summarized in the table below. Items that had a positive impact on market quality are designated as + and items that had a negative impact are designated as -. The results show a mixture of positive and negative impacts, but as we confirmed in our analysis of volatility, it is considered that the impact of dark pool trading on market quality varies between low-volatility periods and high-volatility periods.

It is conceivable that in low-volatility environments, execution in dark pools reduces the price impact on the lit market and acts to suppress market price fluctuations. Conversely, in high-volatility environments, execution in dark pools may delay price discovery and contribute to market instability.

Table 5.3.12 Analysis results on dark pool ratio and market quality

	Low-volatility periods	High-volatility periods
Volatility (per 1-minute)	+	-
Volatility (per 10-minute)	+	-
Variance Ratio		
autocorrelation (10 sec)		-
autocorrelation (30 sec)		-
autocorrelation (60 sec)		
Stock price deviation rate at 10:00 a.m. the next trading day	(+)	

5.4 Characteristics of Dark Pools

During the analysis period, 19 trading participants (dark pools) executed trades with a dark pool flag. The results of classifying (clustering[52]) dark pool characteristics based on dark pool transaction data (individual trade execution data within dark pools) are as follows. As shown below, the characteristics differ depending on the dark pool.

Cluster 1 is a dark pool with high proprietary trading ratio and mid ratio, and a relatively high outside ratio. Cluster 2 is a dark pool characterized by extremely large share sizes per trade, no proprietary-trading, low depth, and very high inside and mid-price ratios. Cluster 3 is a dark pool with a high at ratio. Cluster 4 has characteristics similar to Cluster 1 but exhibits a higher inside ratio and a lower outside ratio than Cluster 1.

Since each dark pool has distinct characteristics, we use the cluster number as a dummy variable in subsequent analyses (per-trade analysis of dark pools) to control for its impact.

Table 5.4.1 Key data for each cluster (average values per cluster)

	Number of shares per trade	Proprietary trading ratio	Depth	at ratio	inside ratio	outside ratio	Mid ratio
Cluster 1	204	8.6%	24,741	20%	69%	11%	52%
Cluster 2	11,252	0.0%	3,031	4%	92%	4%	83%
Cluster 3	348	6.2%	50,963	81%	19%	1%	15%
Cluster 4	141	8.5%	20,717	17%	80%	3%	56%

5.5 Execution Prices in Dark Pools (Relative Values)

We analyze the conditions under which execution prices in dark pools are determined. The data analyzed consists of dark pool execution prices that fall within the Tokyo Stock Exchange's the best bid and ask prices (inside), excluding executions at the mid-price. For each execution price (relative value)[53] in dark pools, calculations were performed for each execution across all dark pools during the analysis period for the target stocks. We conducted an analysis using a fixed-effects model, with the dark pool execution price (relative value) as the explained variable.

The analysis results show that the micro-price relative value exhibits a positive correlation. Furthermore, when the depth at the best ask price on the Tokyo Stock Exchange exceeds the time-weighted average depth for each stock on that day (a situation with relatively high selling pressure), the execution price in dark pools tends to be relatively lower (the opposite result applies for depth at the best bid price on the Tokyo Stock Exchange). This indicates that execution prices in dark pools (excluding executions at the mid-price) are affected by the order book conditions on the Tokyo Stock Exchange.

Regarding executions in dark pools, trades involving the proprietary desk tend to be executed at prices that are disadvantageous to the proprietary side (In particular, when the proprietary desk is the seller, the execution price (relative value) in the dark pool tends to be lower).

[52] We performed clustering using the K-means method. The number of clusters is determined using silhouette analysis, elbow method, etc.

[53] The dark pool execution price (relative value) can range from -1 to +1 for executions within the Tokyo Stock Exchange's best bid and ask prices. Prices closer to the Tokyo Stock Exchange's best bid price approach -1, while prices closer to the Tokyo Stock Exchange's best ask price approach +1. This indicates whether the execution price in dark pools is higher or lower relative to the mid-price, based on the spread of the Tokyo Stock Exchange's best bid and ask prices.

