Impact of Speed Competition in High Frequency Trading (HFT)

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Abstract

Based on a paper titled "Quantifying-HFT-Races" (Budish et al. (2021)) published on the website of United Kingdom Financial Conduct Authority (FCA) (FY 2020), we made an attempt to ascertain the speed competition environment of entities registered as entities conducting high-speed trading under the Japanese Financial Instruments and Exchange Act (FIEA) (high frequency traders are hereafter referred to as "HFTers"), using data from the Tokyo Stock Exchange (TSE) on approximately 4,000 issues with a four-digit securities code between September 15 and 22 (for five business days), 2021. The main conclusions of the analysis in this paper are as follows: (1) Also in the Japanese market (just like in the U.K), "races" in which two or more market participants compete for trading speed by placing orders for the same issue at the same price are held. The trading value of these races accounts for approximately 22.8% of the total trading value on the TSE, and the number of races in the total number of take-orders accounts for approximately 31%. (2) No major registered HFTers are classified as make-type, in which only make-orders are placed; major registered HFTers are classified as balanced-type, in which make-orders and take-orders are combined; and registered HFTers specialized in speed are classified as sniper-type. In particular, (3) seven sniper-type registered HFTers who quickly take inferior orders are identified. Three of them classified as sniper-type placed a large number of IOC orders expired, and it is suggested that there are executed orders that cannot be grasped by information in the order book. Furthermore, the observation by strategy/entity revealed

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Many FSA staff, including Naoyuki Yoshino, Director of the FSA Research Center, Takashi Hayashi (Professor at Keio University's Graduate School of Business Administration), Tomonori Yuyama (Visiting Researcher at Georgetown University), and Shintaro Okude, Assistant Director of the macroanalysis Office, Risk Analysis Division, Policy Bureau, the FSA, provided useful opinions on the program implemented in this paper. And also we appreciate the dedicated support from other JFSA staff members, including Megumiko Hirose, for proofreading our English translation. However, the opinions expressed in this paper belong to the authors personally, and do not represent the FSA/SESC's official position. Any possible errors are to be attributed to us personally.

opposing views on races. (4) From a strategic perspective, in ETF (Exchange Traded Fund) trading, large-scale races, which are mainly caused by arbitrage strategies for futures, etc., are active (ranging from 11% to nearly 34% of the total trading value of all races), indicating that they may be contributing to the improvement of price linkages between products/markets. (5) From the viewpoint of the participants, we observed a situation where some market-making firms were constant losers (where they were unsuccessful in their attempt for cancellation) in the race. If, as a result, liquidity providers who quote market making are forced to pull out or change their strategies by players belonging to the sniper-type or balanced-type who conduct take-orders, a question arises as to whether excessive speed racing is meaningful for the overall market.

Keywords: High-speed trading, HFT, take-orders, make-orders, speed competition, IOC orders, liquidity provision, Ghost (Phantom) Liquidity

1. Introduction

Along with the development of information technology, the systems of exchanges have become more sophisticated, and algorithmic trading has recently swept the global trading markets (The Word Federation of Exchanges [2013]). In particular, high-speed/high-frequency traders (hereinafter referred to as "HFTers") have become more sophisticated than other investors in terms of technology, as shown by the speed and frequency of placing and canceling high-speed/high-frequency trades[1] (hereinafter this trading is referred to as "HFT"). The ratio of trading value of registered HFTers[2] to the total placed on the TSE has exceeded 40%, and the ratio of the number of orders[3] placed by registered HFTers has exceeded 70% (大山他[2021]), 大山・津田 [2022]). The intensification of speed competition[4] (Budish et al. [2015]), Hirschey [2021]) due to the emergence of HFTers may exacerbate market participants' sense of unfairness regarding the trading environment. Furthermore, if speed competition among HFTers is deemed to be futile and harmful, various measures may be taken, such as rules proposed specifically for speed bumps[5] to address latency arbitrage and the establishment of batch auctions[6] in the market (Pagano [1996], Budish et al. [2014]), and the environment surrounding HFT has the potential to change completely. HFTers will have to continue to prove their social significance[7] as major players in the

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[1] It is also called HST (High Speed Trading) or HFT (High Frequency Trading), but in this report, the term "HFT" will be used as the basic term. High frequency trading refers to a financial market trading or investment strategy in which short-term trades are repeated at high speed.

[2] The Financial Instruments and Exchange Act ("FIEA"), which came into effect in April 2018 introduced a registration system for high-speed trading activities. People who have obtained such registration are referred to as "registered HFTers," whereas high-speed trading activity conducted by a registered person is referred to as "registered HFT," as opposed to "HFTers" and "HFT," which refer to non-registered traders and trading in general. Financial Instruments Business Operators (hereinafter referred to as "FIBOs") conduct high-speed trading. In this report, we also counted general FIBOs conducting high-speed trading as "registered HFTers."

[3] The number of orders is the total sum of the number of new orders, the number of modified orders, and the number of cancellation orders.

[4] A dispute in which the slow speed or fast speed of order placement, caused by physical distance from the exchange and the communication environment, determines the success or failure of the execution.

[5] Empirical research on trading speed regulation known as a "speed bump" shows that there is a mixture of papers with different views: Hu (2019) argues that the introduction of speed bump regulation leads to a reduction in spread; Chen et al. (2017) argue otherwise; and Khapko and Zoican (2020) argue that symmetrical speed bumps are ineffective but asymmetrical speed bumps are effective. No consensus has been reached in the academic community.

[6] A batch auction, also known as a "periodic auction," is a system that arranges auctions at random intervals ranging from 100 milliseconds to five minutes continuously throughout the day (大墳 (2016)).

[7] As for the social role to be played by HFTers, no unified research results have been obtained. In this regard, the Principles for Financial Market Infrastructures (FMI Principles) recommend the development of a trading environment that enables electronic and automated order processing to respond to the increasing speed and frequency of transactions. (CPSS [Committee on Payment and Settlement Systems] is now known as CPMI [Committee on Payments and Market Infrastructures] as of April 2012, but this committee does not necessarily apply to exchanges.) Although there are various views on this issue, one view is that if HFTers are benefiting from the improved environment, which in effect encourages exchanges to invest in systems and innovate information, thereby promoting the enhancement of social

market through their own transactions on a daily basis. Past research on the effects and functions of HFTers' trading has already been conducted from various angles, such as the functions of providing liquidity[8], price discovery, and controlling market fluctuations, where many market participants are attentive to the results of such analyses. A major area of research is market microstructure,[9] which analyzes the effects of market mechanisms, such as execution method, unit size, tick size, and price limits, on price formation processes (O'Hara [2015]). In particular, Kyle (1985) was a pioneering paper on the analysis of information asymmetries[10] among market participants on securities price formation processes.

When we focus on HFT, many papers such as 大山他 (2021) and Hasbrouck and Saar (2013) argue that HFT contributes to the effect of price discovery by contributing to the tightening of the best bid-offer (hereinafter referred to as the "BBO") spread. Brogaard (2010) and Manahov and Hudson (2014) also evaluate HFT's price discovery functionality in the same way, but there are views against it (Beno and Sagade [2016]). Furthermore, as for the impact of HFT on market volatility, there are analyses that HFT increases market volatility (Virgilio [2016] and Caivano [2015]), in contrast to analyses that HFT decreases market volatility (Myers and Gerig [2015] and Hagströmer and Nordén [2013]). A recent study worth noting is an assertion that no liquidity of HFTers actually exists (also known as Ghost liquidity or Phantom liquidity) (Authority for the Financial Markets [2016], Degryse et al. [2021], Ersan et al. [2021]). 大山・津田 (2020) also point out that HFT merely provides liquidity thinly near the BBO when viewed from depth of order book rather than BBO spread. In this paper, while we also observe that the highly frequent make-orders of registered HFTers contribute to the order book (in the ETF market), the trading value of take-orders was nearly twice that of make-orders, suggesting that on the basis of trading value, registered HFTers demand liquidity from the order book more than providing

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infrastructure, which is a public good, HFT is expected to contribute by eliminating distortions in market prices, providing liquidity, etc.

8 Liquidity is a market characteristic of whether a market can trade a larger number of orders faster and with smaller price impact (林 高樹・佐藤彰洋 [2016b]). Kyle (1985) describes the elements of market liquidity characteristics as (i) best bid offer spread (=best offer price - best bid price), (ii) depths (the amount of orders required to move prices by a given amount), and (iii) resilience (the speed with which markets recover from random, uninformed shocks). In the empirical analysis, in addition to the spreads and depths mentioned above, liquidity is also measured by volume (number of execution), trading turnover, Kyle's (1985) λ, Amihud's (2002) ILLIO (Illiquidity Indicator), and Deuskar and Johnson's (2011) ILOBS (inverse limit order book slope).

9 See, for example, 林 高樹・佐藤彰洋 (2016b) for the mechanism of market transactions that is the basis of market microstructure research. See, for example, empirical research on market microstructure, 林 高樹・佐藤彰洋 (2016a) and Hasbrouck (2007).

10 The high-speed and high-frequency characteristics of HFTers are not directly linked to the quantity and quality of information. As a result, such characteristics may not necessarily cause information symmetries among market participants.

liquidity.[11] On the other hand, on July 2, 2018, the TSE introduced an ETF Market Making Incentive Scheme,[12] and as of July 2022, 9 out of 12 market makers that fulfill quoting obligations are registered HFTers. The purpose of the market-making system is to create a market environment that is easy for a wide range of investors to buy and sell, and while registered HFTers receive incentives (compensation) for fulfilling their obligations, their entry into the system seems to play the role of providing liquidity to the order book. In any events, the competitive environment surrounding HFT differs depending on the taxation system, the trading system of each exchange[13] (including the tick size, liquidity of each issue, attributes of investors who trade, trading systems, etc.), and market conditions and trends. Above all, since the results of analyses are influenced by analyses' methods, there is no unified view on the merits and demerits of HFT at present.

In analyzing HFT in light of this prior literature, our viewpoint is as follows. First, this paper considers that there are high barriers to identifying which frequently repeated new orders and cancellation orders are based on what kind of strategy (even if the market share and presence of registered HFTers can be understood) by aggregating orders from each and every registered HFTer. In addition, we do not fully understand all the trading strategies of the many existing HFTers, so even analyzing registered HFTs on the basis of the trading strategies we understand does not give us an overview of HFTs as a whole. However, if multiple registered HFTers compete in the world of several milliseconds and microseconds and engage in speed competition every day, there must be a trace of transactions that have lost the speed competition. In this paper's analysis, therefore, we believe that we can identify and reveal the entire picture of speed competition one by one by searching for winners who were able to place and execute (or cancel) orders prior to the losers' attempts (the trace of speed competition) to place IOC orders or cancel orders, starting from the point at which the losers' attempts to place IOC orders or cancel orders failed. In addition, since the search scope is set at a short interval of 10 milliseconds (1/100 second), the subject of analysis is naturally limited to high-speed traders, centered on registered HFTers. This exhaustively captured speed competition is a trace of the battle among registered HFTers, and it is

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[11] However, 大山他(2021) found no significant trading behavior of registered HFTers directly linked to amplification of market fluctuations when they looked at all registered HFTers trading and the overall market in "4.5 Analysis on the contribution ratio of averaging-down/averaging-up to surging or plunging in stock prices."

[12] For more information, please visit the TSE website at:
(https://www.jpx.co.jp/equities/products/etfs/market-making/index.html: last viewed October 13, 2022)

[13] Menkveld (2013) explained HFT's contribution to Chi-X and pointed out good compatibility between PTS and HFT.

deemed to condense various information as to why, when, and how the competition occurred, who developed what kind of strategy, and so on.[14]

As a concrete analysis, the Securities and Exchange Surveillance Commission (SESC) first obtained from TSE the most granular order book data (hereinafter referred to as "Order Book Data ")[15] of about 4,000 issues with a four-digit securities code[16] (hereinafter referred to as "cash equities") from September 15 to 22, 2021 (for five business days), as well as the message data[17] of cash equities including information on expirations in order or cancellation attempts ("IOC order attempt" and "cancellation order attempt failure"). Based on "Quantifying the High Frequency Trading 'Arms Race'"(Budish et al. [2021]) published on the website of the U.K. FCA in 2020, we aggregated the aforementioned speed competition (strictly speaking, what satisfies the definition of speed competition to be described later is called a "race," which generally means that two or more market participants compete for speed when placing orders for the same issue and price). Because it is necessary to gather information on speed competition among registered HFTers without touching on information on individual firms when publishing information, we divided the 36 registered HFTers that placed orders during the analysis period into three groups (make-type, balanced-type, and sniper-type) and tried to clarify the characteristics of each group.