Table 5.5.1 Analysis results for execution prices (relative values) in dark pools

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Above average depth (both sides) dummy	2.20×10^{-3}**	0.02	2.42	3.00×10^{-49}	0.69	0.40
Above average depth (Ask) dummy	-1.47×10^{-2}***	0.00	-3.55	-1.43×10^{-2}***	0.00	-7.04
Above average depth (Bid) dummy	8.00×10^{-3}**	0.01	2.45	1.13×10^{-2}***	0.00	8.03
Micro price (relative value)	4.46×10^{-2}***	0.00	9.87	3.08×10^{-2}***	0.00	13.07
Seller-side proprietary dummy	-3.70×10^{-3}**	0.01	-2.49	-1.40×10^{-2}***	0.00	-5.92
Buyer-side proprietary dummy	1.02×10^{-2}***	0.00	6.15	1.19×10^{-2}***	0.00	7.32
Cluster 2 dummy	5.00×10^{-4}	0.16	1.41	-3.04×10^{-5}	0.91	-0.11
Cluster 3 dummy	4.00×10^{-4}	0.28	1.08	8.00×10^{-4}	0.11	1.58
Cluster 4 dummy	9.60×10^{-3}**	0.01	2.45	2.40×10^{-3}	0.52	0.65
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	2,193,731			3,058,281		
R-squared (Within)	0.02			0.01		

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

5.6 Price Improvement Rate in Dark Pools

We also analyze the factors affecting the price improvement rate in dark pools. For this analysis, we exclude trades executed at the mid-price and perform fixed-effects analysis separately for the buyer's price improvement rate and the seller's price improvement rate relative to the explained variables. Furthermore, since a correlation exists between the depth on the Bid-side (buy side) and the depth on the Ask-side (sell side) used as explanatory variables, we conduct the analysis by separately adding the depth on the Bid-side and the depth on the Ask-side as explanatory variables.

5.6.1 Buyer-side Price Improvement Rate

The analysis results for the buyer-side price improvement rate are shown in Table 5.6.1. As mentioned above, we conducted separate analyses for the explanatory variables by adding Bid-side depth and Ask-side depth.

Examining the results after adding bid-side depth as an explanatory variable reveals that the coefficient for bid-side depth during high-volatility periods is negatively significant. This indicates that an increase in the best bid depth on the Tokyo Stock Exchange leads to a decline in the buyer-side price improvement rate in dark pools. Furthermore, when we examine the results after adding the Ask-side depth as an explanatory variable, the coefficient for the Ask-side depth is found to be positive and statistically significant. This indicates that an increase in the depth at the best ask price on the Tokyo Stock Exchange leads to an increase in the buyer-side price improvement rate in dark pools. These results align with the aforementioned finding that execution prices in dark pools (relative values) are proportional to micro-prices.

Furthermore, when the seller is proprietary, the buyer-side price improvement rate is positive, whereas when the buyer is proprietary, the buyer-side price improvement rate is negative. This indicates that proprietary trades in dark pools tend to execute at relatively unfavorable prices. Regarding execution volume, while a large execution volume is expected to negatively impact the price improvement rate, a positive impact was observed on the buyer-side price improvement rate. The reason for this is unclear. Analysis of the sell-side price improvement rate shows a negative impact during low-volatility periods. The fact that a larger execution volume improves the buyer-side price improvement rate but worsens the seller-side price improvement rate may be due to the impact of other variables not included in this analysis.

The relative spread on the Tokyo Stock Exchange (calculated by subtracting the best bid price from the best ask price, dividing by the stock price, and standardizing the spread for each stock) has a positive correlation with price improvement.

This suggests that when spreads are wide on the Tokyo Stock Exchange, market makers in dark pools gain greater flexibility in the prices they can quote (executions are more likely to occur at prices deviating from the midpoint), potentially leading to a higher price improvement rate.

Table 5.6.1 Analysis results for the buyer-side price improvement rate (Depth_Bid as the explanatory variable)

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Above average depth (both sides) dummy	1.98×10^{-6}***	0.00	5.62	1.08×10^{-7}	0.88	0.15
Depth (Bid)	-7.51×10^{-7}*	0.05	-1.95	-7.19×10^{-6}***	0.00	-6.32
Seller-side proprietary dummy	2.41×10^{-5}***	0.00	31.24	2.70×10^{-5}***	0.00	23.33
Buyer-side proprietary dummy	-2.51×10^{-5}***	0.00	-26.63	-4.08×10^{-5}***	0.00	-33.26
Cluster 2 dummy	4.50×10^{-7}**	0.02	2.25	2.31×10^{-7}	0.27	1.10
Cluster 3 dummy	-5.92×10^{-6}**	0.05	-1.98	-2.97×10^{-6}	0.12	-1.55
Cluster 4 dummy	8.47×10^{-7}	0.55	0.60	9.46×10^{-6}***	0.00	5.50
Execution volume	2.70×10^{-6}***	0.00	5.08	4.92×10^{-6}***	0.00	3.73
Relative spread	1.00×10^{-4}***	0.00	26.36	1.52×10^{-5}***	0.00	2.91
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	4,324,531			6,315,261		
R-squared (Within)	0.11			0.02		

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

Table 5.6.2 Analysis results for the buyer-side price improvement rate (Depth_Ask as explanatory variable)

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Above average depth (both sides) dummy	1.36×10^{-6}**	0.02	2.27	-1.28×10^{-6}	0.19	-1.32
Depth (Ask)	1.23×10^{-5}***	0.00	6.22	1.33×10^{-5}***	0.00	8.18
Seller-side proprietary dummy	2.41×10^{-5}***	0.00	31.22	2.69×10^{-5}***	0.00	24.00
Buyer-side proprietary dummy	-2.51×10^{-5}***	0.00	-26.45	-4.09×10^{-5}***	0.00	-34.03
Cluster 2 dummy	4.46×10^{-7}**	0.03	2.22	2.32×10^{-7}	0.26	1.12
Cluster 3 dummy	-6.00×10^{-6}**	0.05	-1.97	-2.87×10^{-6}	0.12	-1.56
Cluster 4 dummy	8.96×10^{-7}	0.53	0.63	9.36×10^{-6}***	0.00	5.54
Execution volume	2.81×10^{-6}***	0.00	5.22	4.83×10^{-6}***	0.00	3.66
Relative spread	1.00×10^{-4}***	0.00	26.36	1.51×10^{-5}***	0.00	2.91
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	4,324,531			6,315,261		
R-squared (Within)	0.11			0.02		

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

5.6.2 Seller-Side Price Improvement Rate

The analysis results for the seller-side price improvement rate, conducted similarly to the buyer-side analysis, are as follows. Contrary to the aforementioned analysis results for buyer-side price improvement, the depth on the Bid-side is positively significant, while the depth on the Ask-side is negatively significant. This indicates that the price improvement rate in dark pools also varies depending on the order book conditions at the Tokyo Stock Exchange.

Furthermore, regarding the impact of proprietary trading on price improvement rate, when the seller is proprietary, the seller-side price improvement rate is negative, while when the buyer is proprietary, the seller-side price improvement rate is positive. This reveals that in analyzing the seller-side price improvement rate, the proprietary side's price improvement rate also tends to execute at relatively unfavorable prices.

Table 5.6.3 Analysis results for the seller-side price improvement rate (Depth_Bid as explanatory variable)

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Above average depth (both sides) dummy	-1.25×10^{-6}***	0.00	-3.75	6.14×10^{-7}	0.37	0.91
Depth (Bid)	7.73×10^{-7}**	0.05	2.00	9.15×10^{-6}***	0.00	9.46
Seller-side proprietary dummy	-2.37×10^{-5}***	0.00	-30.83	-3.98×10^{-5}***	0.00	-32.09
Buyer-side proprietary dummy	2.51×10^{-5}***	0.00	28.27	2.66×10^{-5}***	0.00	29.31
Cluster 2 dummy	-8.57×10^{-8}	0.66	-0.44	5.87×10^{-7}**	0.02	2.39
Cluster 3 dummy	5.44×10^{-6}*	0.06	1.87	9.70×10^{-6}***	0.00	7.17
Cluster 4 dummy	4.24×10^{-6}***	0.00	3.08	1.38×10^{-5}***	0.00	8.09
Execution volume	-2.84×10^{-6}***	0.00	-7.34	-1.45×10^{-6}	0.13	-1.51
Relative spread	1.00×10^{-4}***	0.00	58.62	1.23×10^{-5}**	0.04	2.10
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	4,324,532			6,315,262		
R-squared (Within)	0.11			0.02		

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

Table 5.6.4 Analysis results for the seller-side price improvement rate (Depth_Ask as explanatory variable)