The main conclusions of the analysis in this paper are as follows: (1) Also in the Japanese market, "races" (as well as Budish et al. (2021)) in which two or more market participants compete for trading speed by placing orders for the same issue at the same price are held and the trading value of these races accounts for approximately 22.8% of the total trading value on the TSE, and the number of races in the total number of take-orders accounts for approximately 31%. (2) Small-scale registered HFTers are classified as make-type, in which only make-orders are placed, large-scale[18] registered HFTers are classified as balanced-type, in which make-orders and take-orders are combined, and registered HFTers specialized in speed are classified as sniper-type. In particular, (3) seven sniper-type registered HFTers who quickly take inferior orders are identified. Three of them are classified as sniper-type

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[14] "IOC order" stands for "Immediate or Cancel order" and is a conditional order that is executed immediately in whole or in full at a designated price or a more favorable price, and immediately terminates any order not executed.

[15] The most granular order book data on the TSE, consisting of multiple items.

[16] Listed financial instruments (such as preferred stocks) other than those represented by a four digit code are excluded.

[17] Since the message data contains information about trading and cancellation attempts (termination information) that is not related to order book updates, it is possible to observe both winners and losers in the speed race.

[18] It does not refer to specific firms, but only to registered HFTers that have the highest market share in terms of the number of orders and trading value on the TSE.

and placed a large number of IOC orders expired, and it is suggested that there are executed orders that cannot be grasped by information on the order book. Furthermore, the observation by strategy/participant revealed opposing views on the race. (4) From a strategic perspective, in ETFs, large-scale races, which are mainly caused by arbitrage strategies for futures, etc., are active (ranging from 11% to nearly 34% of the total trading value of the race), indicating that they may be contributing to the improving of price linkages between products/markets.[19] Yet, while only a limited number of participants may benefit from the increasingly faster millisecond (1/1000 second) and microsecond (1/100,000,000 second) price linkage, technological developments may indirectly and directly benefit other investors, including retail investors, in other unimaginable ways in the future. (5) From the viewpoint of the participants (HFTers), we observed a situation where some market-making players were constant losers (where they were unsuccessful in their attempt for cancellation) in the race. If, as a result, liquidity providers who quote market making are forced to pull out or change their strategies by players who are sniper-type or balanced-type and conduct take-orders, a question arises as to whether excessive speed racing is meaningful for the overall market.[20] (6) Although it was suggested that other investors[21] who are not HFTers may be participating in the race unintentionally, but under the definition of "race" in this paper, other investors are only counted as winners in a specific competitive environment, and there was no indication that other investors who are not HFTers were suffering losses as a result of the speed race. While this paper is intended to comprehensively capture the picture of speed racing and not to measure the existence or extent of losses for other investors who are not HFTers, a detailed analysis will be necessary if an investment behavior of other investors is predicted and causes the race of registered HFTers to occur in the future.

This paper is structured as follows: Chapter 2 explains the definition of high-speed trading, virtual servers, and data, and points to keep in mind based on the analysis of time differences between order placement times based on the timing of "timestamping" (recording time) in the data. Chapter 3 classifies registered HFTers into three categories: "make-type," "balanced-type," and "sniper-type," and Chapter 4 presents the results of an analysis of the

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[19] Budish and Cramton, Shim (2015) note that the arbitrage appearance interval between the E-mini S&P 500 future (ES) and the SPDR S&P 500 ETF (SPY) has shortened to within 10 milliseconds in 2011. They also state that 89% of arbitrage opportunities were initiated by price changes in the ES (futures-driven theory).

[20] Analysis and arrangement of price linkage between products and markets (regarding the extent to which HFTers are currently involved, the extent to which they should be expected, etc.), the extent to which linkage is required, and whether there is any viewpoint in the industry, including experts).

[21] As explained in Section 4.3.2 below, this refers to other investors, including individual investors who conduct non-high-speed trading.

state of speed competition on the TSE. Chapter 5 concludes with a summary and future issues.

2. Definitions, data, etc.

2.1. Definition of High Speed Trading

This section explains the definition of "high-speed trading" under the Financial Instruments and Exchange Act (hereinafter referred to as the "FIEA"), and then introduces trends in the number of registered HFTers.[22]

The FIEA defines "high-speed trading" as securities trading and market derivatives transactions that satisfy all of the following requirements (including entrustment /management of such transactions and over-the-counter derivatives transactions for the purpose of such entrustment/management).[23]

(1) Decisions on the purchase and sale of securities and market trading of derivatives are automatically made by an electronic data processing system.
(2) The facility where the electronic data processing system described in (1) above is installed is located in the same place as, or adjacent to, or in close proximity to, the trading system (matching engine) of an exchange, etc.[24]
(3) A system is in place to prevent orders placed with the trading system described in (2) above from competing with other orders placed.

(1) above corresponds to cases where stocks, etc. are traded in so-called algorithmic trading transactions (transactions in which a computer system automatically makes investment decisions and places orders). (2) above corresponds to cases where systems with investment algorithms are typically installed in co-location[25] areas, such as exchanges. (3) above corresponds to cases where virtual servers (in the case of TSE) are typically used

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[22] For background and details, see 齋藤馨・田原泰雅（2018）.

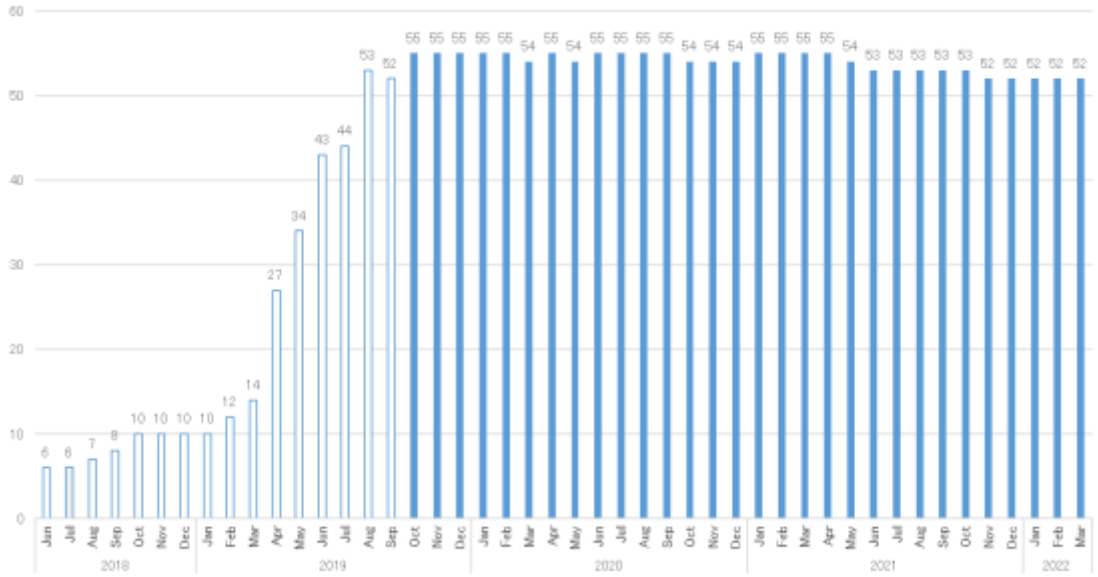
[23] Article 2, Paragraph 41 of the Financial Instruments and Exchange Act, Article 1-22 of the Enforcement Order of the Financial Instruments and Exchange Act; Article 26 of the Cabinet Office Order on definitions as stipulated in Article 2 of the Financial Instruments and Exchange Act; Financial Services Agency Regulatory Notice No. 50 of 2017; and Comprehensive Guidelines for Supervision of Financial Instruments Business Operators, etc. III-3-1-2 "Points to Note Regarding the Method of Communication of Information that Constitutes High-Speed Trading Activities."

[24] The Tokyo Stock Exchange (TSE), Osaka Stock Exchange (OSE), Nagoya Stock Exchange, Fukuoka Stock Exchange, Sapporo Securities Exchange, and PTSs [Proprietary Trading Systems], such as Japan Next, Cboe [Chicago Board Options Exchange], and Osaka Digital Exchange are covered, whereas Tokyo Financial Exchange (TFX) and fixed income PTS are not covered.

[25] A co-location service is a service that provides space and a network for setting up trading servers, etc. in a co-location area within the primary site where the TSE trading system is located. By using this service, the distance between the TSE's trading system and the market information distribution system is minimized, and the time to obtain quote information and transmit orders can be reduced to a few microseconds each way. This service is designed to be fair and to prevent some participants from buying up land around the trading system.

exclusively. However, in a public comment[26] on December 27, 2017, the FSA stated that "even if there is no mechanism for exclusive use itself, cases where a system configuration substantially equivalent to the exclusive use of virtual servers, etc., for example, fall under this."

Since October 2019, when all firms subject to the transitional measures began to be registered, the number of registered HFTers (dark blue bars) has remained almost unchanged, with more than 50 registered HFTers entering the Japanese securities market (Figure 2.1.1).



Source: Prepared by the author based on materials disclosed on the FSA website

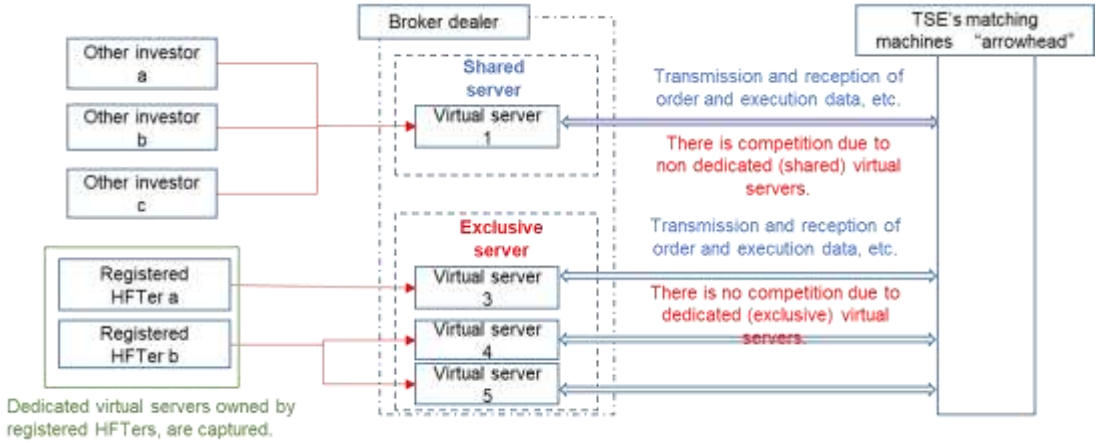
Figure 2.1.1 Changes in the Number of Registered HFTers

2.2. Virtual server

A "virtual server" is a logical device that is installed in each investor's system in order for a securities company that accepts orders from investors to send and receive data to and from the trading system of the TSE. It is like an ID given to each securities company as a unit of connection (Fig. 2.2.1). One virtual server establishes one TCP connection with the trading system. Limiting to the virtual servers that are reserved by investors ("reserved [virtual] server" in Fig. 2.2.1), it is possible to directly observe the trading behavior of investors

[26] Financial Services Agency, "Publication of finalized amendments to the related Cabinet Orders and Cabinet Office Orders, etc., following the 2017 revision of Financial Instruments and Exchange Act (FIEA)," December 2017 (2017) (https://www.fsa.go.jp/news/29/syouken/20171227.html: Last viewed date: Oct 13, 2022) (One point press release: the FSA Weekly Review No.276 https://www.fsa.go.jp/en/newsletter/weekly2018/276.html)

("HFTer A" and "HFTer B" in Fig. 2.2.1) by aggregating trading orders for each virtual server. In addition, the upper limit of the number of orders that can be placed per second is set by type.[27] In order to avoid competition with other investors and reliably execute orders even in an overheated market, investors need to pay additional costs to the TSE through the securities company and reserve a virtual server suited to their use.