	Low-volatility periods			High-volatility periods		
	Unstandardized coefficient	Significance probability	t-value	Unstandardized coefficient	Significance probability	t-value
Above average depth (both sides) dummy	-6.31×10^{-7}	0.29	-1.07	1.74×10^{-6}*	0.08	1.77
Depth (Ask)	-1.21×10^{-5}***	0.00	-6.30	-7.93×10^{-6}***	0.00	-7.11
Seller-side proprietary dummy	-2.36×10^{-5}***	0.00	-30.80	-3.98×10^{-5}***	0.00	-32.37
Buyer-side proprietary dummy	2.51×10^{-5}***	0.00	28.04	2.67×10^{-5}***	0.00	29.91
Cluster 2 dummy	-8.17×10^{-8}	0.68	-0.41	5.86×10^{-7}**	0.02	2.39
Cluster 3 dummy	5.52×10^{-6}*	0.06	1.86	9.63×10^{-6}***	0.00	7.36
Cluster 4 dummy	4.20×10^{-6}***	0.00	3.04	1.39×10^{-5}***	0.00	8.19
Execution volume	-2.95×10^{-6}***	0.00	-7.48	-1.38×10^{-6}	0.15	-1.45
Relative spread	1.00×10^{-4}***	0.00	58.63	1.23×10^{-5}**	0.04	2.10
Stock fixed effects	Yes			Yes		
Time fixed effects	Yes			Yes		
No. Observations	4,324,532			6,315,262		
R-squared (Within)	0.11			0.02		

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

5.6.3 (Supplement) Analysis of Proprietary Executions in Dark Pools

Analysis of price improvement rates thus far shows that for proprietary orders, the price improvement rate on the proprietary side is relatively poor. However, questions remain as to why the proprietary side's price improvement rate is deteriorating. Analyzing the conditions under which proprietary executions in dark pools are likely to occur could provide clues to understanding why executions on the proprietary side result in lower price improvement rate.

Regarding the conditions under which proprietary executions are more likely to occur in dark pools, we code proprietary executions as 1 and agency executions as 0, and, as before, use logistic regression separately for the low-volatility and high-volatility periods to analyze the cases where the buyer is proprietary and where the seller is proprietary.

Some dark pools have no or nearly zero proprietary execution ratios. Including data from such dark pools in the analysis would likely yield inappropriate results. Therefore, this analysis only considers data from dark pools with a proprietary execution ratio (based on number of transactions) of 0.1% or higher. Furthermore, to control for dark pool-specific impacts, a logistic regression analysis model incorporates dummy variables for each dark pool. Additionally, all explanatory variable data is standardized (mean 0, variance 1) for this analysis.

Logistic Regression Analysis Model

When constructing a model using n explanatory variables(x_1 , x_2 , ⋯ , x_n) and n+1 partial regression coefficients (β_0 , β_1 , ⋯ β_n) (including constant terms) to estimate the probability p that the binary dependent variable Y takes the value 1(in this analysis, proprietary execution), the model is expressed as follows.

For estimating partial regression coefficients, the maximum likelihood method shall be used, and the maximum likelihood estimates obtained by this method shall be employed.

$$log(p(Y = 1)/1 - p(Y = 1)) = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n$$

The results of the logistic regression analysis model are as follows. To evaluate the model, 85% of the data was allocated as training data and 15% as validation (test) data. A model was created using the training data and then applied to the validation data. Model performance was quantified using Accuracy[54], F1 Score[55], and the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) curve[56].

Upon reviewing the results, the odds ratio for dummy variables at or above the average depth (both sides) (for the execution timing in the dark pool, if both the Bid-side and Ask-side depth in the Tokyo Stock Exchange market were equal to or greater than the time-weighted average depth for that stock on the day of execution in the dark pool, then 1; otherwise, 0) is below 1. This indicates that greater depth on both the Bid and Ask sides in the Tokyo Stock Exchange market is associated with the lower execution probability of proprietary orders.

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[54] This is a metric called Accuracy, represented using the confusion matrix: "TP (True Positive): Actual is positive and predicted is positive, TN (True Negative): Actual is negative and predicted is negative, FP (False Positive): Actual is negative and predicted is positive, FN (False Negative): Actual is positive and predicted is negative", the calculation formula is
$Accuracy = (TP + TN)/(TP + TN + FP + FN)$.

[55] This is used to evaluate model performance more balanced in imbalanced datasets (where the proportion of y=1 is skewed). Using precision ($Precision = TP/(TP + FP)$) and recall ($Recall = TP/(TP + FN)$), the F1 Score is calculated as: $F1$ score = 2 × ($Precision \times Recall)/(Precision + Recall$)

[56] Receiver operating characteristics. The X-axis represents the false positive rate ($FP/(FP + TN)$), and the Y-axis represents the true positive rate ($TP/(TP + FN)$). Since this is a binary problem, when a certain threshold is set, (e.g., threshold=0.5), values exceeding the threshold (e.g., 0.6) are classified as Y=1. By varying this threshold from 0 to 1 and plotting the corresponding false positive rate and true positive rate, we can construct a ROC curve. If the model's predictions were random, moving the threshold from 1 to 0 would cause both the false positive and true positive rates to increase at the same rate, and the area bounded by the ROC curve and the X axis (AUC) would be close to 0.5. Furthermore, as the model's predictions become more accurate, the area bounded by the ROC curve and the x-axis (AUC) approaches 1. The closer it is to 1, the higher the model's predictive accuracy is considered to be.

On the other hand, when the buyer is the market maker (proprietary trader), the odds ratio for the depth (Bid) exceeds 1, and when the seller is the market maker (proprietary trader), the odds ratio for the depth (Ask) exceeds 1. This indicates that the probability of proprietary-execution increases when the depth on the same side as the proprietary-execution is large. Regarding the micro-price (relative value), it also indicates that as the micro-price (relative value) increases, the execution probability for the buyer being proprietary increases, while the execution probability for the seller being proprietary decreases.

Based on the above, we can see that proprietary executions are more likely to occur when the depth in the same direction as the proprietary order is high. Furthermore, the execution probability of proprietary buy orders increases (while the execution probability of proprietary sell orders decreases) when the micro-price (relative value) is high. This suggests that the execution price for proprietary orders appears relatively unfavorable.

Regarding the execution time, the odds ratio exceeds 1, indicating that the execution probability of proprietary orders increases as the time of day gets later. Generally, volatility in the stock market tends to be highest during the morning session opening period as it incorporates information from the previous day, while depth increases and volatility tends to decrease toward the afternoon session closing (see Figure 5.1.1). Prop-trading tends to occur during periods when the market is relatively stable, avoiding times of high volatility.

As for the quoted spread on the Tokyo Stock Exchange, the odds ratio is below 1, indicating that the execution probability of proprietary orders decreases when the quoted spread is wide. Furthermore, the odds ratio for execution volume is also below 1, suggesting that the execution probability of proprietary executions tends to decrease as execution volume increases.

From the above, we can infer that the execution of proprietary orders in dark pools is conducted with risk control measures in place, taking into account factors such as the order book situation on the Tokyo Stock Exchange market. Regarding the price improvement rate, it appears that the proprietary side's price improvement rate has deteriorated as a result of executing trades, likely due to references to micro-prices and similar factors.

Table 5.6.5 Logistic regression analysis results for the buyer-side proprietary

	Low-volatility periods		High-volatility periods	
	Odds ratio[57] (95% CI)	Significance probability	Odds ratio (95% CI)	Significance probability
Above average depth (both sides) dummy	0.858 (0.857 - 0.86)	0.00	0.86 (0.858 - 0.861)	0.00
Depth (Bid)	1.111 (1.109 - 1.114)	0.00	1.096 (1.094 - 1.098)	0.00
Execution time (seconds)	1.221 (1.219 - 1.223)	0.00	1.257 (1.255 - 1.259)	0.00
Quoted spread (TSE)	0.894 (0.892 - 0.896)	0.00	0.854 (0.851 - 0.858)	0.00
Micro price (relative value)	1.038 (1.036 - 1.039)	0.00	1.028 (1.026 - 1.03)	0.00
Mid-price execution dummy	0.993 (0.991 - 0.995)	0.00	0.995 (0.992 - 0.997)	0.00
Execution volume	0.776 (0.771 - 0.781)	0.00	0.682 (0.677 - 0.687)	0.00
No. Observations	7,030,313		7,514,399	
Proportion of y=1	0.17		0.18	
Mcfadden Pseudo R-squared[58]	0.43		0.41	
Log-likelihood	-3,891,050		-4,246,926	
Accuracy	0.71		0.68	
F1 Score	0.45		0.44	
ROC_AUC	0.74		0.74	

[57] The odds ratio can be calculated from the partial regression coefficients derived from the model. For example, if the partial regression coefficient for the execution volume is -0.254, the odds ratio becomes $e^{-0.254} = 0.776$. The odds ratio indicates how much the probability of y=1 (here, the execution probability of proprietary orders) changes when a variable changes by one unit. Given that the odds ratio for execution volume is 0.776, a one-unit increase in the standardized execution volume is associated with a 22.4% decrease in the probability that y=1.