Source: Prepared by the author

Figure 2.2.1 Dedicated (virtual) and shared (virtual) servers

2.3. Data

For the purposes of this analysis, the message data of the cash equities for the period from September 15 to September 22 (five business days), 2021, was newly obtained from the TSE and used for Order Book Data. The message data includes information on transactions and cancellation attempts (expiration information) that was not reflected in an update of the state of the order book. It is possible to identify the losers of the speed competition from this information and to extract all the races of the speed competition by searching for the winner from Order Book Data. Since the order time described in Order Book Data and the message data is the time stamped immediately before the matching engine,[28] the time difference between the winner and the loser includes the processing time required for the process within the exchange, and it is impossible to specify the speed that purely determines the winners and losers of the race (described in detail in the next section). It should be noted that the number of days covered by the analysis is limited to five business days due to data

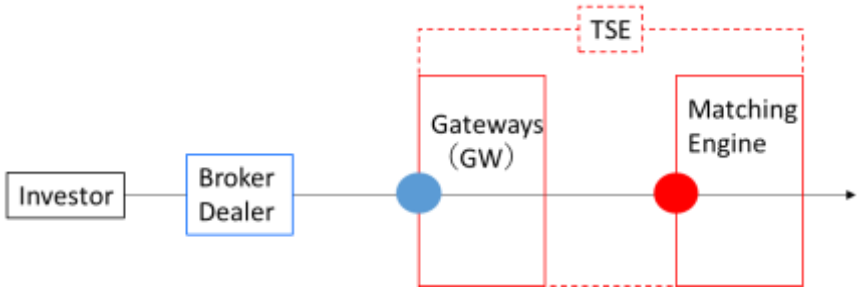
[27] There are three types of virtual servers, each with a different number of orders per second. The largest type of virtual server can place up to 200 orders per second.

[28] Refers to the trading server in arrowhead of the TSE. (https://www.jpx.co.jp/systems/equities-trading/01.html: last viewed on October 13, 2022)

constraints, and it is not possible to cover various market conditions, such as the beginning and end of a month, higher volatility and lower volatility of the market.

2.4. Points to note associated with differences in the distribution of time intervals between orders due to the timestamp

Essentially, the order information received by the exchange (a new order or a cancel or modification of an existing order) is processed in the exchange according to several processes, whereby multiple times are stamped on each order. Budish et al. (2021) measures a race based on transaction data stamped at the time when order information arrives at the exchanges (Figure 2.4.1: the blue dot, hereinafter referred to as "Exchange GWs" [gateways]). In this paper, however, we have to measure a race based on transaction data stamped immediately before it arrives at the TSE Matching Engine (Figure 2.4.1: the red dot, hereinafter referred to as "Matching Point") due to data constraints. This is because there is a queue when orders are crowded (two or more orders at the same time) between each process processed within the exchanges and the time processed by the Matching Engine. Even if two orders were timestamped at the Exchange GW at almost the same time, it was found that there would be a time difference of approximately 450 microseconds[29] between the timestamps at the Matching Point due to the second one order's waiting in front of the Matching Point until the first one order is processed. It is unavoidable that a certain amount of time is required for order processing in the first place, and although further speed-up is desirable, it may be that priority should be given to ensuring that the sequence of order at the time when it arrives at the Exchange GW is not reversed by the systems within the Exchanges.[30]



[29] It does not track one order and does not show that the time difference between the time stamped on exchange GW and the time stamped at the matching point is about 450 microseconds. In addition, from the viewpoint of speed competition, it is important which side reaches the exchange GW first, and this difference of about 450 microseconds does not give an advantage in sniping.

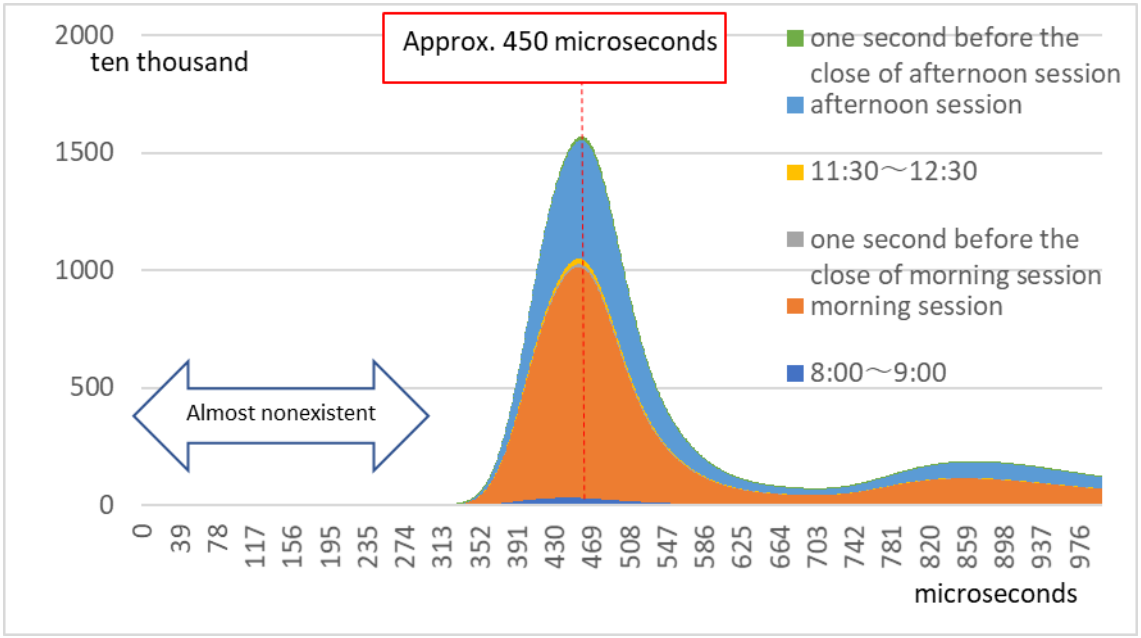
[30] In Budish (2021), it was pointed out that there were different sequences about 4% of all races in the process from the arrival at the gateway of the London Stock Exchange to the processing by the matching engine. In this analysis, since this cannot be verified due to data constraints, the analysis was performed on the assumption that the different sequence did not occur.

Source: Prepared by the author

Figure 2.4.1: Timestamp location

In fact, we can draw a frequency table as shown in Exhibit 2.4.2 by arranging all orders (a new order, cancel order, or modification of an existing order) for each issue in order using the Order Book Data for four months from June to September 2021, and measuring the order interval based on the timestamps at the matching point.[31] The mode is around 450 microseconds, with most orders in the morning and afternoon continuous sessions accounting for the majority. A characteristic pattern of around 875 microseconds can be seen, which is assumed to have occurred due to various factors, such as the type of order and processing involving a large value of orders.

In addition, the SESC obtained data for one business day (as of April 22, 2022) from the TSE by especially storing data indicating the arrival time at the GW of the TSE, and as described above, we arranged all orders (a new order, cancel order or modification of an existing order) for each issue in order sequence, and measured the interval between orders by the timestamps at the GW. The result is shown in Figure 2.4.3. This is a pure order situation that does not include noise required for processing within the exchange, and it can be seen that orders are actively placed in the unit of several microseconds.

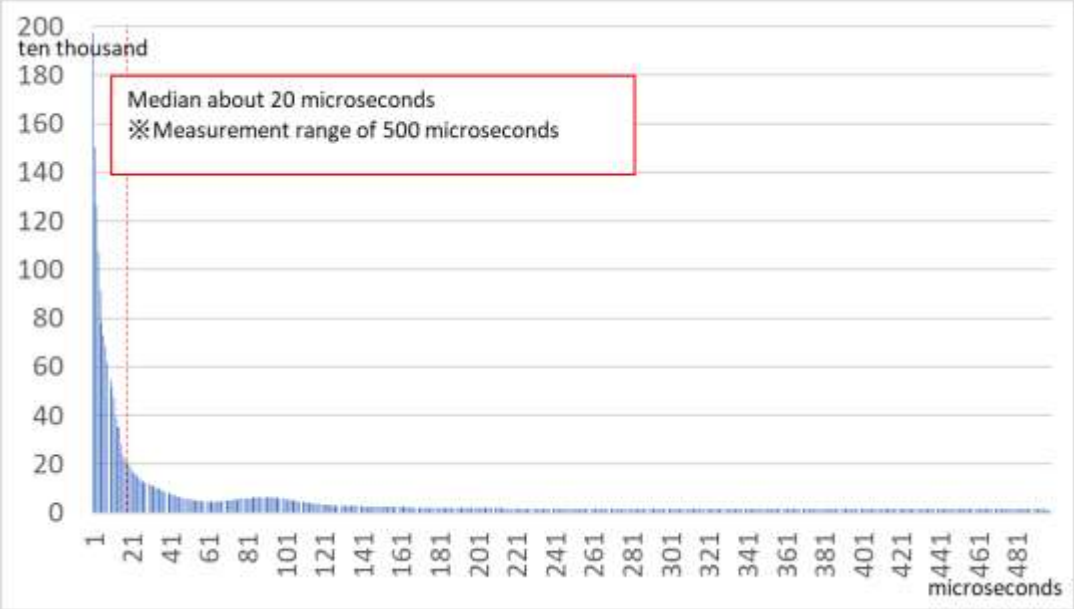


[31] Although the frequency of about 300 microseconds or less was not 0, it could have occurred merely in the system processing.

Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 2.4.2: Time of order placement, by issue, time difference between orders (for a new order, cancel order, or modification of an existing order:

Timestamped at matching points (the red dot in Figure 2.4.1)



Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 2.4.3: A time lag between orders by time of order placement, issue, and order placement (measured by the interval of time stamped at Exchange GW for a new order, cancel order, or modification of an existing order (blue circle in Figure 2.4.1))

3. Transactions of Registered HFTers Classified by Transaction Strategy Category

3.1. Number of Take-/Make-Orders and Trading Value of Registered HFTers by Strategy

In order to conduct an analysis in line with the transaction characteristics and transaction strategies of registered HFTers, this section classifies the 36 registered HFTers that placed orders during the analysis period into three groups—"Make-type," "Balanced-type," and "Sniper-type"—by aggregating and contrasting the number of orders and trading value by transaction and take-/make-order, using the five business days' of Order Book Data referred to in Chapter 2 (Figure 3.1.2). In addition, in view of the analysis of speed competition in Chapter 4, which will be described later, the characteristics of the group of registered HFTers classified in this section are clarified as much as possible. In this section, "order" includes a new order, cancel order, or modification of an existing order, except where otherwise specified.

As shown in Figure 3.1.1, new orders are classified into two types: "take-orders[32] that are immediately executed" and "make-orders[33] that are not immediately executed and quote to the order book." Make-orders provide liquidity to the order book, while take-orders consume liquidity from the order book. Therefore, registered HFTers that have a higher number of make-orders than take-orders and a greater trading value of make-orders than take-orders are classified as "make-type (liquidity supply type)" but hereinafter referred to as "make-type." On the other hand, registered HFTers that have a higher number of take-orders and a greater trading value of take-orders are classified as "take-type (sniper-type[34])" but hereinafter referred to as "sniper-type." The remaining registered HFTers that are not classified as "make-type" or "sniper-type" are classified as "balanced-type" because they have a higher number of make-orders than take-orders and a greater trading value of take-orders than make-orders. This chapter also includes the number of "expired IOCs" (failures to attempt to execute take-orders), which is one of the conditions for speed competition losers in Chapter 4.[35]

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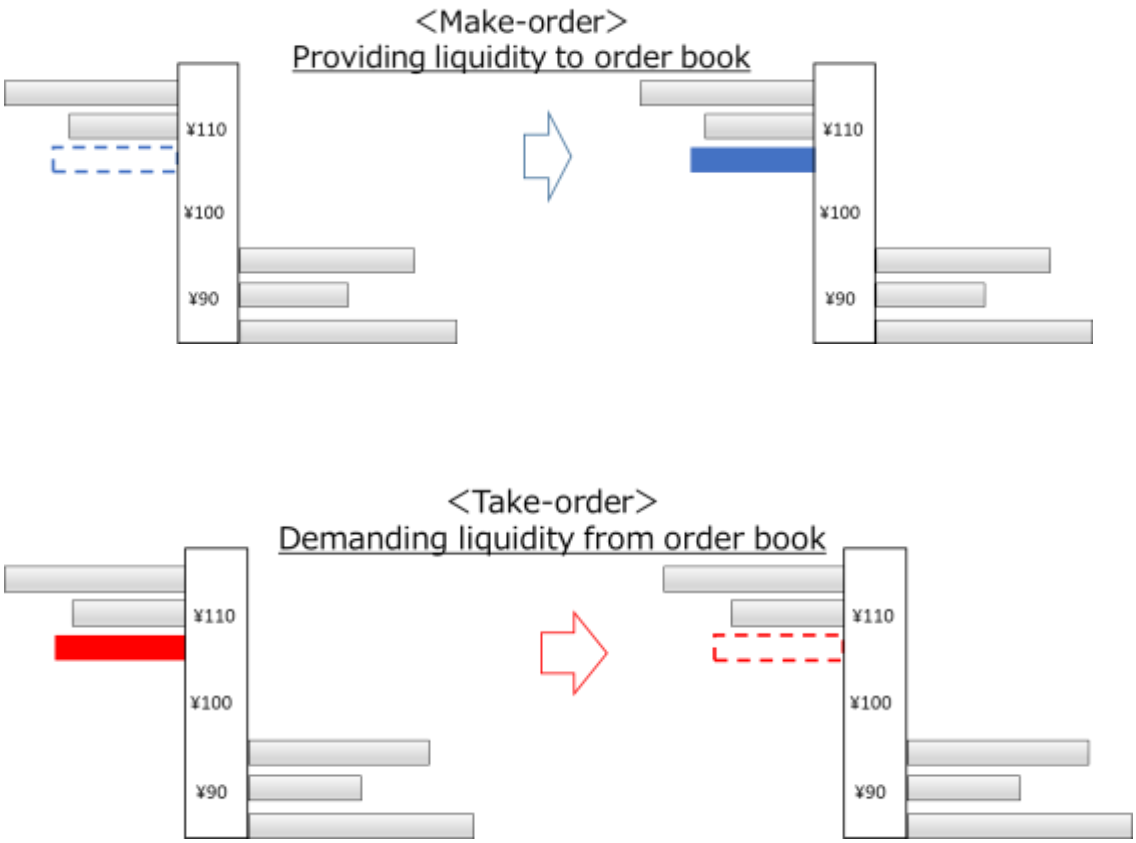
[32] Partially settled limit-orders, orders with IOC conditions, and market-orders (including those with IOC conditions) are candidates.

[33] Limit-orders that are not even partially executed immediately become candidates.

[34] It may be called the take-type because it is paired with the make-type, but it is referred to as the sniper-type following Budish (2021) because it seems to be a trading style to target and win the orders left on the board.

[35] The number of make-orders shall be the number of new orders that were not immediately executed during the trading session. In this Section, the number of take-orders shall be the number of new orders that were immediately executed during the trading session plus the number of expired IOC orders. In sections (except Section 2), the number of take-orders shall be the number of new orders that were



Source: Prepared by the author

Figure 3.1.1 Example of a Make-Order (top) and Take-Order (bottom)

First, the "make-type," whose orders are executed by make-orders with almost no take-orders, is assumed to be a registered HFTer that mainly engages in market making strategies, representing a typical liquidity provider. Of the 36 registered HFTers that traded during the period under analysis, 14 firms fell into this category, and 8 of them had no significant difference in the number of orders and trading value between sell orders and buy orders.[36] Second, 15 firms fell into the "balanced-type," which mainly executed take-orders, while placing a large number of make-orders, indicating that this category of registered HFTers is a composite of market-making strategies and directional or arbitrage strategies.

immediately executed during the trading session.

[36] If the ratio between the number of buy orders and number of sell orders and the ratio between the trading value of buy orders and trading value of sell orders are 80% or more and 120% or less over the five day analysis period, "balanced" is indicated in the item of "Ratio between buy and sell."

Finally, seven firms fell into the "sniper-type" category, in which a type of a registered HFTer that specializes in speed mainly engages in directional or arbitrage strategies, with almost no placement of make-orders but with the execution of take-orders. In addition, 6 firms of the make-type, 6 firms of the balanced-type, and 3 firms of the sniper-type do not have balanced buy/sell trading value. This may be due to a strategy to carry positions overnight,[37] but it is more likely due to arbitrage trading in other markets or derivatives, or non-high-speed trading (trading that cannot be captured by registered HFTers' orders). As for the transactions of registered HFTers that are not in "equilibrium," it is not possible to classify them directly into the above three groups, since only a part of their trading strategies may have been captured in this report. Therefore, we have set up a separate frame (category) within each group as "Others." In the future, it is also likely that adding aspects other than the number of orders and trading value will lead to a better understanding of HFT's strategies and clarify and divide the categories in the "Other" category.

		Category	Nums of order			Trading value			Nums of registered HFTers	note
			Take	Make	Sell/Buy Ratio	Take	Make	Sell/Buy Ratio		
Make-type		①	×	○	Equilibrium	×	○	Equilibrium	8	"Make-type" that is executed with a make-order.
	Other	②			-			-	6	
Balanced-type		③	▲	○	Equilibrium	○	▲	Equilibrium	9	"Balanced-type" with many make-orders, but mainly executed by take-orders.
	Other	④			-			-	6	
Sniper-type		⑤	○	×	Equilibrium	○	×	Equilibrium	4	"Sniper-type" or "Take-type" that executes on a take-order.
	Other	⑥			-			-	3	

Source: Prepared by the author

Figure 3.1.2. Registered HFTers are Classified into Three Groups (○ : Many, ▲: Few, X: Almost none)

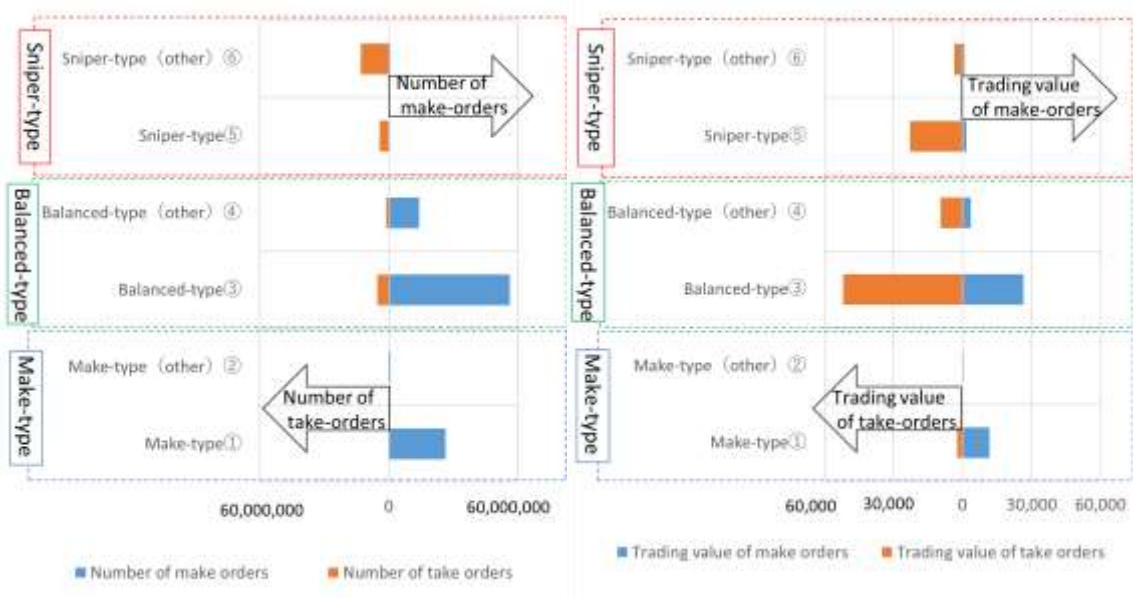
Chart 3.1.3 shows the number of "Make/Take-" orders and the trading value of "Make-/Take-" orders placed by registered HFTers in each of the three categories of "Make," "Balanced," and "Sniper." (sub-categories are (1) to (6)). First, looking at the overall number of orders of registered HFTers, it can be seen that there are many make-orders on a number-of-orders basis, and many take-orders on a trading-value basis.[38] This may be part of the so-called ghost liquidity, which quotes liquidity to the order book but does not actually execute trades (which shows as information on the order book but does not execute trades).

[37] Since HFTers basically maintain a neutral position during intraday (trading on a daily basis), if there is a bias in positions for five days, it is usually assumed that there will be an uncaptured order (such as an order through non-high-speed trading).

[38] If trading entities are not limited to registered HFTers, the total trading value from take-orders for all entities will match the total trading value from make orders.

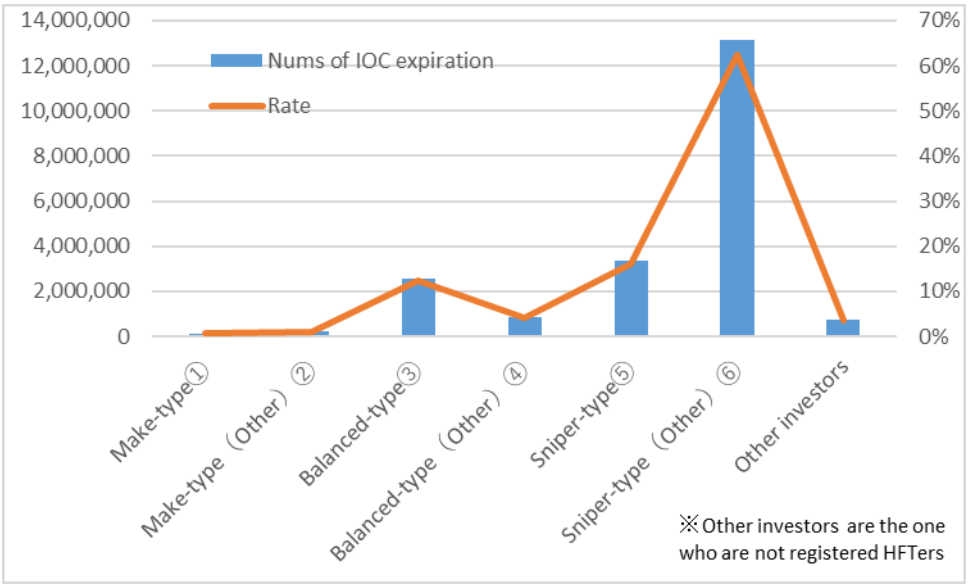
Next, looking in detail by category, as expected, registered HFTers specializing in make-orders and take-orders were classified into the "make-type" (category (1) and (2)) and the "sniper-type" (category (5) and (6)). The "balanced type" (category (3) and (4)) has 15 registered HFT firms, which is almost the same as the number of 14 registered HFT firms belonging to the "make-type." In particular, category (3) far outperforms other categories in terms of both the number of orders and trading value, indicating that major HFTers are classified in this category. Compared to Category (5) of "sniper-type," Category (6) of "sniper-type" has a larger number of take-orders (cf. the comparison between orange bars in Figure 3.1.3, left chart [5] and [6]), but has a smaller trading value of take-orders (cf. the comparison between orange bars in Figure 3.1.3, right chart [5] and [6]). Usually, take-orders refer to new orders associated with immediate execution, but as mentioned above, the number of expired IOC orders (the number of take attempts) is added to the number of take-orders, and thus the lower the success rate of sniping, increasing the number of orders, and decreasing the relative trading value (execution value). The number of expired IOC orders in Category (6) reaches about 65% of the total number of expired IOC orders (Figure 3.1.4), indicating that the low sniping success rate is likely the cause. However, since Category (6) includes registered HFTers whose ratio of selling and buying is not "balanced (in equilibrium)," the probability of the existence of potential trading that cannot be captured by the current high-speed trading regulations is higher than in the "balanced" category group. If that potential trading is added, the trading value may rise.