[58] A goodness-of-fit measure for logistic regression models proposed by McFadden (1974), typically taking values between 0 and 1 and analogous to the coefficient of determination in multiple regression analysis. By denoting the likelihood calculated using partial regression coefficients estimated by maximum likelihood estimation as L_{full}, and denoting the likelihood with all partial regression coefficients set to zero as L_{null}, $Mcfadden\ pseudo\ R^2 = 1 - L_{full}/L_{null}$ is used for the calculation.

Table 5.6.6 Logistic regression analysis results for the seller-side proprietary

	Low-volatility periods		High-volatility periods	
	Odds ratio (95% CI)	Significance probability	Odds ratio (95% CI)	Significance probability
Above average depth (both sides) dummy	0.854 (852 - 0.855)	0.00	0.838 (0.836 - 0.839)	0.00
Depth (Ask)	1.193 (1.191 - 1.194)	0.00	1.316 (1.314 - 1.319)	0.00
Execution time (seconds)	1.213 (1.211 - 1.216)	0.00	1.151 (1.149 - 1.153)	0.00
Quoted spread (TSE)	0.864 (0.862 - 0.866)	0.00	0.877 (0.873 - 0.88)	0.00
Micro price (relative value)	0.949 (0.948 - 0.951)	0.00	0.98 (0.978 - 0.982)	0.00
Mid-price execution dummy	0.99 (0.988 - 0.992)	0.00	0.927 (0.925 - 0.929)	0.00
Execution volume	0.623 (0.618 - 0.628)	0.00	0.581 (0.577 - 0.586)	0.00
No. Observations	7,030,313		7,514,399	
Proportion of y=1	0.15		0.17	
Mcfadden Pseudo R-squared	0.43		0.44	
Log-likelihood	-3,977,799		-4,158,020	
Accuracy	0.69		0.66	
F1 Score	0.40		0.44	
ROC_AUC	0.72		0.75	

6 Conclusion

We analyzed data from August 17, 2020 onward, following the introduction of dark pool flags, and examine the impact of dark pool trading on the market under different market conditions.

Our results show that the dark pool ratio (relative to the Tokyo Stock Exchange's on-auction market) tends to decline in high-volatility environments. This decline is observed not only during periods of elevated overall market volatility, but also in situations characterized by high stock-specific volatility, high order volume, or high market order ratios. These findings suggest that investors—primarily institutional investors, since retail investors are generally assumed to access dark pools via smart order routing (SOR) services provided by trading participants—become more sensitive to execution uncertainty, such as delay costs, in dark pools, where order book information is opaque. As a result, the proportion of trades executed in dark pools tends to decrease.

With respect to market quality, we find that an increase in the dark pool ratio tends to suppress price impact in low-volatility environments, thereby exerting a relatively positive effect on market quality. In contrast, in high-volatility environments, a higher dark pool ratio may impair price discovery and have a negative impact on market quality. Looking ahead, if the dark pool ratio were to rise substantially above its current level, adverse effects—such as a deterioration in the overall market's price discovery function—could become more pronounced. This raises the possibility that even in low-volatility environments, excessively high levels of dark pool activity could eventually undermine market quality.

Regarding execution prices, we find a positive relationship between micro-prices—reflecting order book conditions, particularly depth, in the Tokyo Stock Exchange's on-auction market—and execution prices in dark pools. This indicates that order book conditions in the lit market play an important role in determining execution prices in dark pools.

We also find that price improvement rates in dark pools are influenced by order book conditions in the on-auction market in a manner similar to execution prices. While buyer-side price improvement rates exhibit a positive relationship with executed volume, seller-side price improvement rates display a negative relationship. Although one might expect price improvement to decline mechanically as execution volume increases, our results suggest that the relationship is more complex and may be driven by factors beyond the variables considered in this study.

Finally, our analysis shows that proprietary trades executed by firms in dark pools tend to occur at prices that are relatively disadvantageous compared to those of their counterparties. One possible explanation is that when depth on the same side of the order book is large in the Tokyo Stock Exchange's on-auction market, proprietary orders are more likely to be executed. Under such conditions, micro-prices tend to move in an unfavorable direction relative to the midpoint. In addition, given the decline in execution probability when spreads widen or execution volumes increase in the Tokyo Stock Exchange's on-auction market, as well as the tendency for proprietary executions to increase in the afternoon session when volatility stabilizes, it appears that proprietary trading in dark pools is conducted in a manner that balances execution opportunities with risk management considerations.

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