In addition, expired IOC orders are processed without being reflected on the order book. Figure 3.1.4 suggests that there is a large number of order attempts (referring to expired IOC orders here) made by the three HFTers in Category (6), which cannot be ascertained by looking at the order book. Looking ahead, capturing more details for the trading of Category (6) may shed light on why expired IOC orders are so frequent.



Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 3.1.3 Make-/Take-Orders in Each Category (1) to (6)
(Left: number of orders; Right: trading value [billions of yen])



Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 3.1.4 Expired IOC Orders and Percentages by Strategy

3.2. Comparison of declaration-based strategies by three categories (six categories)

The amendments to the FIEA and other relevant and applicable laws and regulations in 2017 (Heisei 29) have made it possible to identify the proprietary virtual servers used by registered HFTs and high-speed trading strategies. Therefore, we can identify trends in registered HFTs by classifying them into four categories: (1) market-making strategies (market-making strategies in a general sense and declaration-based market-making strategies, the declaration-based strategies are hereinafter referred to as "MM strategies"), (2) arbitrage strategies (hereinafter referred to as "AR strategies"), (3) directional strategies (hereinafter referred to as "DR strategies"), and (4) other strategies (hereinafter referred to as "other strategies"). Each strategy is outlined in the Comprehensive Guidelines for Supervision of Financial Instruments Business Operators, etc. (hereinafter referred to as "Comprehensive Guidelines for Supervision" or "Comprehensive Guidelines").[39]

As strategic flags are assigned to all registered HFTs in accordance with the business regulations of the TSE, it is possible to understand the overall trend of registered HFTs and the general characteristics of each registered HFTer based on the above four strategies. However, in order to accurately ascertain the actual trading conditions of each registered HFTer, it is necessary to first identify the trading strategies of each registered HFTer with the above four strategies, and further it is necessary for each strategy to be completed by trading through high-speed trading.[40] Furthermore, it is also possible that one algorithmic trading may consist of multiple trading strategies, including the above four strategies, or trading that are not high-speed trading. In addition, it should be noted that the results of analyses based on the above four strategic flags may be misleading if different firms define different strategies differently. For example, taking the MM strategy as an example, it is described that "a strategy to obtain profits equivalent to the spread between two prices by placing both buy and sell orders on the market and becoming counterparties to other investors", there is a possibility that some registered HFTs may take the view that only a

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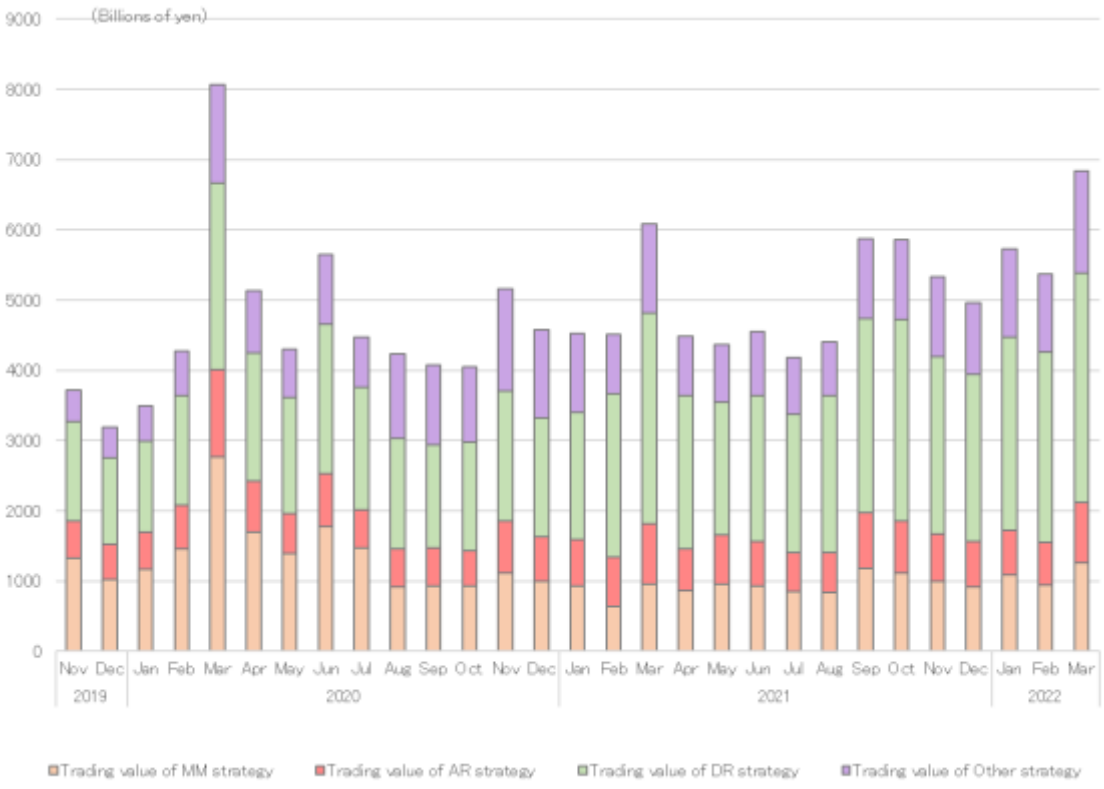
[39] III-3-1-1 (2) (I) in the Comprehensive Guidelines for Supervision of Financial Instruments Business Operators, etc. (Supplementary Guidelines): Guidelines for Supervision of High Speed Traders state as follows: The MM strategy is a strategy to obtain profits equivalent to the spread between both prices by placing both buy and sell orders on the market and becoming counterparties of other investors. The AR strategy is a strategy to obtain profits by arbitrage focusing on price differences between multiple issues correlated with price fluctuations or price differences between markets for the same product. The DR strategy is a strategy to obtain profits by predicting price fluctuations in the near future. The "other strategy" is a strategy that does not fall under either the MM strategy, the AR strategy, or the DR strategy.

[40] Some virtual servers are shared by multiple investors ("shared [virtual] servers" in Figure 2.2.1), and the possibility cannot be ruled out that a registered HFTer conducts transactions through a shared virtual server (for non-HFT transactions), and it is not possible to capture all transactions of a registered HFTer by analyzing only the dedicated virtual server.

limit order placed for sell and buy at all times[41] is regarded as an MM strategy, and if a limit order is temporarily withheld and only a sell or buy order is placed on the market, it is not regarded as an MM strategy but a DR strategy or any other strategy. Therefore, this paper uses the declaration-based strategy flag just as reference information for the analyses conducted in Chapter 4 because it may cause deviation from the actual trading strategy.



Source: Prepared by the author based on materials disclosed on the FSA website

Figure 3.2.1 Trading Value by Strategy

[41] ETF Market Making Incentive Scheme of the TSE refers to the quoting time, and it is necessary to show quotes for no less than 80% of the time during continuous auction (time subject to measurement).

Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 3.2.2 Trading Value by make/take-orders (Left: registered HFTers; Right: other investors)

(* Trading Value at month-end is aggregated)

In recent years, Exhibit 3.2.1 shows that the MM strategy, which has been considered as the main strategy of registered HFTers, has been on a downward trend, while the DR strategy and the other strategy seem to have emerged. However, from the perspective of trading value by make-/take-order shown in Exhibit 3.2.2 (left side),[42] the ratio of trading value by make-order to total trading value of registered HFTers has remained relatively stable for the past two years, at around 33%, showing no major change. This suggests that rather than a decline in providing liquidity by MM strategies, pure market-making strategies are declining as declaration based strategies are reassessed and become more sophisticated, and that multiple strategies combining directional, arbitrage, and other strategies are on the rise. In the classification in the previous section, the 14 firms classified as the make-type are not large-scale companies, while the balanced-type included major HFT firms. This suggests that the HFT strategy itself is evolving from simple to more sophisticated and complex on a daily basis in a competitive environment.

Next, we aggregated the number of orders and trading value by make/take-orders to see what strategy flags each registered HFTer belongs to among the three categories (sub-categories 1 to 6) in the previous section assigned to their trades. (Figures 3.2.3 and 3.2.4). Figure 3.2.5 shows the strategic flag items assigned to Figure 3.1.3.

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42 The trading volume at each closing session in the morning and afternoon is not included in the trading value by make/take in this report.(During the period under analysis from November 2019 to September 2021, the ratio of trading value at the closing session to the total trading value on a daily basis exceeded 10% on average).

"Make-type" HFTs tend to place make-orders based on the DR strategy rather than the MM strategy, as expected (Figures 3.2.3 and 3.2.4). This may be due to differences in the definition of each of the strategies mentioned above, and may also be due to a placement of a limit order purely in anticipation of market momentum. In this case, even if it is a DR strategy, the contribution of providing liquidity to the order book is high because they only place make-orders. In addition, the liquidity provided by registered HFT firms in this "make-type" will decrease volatility in volatile markets (the limit-orders of the HFTs serve as the thickness of the order book, decrease volatility, and hold prices up-down).

For the "balanced-type," the number of make-orders for the MM strategy is overwhelmingly large in terms of the number of orders, but in terms of trading value, the trading volume of take-orders for the DR strategy is large (more than twice as much as the trading value of make-orders for the MM strategy). It can be seen that they frequently place new orders and cancellation orders as a market-making strategy while placing take-orders as a directional strategy and trades are executed. Of course, since the trading value of make-orders is by no means small, it is expected that limit-orders will be placed near BBO, which may contribute to reducing BBO spreads. However, since the trading value of take-orders under the DR strategy is large, it is necessary to carefully monitor how they are placed and whether they are orders that increase volatility.

The "sniper-type" is dominated by take-orders, and the trading value of take-orders by DR and AR strategies accounts for a large portion of the total trading value of the category. There are characteristic differences in the number of orders and trading value by take-/make-orders for the three DR strategies: Category (1), Categories (3) and (5), and Category (6). The results of aggregation suggest that category (1) is a directional sniper of make-type, categories (3) and (5) are a sniper of sniper-type (whose trading value is high relative to the number of orders), and category (6) is a sniper of random-type (whose trading value is low relative to the number of orders). With respect to categories (3), (5), and (6), we will analyze the hitting ratio and sniper methods in more detail in Section 4.5.1.

In the case of category (4), JPY 245.1 billion, which accounts for approximately 26% of the total trading value of takes [take-orders] (approximately JPY 955.3 billion: JPY 245.1 billion + JPY 509.8 billion + JPY 199.1 billion + JPY 1.3 billion), and in the case of category (6), JPY 193.9 billion, which accounts for approximately 53% of the total trading value of takes (JPY 368.2 billion: JPY 193.9 billion + JPY 26.1 billion + JPY 148.2 billion), were placed as MM strategies even though they were executed by take-orders. It is not hard to imagine the difficulty of applying the strategies of each company to the four strategies defined by the FIEA and the Comprehensive Guidelines, but it can be said that this indicates the risk of judging the liquidity supply situation of HFT from the number of MM and DR strategies by

aggregating strategy flags without considering whether the type of order tied to the actual execution is a make-order or a take-order.[43]

			Nums of make-orders(ten thousand)				Nums of take-orders(ten thousand)				Nums of registered HFTers
			MM	AR	DR	Other	MM	AR	DR	Other	
Make-type		①	279	333	1,486	518	1	3	11	15	8
	Other category	②	47	0	7	10	0	0	25	0	6

			Nums of make-orders(ten thousand)				Nums of take-orders(ten thousand)				Nums of registered HFTers
			MM	AR	DR	Other	MM	AR	DR	Other	
Balanced-type		③	3,562	5	438	1,594	38	20	333	154	9
	Other category	④	1,198	31	137	24	25	84	18	0	6

			Nums of make-orders(ten thousand)				Nums of take-orders(ten thousand)				Nums of registered HFTers
			MM	AR	DR	Other	MM	AR	DR	Other	
Sniper-type		⑤	42	0	9	0	1	288	145	0	4
	Other category	⑥	61	3	0	0	493	5	837	0	3

Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 3.2.3 Number of Orders by Make-/Take-Orders and Each Category (1) to (6)

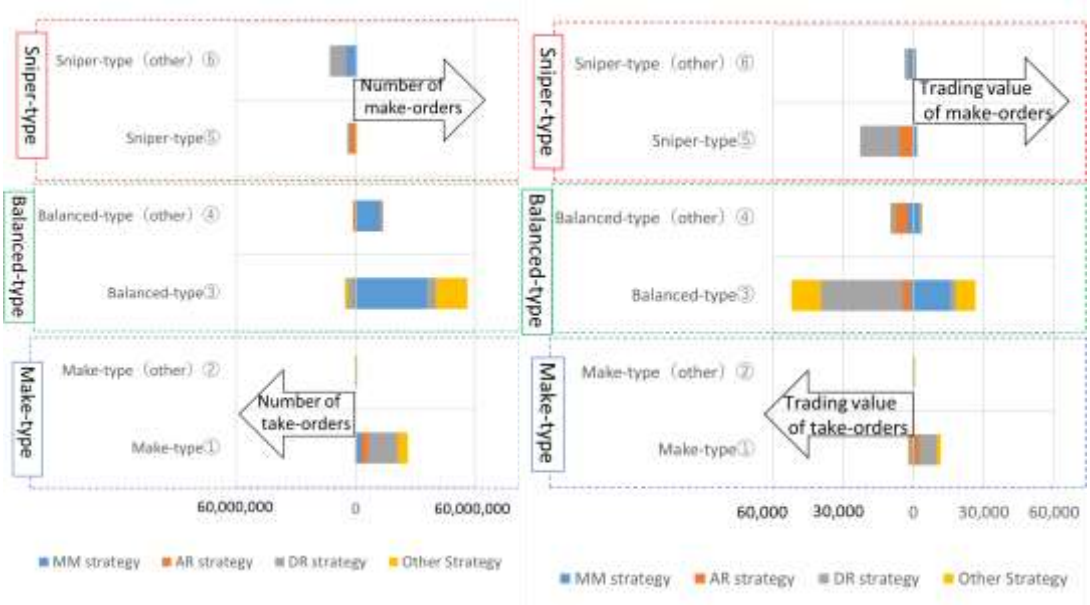
			Trading value from make-orders(hundred millions yen)				Trading value from take-orders(hundred millions yen)				Nums of registered HFTers
			MM	AR	DR	Other	MM	AR	DR	Other	
Make-type		①	804	1,806	7,461	1,640	131	633	1,049	541	8
	Other category	②	378	5	156	45	8	70	151	32	6

			Trading value from make-orders(hundred millions yen)				Trading value from take-orders(hundred millions yen)				Nums of registered HFTers
			MM	AR	DR	Other	MM	AR	DR	Other	
Balanced-type		③	15,687	69	2,289	8,392	1,200	3,537	34,579	12,574	9
	Other category	④	2,411	34	1,063	44	2,451	5,098	1,991	13	6

			Trading value from make-orders(hundred millions yen)				Trading value from take-orders(hundred millions yen)				Nums of registered HFTers
			MM	AR	DR	Other	MM	AR	DR	Other	
Sniper-type		⑤	1,370	0	369	0	131	5,674	16,970	0	4
	Other category	⑥	824	53	0	0	1,939	261	1,482	0	3

Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 3.2.4 Trading Value by Make-/Take-Orders, Each Category (1) to (6)



[43] There is also the "other" strategy for which trading strategy is unclear. In the Guidelines, "other strategy" refers to a strategy that does not fall under any of the MM, AR, or DR strategies. In order to conduct a unified analysis of registered HFTs, it is essential to identify strategies such as make-take-orders.

Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 3.2.5 Make-/Take-Orders, Strategies, Make-/Take-Orders, Strategies (Left) and 0.1 billion yen (Right)

3.3. Considerations on Trading Strategies of HFTers

Market-making strategies are considered to be the main strategies of HFTers, where profitability depends on the difference between fair prices calculated by their own price models and market prices. In other words, HFTers' market-making strategies depend on their ability of price discovery,[44] referring to how accurately they can calculate fair prices. This is because, if the fair price cannot be calculated accurately, the quote price, which uses the fair price but widely from BBO spread, becomes the sell price and the buy price of the issue, as well as a revenue source of firms that engage in market-making strategies. This strategy is risky because once the market crashes, it may end up buying at a high price, and once the market surges, it may end up selling at a low price. In such market-making strategies, it is also important to assess whether the impact of market volatility is a linear instantaneous impact, a transitional impact, or a permanent impact (Alfonsi, et al. (2012)). If the impact is an instantaneous impact or a transitional impact (for example, a large-size market-order), even if the price volatility is significantly over the BBO spread for a short time, a subsequent rebound can be expected due to the resilience[45] effect of market prices. However, if the impact is a permanent impact caused by a permanent change in prices due to information leakage on the essential value of a company, etc., firms that engage in market-making strategies must review the basis of fair prices immediately and search for fair prices again. The extent of the time frame for the trading strategy, the ability to accurately calculate an appropriate fair price as a reasonable price, and the ability to avoid an impact that could be a risk to the strategy are key factors that determine the success or failure of the market-making strategy. Under such risk circumstances, firms that engage in market-making strategies must compete with each other in order to quote prices at lower sell prices (and at the same time, at higher buy prices) than any other firm. Also, it is expected that the market-making strategies will naturally improve and strengthen their price-discovery ability. It is possible to develop not only market-making strategies but also directional strategies and various other strategies if they can calculate prices close to fair prices faster than anyone else. As a result, many of the major HFTers that have won the competition may have come to be classified as balanced-type HFTers.[46]

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[44] Nasdaq refers to "market quality" as a concept that encompasses liquidity and "provides retail investors with a fair price." Whether or not HFTers demonstrate their price-discovery ability and contribute to market quality is a point of attention. In this section, fair price is defined as a price obtained in the absolute pursuit of truthfulness. (https://www.nasdaq.com/articles/assessing-market-quality-2015-12-22: last viewed October 13, 2022)

[45] Resilience is the resilience of the market to recover from a shock. In a resilient market, market prices are less affected by order volumes.

[46] Budish et al. (2021) classified race participants into two types: balanced type and sniper type. There is no make-type.

With respect to directional strategies, it is common to think of transactions following price momentum in a certain direction. However, there are also directional strategies based on fair prices, which have a relatively long time horizon. If a price close to a fair price can be calculated, even a take-order will perform the resilience function of market prices by itself in the form of adjustment (resilience) to a fair price. In other words, it is not possible to judge whether an HFTer increases market volatility based on the fact that the ratio of trading value from take-orders reaches 67% (≒ 100% -33%) as shown in Figure 3.2.2 and the number of DR strategies is increasing as shown in Figure 3.2.1.

Arbitrage strategies may be based on the target for derivatives, such as between ETFs and futures, and its contribution to price linkage between products and markets. However, this type of speed competition, if it competes with market makers for the same issue, may lead to factors that increase losses for market makers who aim to trade based on fair prices (for example, factors that have an impact of a transitional degree) (Budish et al. (2015)). It may be necessary to continue to analyze the reality of speed competition in the next chapter and to discuss excessive speed competition by assessing its merits and demerits.

Finally, analysis of trade data reveals not only market-making strategies but also a wide variety of strategies of registered HFTers. It is also premature to question the merits and demerits of all registered HFTers based on one trading strategy.

4. Understanding speed competition

4.1. What is a race?

Following Budish et al. (2015) and Budish et al. (2021), speed competition that simultaneously satisfies the following four conditions is defined as a "race":

(1) There are two or more market participants trading the same issue at the same price.

(2) There is an expiration of one or more take-orders (limited to IOC orders) or an expiration of a cancellation order ("failure").

(3) When the transaction in (2) is regarded as a loser, there is a winner who is a counterpart to the loser.

(4) All of the above orders occur "almost at the same time" (within 10 milliseconds in this case).

Budish et al. (2021) assumed that there were different trading desks within the same firm and assumed the race by user IDs.[47] However, in this paper, we aggregated races by firm as well as by virtual server ID as necessary. Naturally, the number of races by firm is smaller than that by virtual server ID. The style of sniping quickly at target orders is not limited to one-shot sniping like a sniper. Even if multiple IOC orders are placed at the same time, there will always be latency in the timing of arrival at the TSE by only a small difference, and the order that arrives earliest will be executed. HFT firms who are concerned about this latency may snipe multiple overpriced price (or underpriced) limit orders from a particular virtual server, or multiple times from multiple virtual servers. However, if there is another firm as a winner, regardless of whether it is a virtual server or a firm that places multiple orders at the same time (for example, placing multiple IOC orders at the same time for 100 yen), it will be counted as a loser multiple times in one race.[48] In order to avoid this situation, when defining a race by firm, a situation where the same firm is counted as a loser multiple times in one race was avoided by tallying only the fastest order among multiple orders placed via multiple virtual servers owned by the same firm (excluding any other expired orders).

Definition (3) searches for the existence of a winner based on the order expiration information of definition (2), and if it can be found, definition (3) and definition (4) will be satisfied. In Section 4.4, the search time is set for four patterns of 1 millisecond or shorter,

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[47] Conceptually, it can be considered to be similar to the IDs (virtual servers) that TSE assigns to securities companies as a connection unit. However, the details of user IDs described by Budish et al. (2021) are not available.

[48] This does not apply to the expiration of cancellation orders ("Competitive Environment [A]" in the following sections), and since the "order to be cancelled" and the "order to attempt cancel" have the same "order IDs," multiple cancels via one or more virtual servers will all have the same "order IDs," and will not be counted multiple times as a loser. If multiple orders to be cancelled are executed, there will be multiple winners, each of which will be counted as a separate race.

10 milliseconds or shorter, 100 milliseconds or shorter, and 500 milliseconds or shorter. However, there was no significant difference in the lineup of registered HFTers among the three patterns of 10 milliseconds or shorter, 100 milliseconds or shorter, and 500 milliseconds or shorter. For this reason, the interpretation of definition (4) "almost same time" is set at 10 milliseconds or shorter.

4.2. Race overview and analytical results (in contrast to Budish et al. (2021))

An overview of the race and a detailed analysis of the results are described in the following sections (Competitive environment (A)-(D) in Figure 4.3.2). First, in order to grasp the overall picture of the race, we compared the summary and analytical results with those of Budish et al. (2021) (Figure 4.2.1). Budish et al. (2021) analyzed the FT350 index (350 issues), this analysis was based on cash equities (approximately 4,100 issues), which lasted only five business days, but the number of analyzed data (business days x issues) was 20,600 symbols,[49] which is nearly 1.5 times larger than the approximately 15,000 symbols used by Budish et al. (2021). (In this paper, we also checked the occurrence of races by market division.)

As for the average number of races per day, Budish et al. (2021) accounted for 21.4% of the total trading value, while this paper's result was 22.8%, showing not much difference. While the average number of races[50] per day in this paper was 893,631, which is more than 10 times the 71,493 in Budish et al. (2021), the average number of races is not much different in percentage terms, since the number of stocks analyzed is about 4,100, which is more than 10 times the number of stocks (350) in Budish et al. (2021). The number of races per day accounts for approximately 31% of the total number of take-orders[51] (3,553,770 races in five days excluding duplication between competitive environments (a) and (c); 11,524,573 take-orders), indicating that races are held at a high frequency. As mentioned in Section 1.4, the "time measurement point" in No. 1 in Figure 4.2.1 is different, and the search scope of races (Definition (4)) cannot be unified, so the race conditions are not necessarily the same. However, there are generally no significant differences in the results of the analysis, including the number of participants per race, and it is found that the same level of race is developed in the London Stock Exchange and the TSE.

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[49] The number of symbols is calculated as 1 symbol equals business day times 1 issue.

[50] The total number of races can be calculated by adding up the number of winners, but duplication of winners can occur in competitive environment (a) and competitive environment (c). Therefore, it is necessary to recalculate the total number of races, so that there is no duplication.

[51] With the exception of the competitive environment (d), the total number of potential races is the number of take-orders for which orders are executed immediately.

No	Description of Analysis	Quantifying-HFT-Races	Total Number of Result	(A)'s Racing Environment	(D)'s Racing Environment	(C)'s Racing Environment	
1	Time Stamp	Gateways	Matching Engine				
2	Stocks Issue	FTSE 350 Index	Approximately 4,100 stocks of Tokyo Stock Exchange				
3	Market Segments	-	1st Section, 2nd Section, Mothers, JASDAQ, ETF, REIT				
4	Description of Data	Message Data	Combination of Stock Quote Details Data and Message Data		Stock Quote Details Data		
5	Description of Races	Winner : Limit Order (including IOCs)	Winner : deduplicated (A) (C) (D)	Winner : Take Order	Winner : successful Cancel	Winner : successful IOC	
		Loser : Failed Cancel	Loser : deduplicated (A) (C) (D)	Loser : Failed Cancel	Loser : Failed IOC	Loser : Failed IOC	
6	Unit of Participants	UserID	ServerID				registered HFTers
7	Description of Terms	From Aug 17 - Oct 16 ,2015	From Sep 15 - Sep 22 ,2021				
		43 Trading Days	5 Trading Days				
8	Number of Symbol - Day (Trading Daystimes Number of stocks)	About 15,000 symbol-day pairs	About 20,600 symbol-day pairs				
9	Upper Bound On the Information Horizon	500μs	10ms	1ms 10ms 100ms 500ms	10ms		
10	Number of races per day across dates	71,493	893,631 (A) + (D) + deduplicated(C)	304,920 Number of Winner	182,876 Number of Winner	474,832 Number of Winner	387,253 Number of Winner
11	Number of Participants	3.64 within 1ms		2.53 within 10ms	3.04 within 10ms	4.27 within 10ms	2.72 within 10ms
12	Race Duration (mean)	78μs		2,960μs	4,820μs	3,500μs	3,010μs
		Timestamp at the Gateways location in capped at 500ms		Timestamp at the Matching Engine location in capped at 10ms (Affected by the Exchange System)			
13	Trading Volume in Races (mean)	21.4%	22.8% (A) + (C) + deduplicated(C)	11.4% Trading Volume of Winner	2.8% Trading Volume of Winner	12.1% Trading Volume of Winner	10.1% Trading Volume of Winner

※ No10-13 of (A) is within 10ms result

Source: Prepared by the author

Figure 4.2.1: Comparison of data summary and analytical results with the UK's FCA paper (Budish et al. [2021])

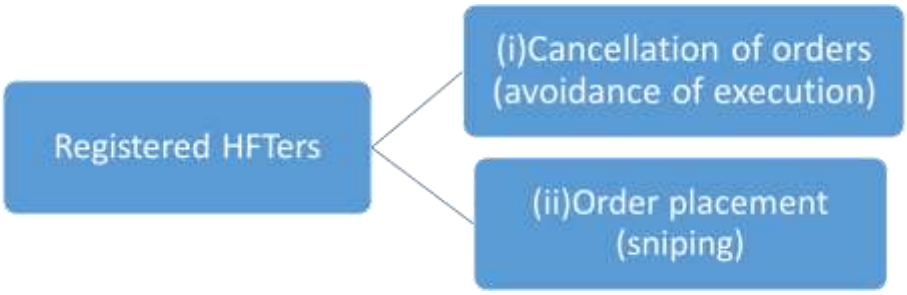
4.3. Expected competitive environment and position of other investors

This section considers the competitive environment for races based on information on the order expiration (cancellation orders and IOC orders) and refers to the existence of other investors who unintentionally participate in races other than registered HFTers.

4.3.1. Expected Competitive Environment

There are two types of orders (Exhibit 4.3.1) that can be executed only by investors with high speed trading: (i) quickly order cancelation (avoidance of execution) by the market-making type and (ii) quick order placement (sniping) by the take-type. As for (i), if it is not possible to quickly cancel the limit-order placed without being aware of changes in the market environment, a loss incurred will be the amount of a price inferior to the fair price. This means an increase in the risk of providing liquidity to the market. It can be a life-or-death problem for the market-making type. In the case of (ii), if the strategy is the arbitrage

strategy (between other exchanges/products), a profit equivalent to the deviation can be obtained by quickly targeting the remaining inferior shares. Even in the case of failure to execute at the price desired to snipe (buy low or sell high) [even if the target is missed with sniping], the IOC order merely expires and is not executed at an inferior price (buy high or sell low), unlike (i).



Source: Prepared by the author

Figure 4.3.1: Trading Activities of Entities Participating in Planned Races (Registered HFTers)

		Conditions to be a Loser	Conditions to be a Winner		With or without race	Analyzed in this paper	note
Racing Environment	(A)	The Case for Failure in Figure 4.3.1(i)	The Case for Success in Figure 4.3.1(ii)		○	○	It is possible that other investors that do not intend to participate in the race could be mixed in.
				Limited to IOC orders only		–	Limited to speed competition for HFT basically.
	(B)		The Case for Success in Figure 4.3.1(i)		×	×	Only the same investor can cancel an order it placed.
	(C)	The Case for Failure in Figure 4.3.1(ii)	The Case for Success in Figure 4.3.1(ii)		○	–	It is possible that other investors that do not intend to participate in the race could be mixed in.
				Limited to IOC orders only		○	Limited to speed competition for HFT basically.
	(D)		The Case for Success in Figure 4.3.1(i)		○	○	There is almost no possibility of mixing in other investors that do not intend to participate in the race.

Source: Prepared by the author

Figure 4.3.2 Competitive Environment and Winners/Losers

From (i) and (ii), the competitive environments for all possible races can be summarized into the following four categories: (A), (B), (C), and (D) [Figure 4.3.2]. Firstly, (A) and (B) are

possible competitive environments based on the information on the losers of "failure of (i) in trading attempt" = "failed to cancel order" in Figure 4.3.1, where (A) is the race in which the order placement (sniping) of (ii) is successful, and (B) is a race in which the order cancellation of (i) is successful. However, with regard to (B), although it is a competitive environment that exists on a case-by-case basis, the firm that cancels an order is limited to the firm that placed the order, and the winner and the loser are the same entity. Therefore, it does not satisfy definition (1) (the existence of two or more participants) in the first place. Secondly, the following (C) and (D) are possible for the competitive environment based on the information on the losers of "the failure of (ii) in trading attempt" = "failure in order placement," where (C) is the race in which the order placement (sniping) of (ii) is successful, and (D) is the race in which the order cancellation of (i) is successful.

As shown in the items in "Analyzed in this Paper" in Figure 4.3.2, Section 4.4.1 of this paper examines the extent to which other investors who are not registered HFTers participate in the race by setting the winner condition of competitive environment (A) as "a successful take-order (in all take-orders)," while Section 4.5 attempts to grasp the actual situation of speed competition among registered HFTers by limiting the winner condition of competitive environment (C) from "a successful take order (in all take-orders)" to "a successful IOC order."[52] From the viewpoint of analyzing the competitiveness of make-types that play important roles in providing liquidity, Section 4.4.2 examines whether registered HFTers belonging to the make-type are able to cancel orders quickly from the order book, and comparatively examines the success of cancellation (competitive environment[D]) as well as the failure of cancellation (competitive environment [A]).

4.3.2. Position of Other Investors who are not Registered HFTers in Speed Competition

We would like to take a closer look at the possibility of investors who are not registered HFTers participating in a race, including individual investors who conduct non-high-speed trading (hereinafter collectively referred to as "other investors"). Normally, the expected participants in a race are registered HFTers (※0 in Figure 4.3.3), and they trade for a purpose based on a specific strategy after sensing some information in addition to frequently updated information on the order book. Therefore, except in a niche and monopolistic trading environment, they can be winners or losers due to the presence of competitors. On the other hand, orders placed by other investors can be the winner (※1 in Figure 4.3.3) but

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[52] An order form constituting a take-order is assumed to be a market order, or a limit order, etc. in addition to an IOC order. However, since registered HFTers generally do not place market orders when placing take-orders, only IOC orders were used for our analysis. (Registered HFTers tend to place IOC orders.)

not the loser (※2 in Figure 4.3.3), and cancellation orders by other investors can be neither the winner (※3 in Figure 4.3.3) nor the loser (※4 in Figure 4.3.3). In other words, according to the definition of a race of speed competition, situations in which other investors unintentionally participate in a race are limited to cases in which other investors win a competitive environment of either (A) or (C)[53] as shown in Figure 4.3.3 (※1 in Figure 4.3.3).

			Winner			
			Successful order placement		Successful order cancellation	
			Registered HFTers	Other investors	Registered HFTers	Other investors
Loser	Failure to place an order	Registered HFTers	○ ※0	○ ※1	○ ※0	× ※3
		Other investors	× ※2	× ※2	× ※2	× ※2 and ※4
	Order Cancellation Failure	Registered HFTers	○ ※0	○ ※1		
		Other investors	× ※4	× ※4		

			Winner		
			Successful order placement	Successful order cancellation	
			Registered HFTers / Other investors	Registered HFTers	Other investors
Loser	Failure to place an order	Registered HFTers / Other investors	Competitive environment (C)	Competitive environment (D)	
	Order Cancellation Failure	Registered HFTers / Other investors	Competitive environment (A)	Competitive environment (B)	

Source: Prepared by the author

Figure 4.3.3 Potential Winners and Losers by Firms (Registered HFTers and Other Investors)

First, we consider the reasons why orders placed by other investors who are not registered HFTers can only become winners ("※1" and "※2" in Figure 4.3.3). Orders placed by other investors who are not registered HFTers can become targets[54] of speed competition without their knowledge, thereby unintentionally fulfilling the winner condition of "execution of all take-orders" through market- and/or limit-orders. The fact that other investors' orders are the target of a speed race means that there are registered HFTers that succeed or fail to snipe before the other investor's order is executed. If there is a registered HFTer who fails to snipe before the other investor's order is executed (meaning that there is a loser), the

[53] In this paper, we limit the winner condition of "competitive environment (C)" to IOC orders, so it is unlikely that other investors will unintentionally satisfy the winner condition in "competitive environment (C)".

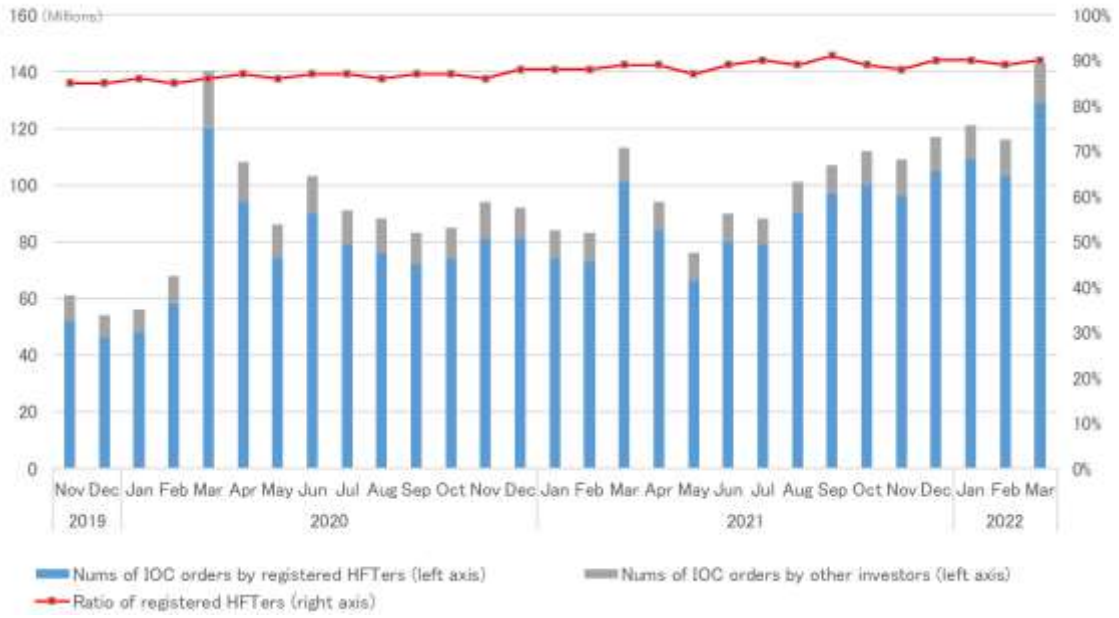
[54] There is a possibility that there may be a race that unfolds based on the detection of other investors' order information. For example, when investors use SOR, there is always a slight time difference in the forwarding of PTS and dark pool. Also, there is a possibility that some kind of regularity, such as VWAP, TWAP, or an order form in which a large order is sliced and placed, may be searched.

market-orders and limit-orders of other investors will be executed without their intention (meaning that there is a winner), and the conditions for defining a race will be met ("* 1" in Figure 4.3.3). On the other hand, even if a registered HFTer successfully snipes other investor's target order before it is executed (meaning that there is a winner), if the other investor's order is a market order, the order will be executed at an inferior price, whereas if the order is a limit order, the order will remain on the order book and will not expire (there is no loser because the order will not expire). Therefore, unless the IOC condition is attached, the definition condition of the race will not be satisfied ("* 2" in Figure 4.3.3). IOC orders are particularly useful in cases where participants are equipped with technology that enables them to accurately place orders near the best quotation by accurately grasping the order book, which is frequently updated, and specifying the specific number of shares and stock price. Therefore, it is usually unlikely that other investors will satisfy the loser condition, and in fact, as shown in Figure 3.1.4, the number of expired IOC orders by other investors is small, except for those by registered HFTers. Of course, there are cases where other investors place IOC orders (approximately 10% of the total number of IOC orders consists of IOC orders placed by other investors who are not registered HFTers, as shown in Figure 4.3.4). In such cases, IOC conditions are attached[55] to orders placed at low prices (or high prices) in order to give a lower limit (or upper limit) to orders placed at low sell prices (or orders placed at high buy prices), but in this case, the expiration of IOC orders would be limited because the IOC orders are basically executed.

Next, we consider the reasons why a cancellation order by another investor does not satisfy either the winner condition of "a successful cancel" or the loser condition of "expiration of cancellation" ("※3" and "※4" in Figure 4.3.3). With the order placement described above, take-orders by market orders or low sell limit orders (or high buy limit orders) can be executed in sequence from the top of the BBO at any point in time without knowing the state of the order book. However, cancellation of an order is based on the assumption that there is an order subject to cancellation (i.e., there is a make-order that has already been placed on the order book). In addition, from definitions (3) and (4) of the race, it is essential that there exists a registered HFTer (and a participant equivalent thereto) that snipes the make-order in a short period of 10 milliseconds (1/100 second) before cancellation. Naturally, in order to be eligible for sniping, the order must be placed precisely near the best BBO, and the participants that can accurately cancel an order according to market situation, etc., while leaving orders near the BBO, are participants who can

[55] There are also market order IOC conditions are attached. The expiration will occur when trading is temporarily halted due to a price exceeding the updated quote range, but the probability of such an expiration is not high.

accurately grasp frequently updated order book information, and are limited to some institutional investors, including registered HFTers. Moreover, if other investors place a make-order on an order book away from the BBO, the winner condition of "success of cancellation" will be easily satisfied (existence of winner), but if it is not a target for sniping (absence of losers), it fails to satisfy the definition of a race. And in this case, the loser condition of "expiration of cancellation" is not satisfied because cancellation is always successful.[56]



Source: Prepared by the author based on materials disclosed on the FSA website

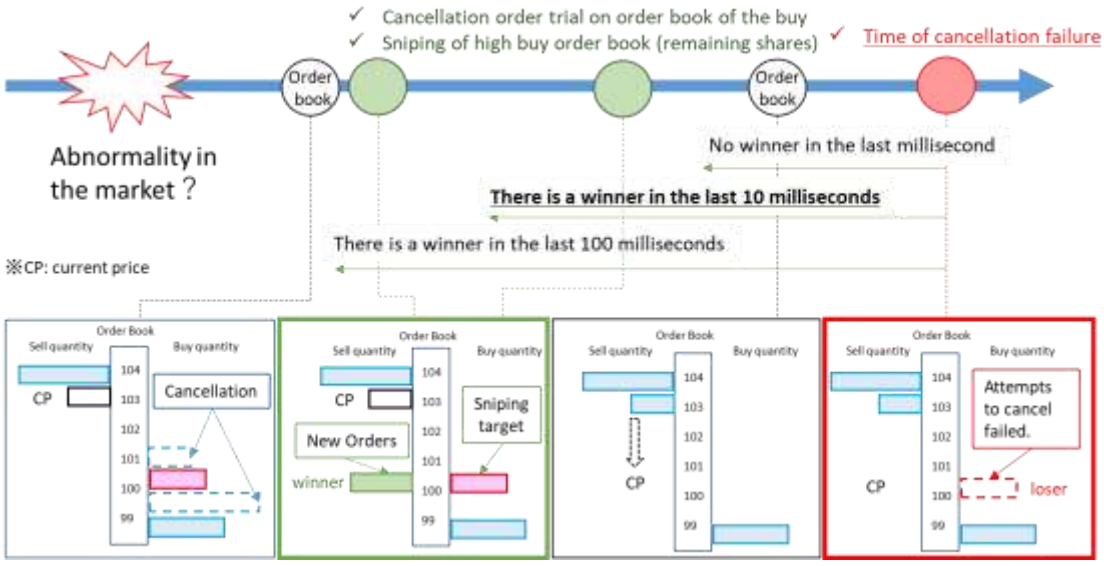
Figure 4.3.4 IOC Orders Trend and Proportion of Registered HFTs

4.4. Competitive environment (A) and (D): order cancellations and sniper races

[56] However, there may be a case where a buy make-order from a registered HFTer happens to match the cancellation order and the cancellation fails (the registered HFTer is the winner and the other investor is the loser), but it will be very limited. For example, there may be a case where a sell make-order is placed by another investor initially away from the BBO, and then approaches the BBO, so the other investor expects a further rise in the stock price and attempts to cancel the order.

This section discusses the competitive environment (A) and (D) from two key perspectives. We examine the extent to which other investors who are not registered HFTers unintentionally participate in the race through an analysis of the competitive environment (A), in which the winner condition is defined as the "execution of all take-orders." Section 4.4.2 considers the sustainability of providing liquidity to the order book in the make-type and balanced-type by examining whether the registered HFTers are able to quickly cancel inferior limit orders through an analysis of the competitive environment (A) in which failure to cancel is a condition for a loser, and of the competitive environment (D) in which success in cancellation is a condition for a winner.

First, starting from the time of the failed cancellation in the competitive environment (A), the time when the order that was about to be cancelled was sniped (executed) is searched for 1 millisecond, 10 milliseconds, 100 milliseconds, and 500 milliseconds, respectively. For example, in the case shown in Figure 4.4.1, the sniper cannot be found even 1 millisecond back from the time of the failed cancellation, but the sniper can be found more than 10 milliseconds back from the time of the failed cancellation. By doing this for all the orders that failed to be cancelled, the race is extracted completely.



Source: Prepared by the author

Figure 4.4.1 Overview of race between take-orders and cancellation orders in competitive environment

During the five days of the analysis period, if the search time is 1 millisecond, the number of combinations of winners and losers is 163,444, and as the search time increases from 1

millisecond to 10 milliseconds, 100 milliseconds, and 500 milliseconds, the number increases to 1952253, 2250617, and 2259021, but the pace of the increase gradually falls (Figures 4.4.2[57] and 4.4.3), with no significant difference of more than 10 milliseconds.[58] In addition, Figure 4.4.2 shows a large peak between 1 millisecond and 3 milliseconds, and a peak that repeats in small increments at intervals of about 500 microseconds. As mentioned in Section 2.4, even if orders arrive at TSE at the same time, there is a time lag of about 450 microseconds between order intervals in the processing process within TSE. Even if there are only two participants—a winner and a loser—in a single race, the order interval will vary by at least 480 microseconds at the fastest, and if there are three participants—a winner, a loser, and a sniper who missed a shot[59]—in a single race, there will be an interval of about 1,000 microseconds (480 microseconds + 480 microseconds) between the winner and the loser. In other words, the appearance of the small peaks in Figure 4.4.2 reflects the number of participants in the race.[60]

Here we mention the difference between the number of races and the number of combinations of winners and losers. The number of races is the same as the number of winners, with one winner and one or more losers in each race being counted. The number of combinations of winners and losers is the same as the number of losers in each race, with one winner and one loser in each race being counted. For example, if there are one winner and three losers in one race,[61] the number of races is one and the number of combinations

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57 In order to narrow down the appropriate search time (one choice among 1 millisecond, 10 milliseconds, 100 milliseconds, or 500 milliseconds), in Figure 4.4.2, when there were multiple cancellations via one or more virtual servers, we dared to adopt the latest cancellation and aggregated the time difference between winners and losers. This is because, as long as there is a possibility that the registered HFTers may try to place orders multiple times, it is necessary to set a search time for capturing all the tried orders. This gives the distribution in Figure 4.4.2 a shape that is suitable for considering reasonable search times (at matching points). When the fastest cancellation is adopted instead of the latest cancellation and the time differences are totaled, the first peak repeated in small increments will have an extremely high shape.

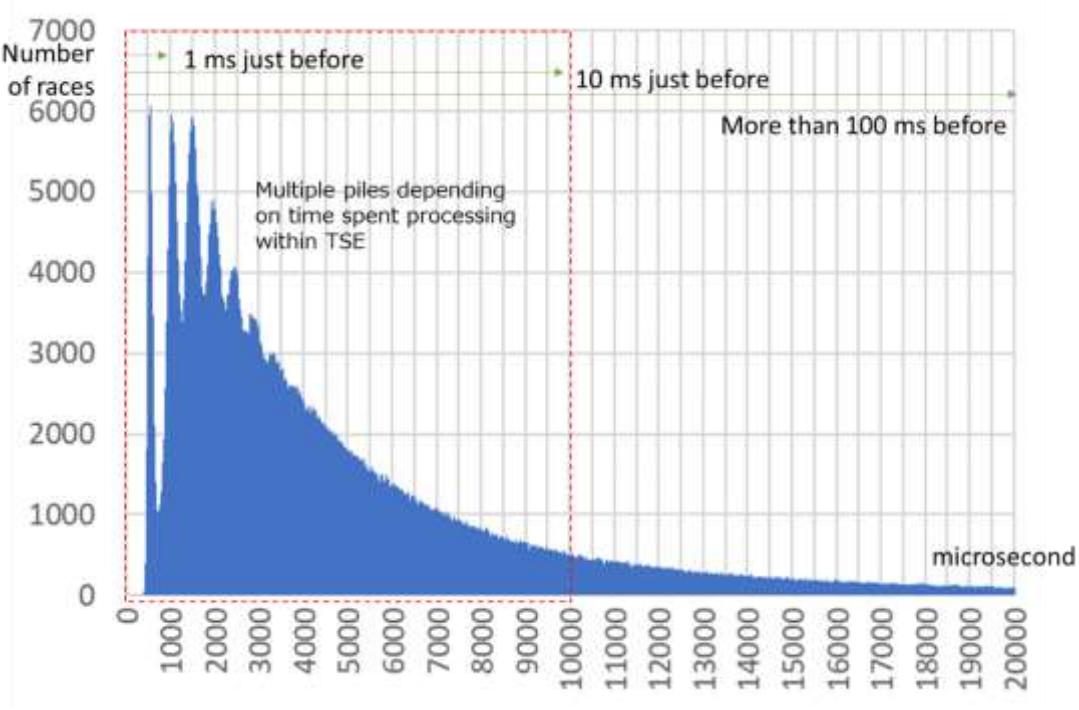
58 For confirmation, all subsequent analyses were performed on all the races captured in the four search times. There were also no major differences in the number of races or the characteristics of winners and losers.

59 The cause of the peaks in Figure4.4.2 reflects not only the presence of a failed sniper, but also the effect of multiple attempts to cancel a particular order.

60 Therefore, as noted in Section 2.4, the time difference between winners and losers calculated in this paper does not affect the result of a race because it includes processing time within the TSE. Also, please note that the processing speed of the TSE does not increase the number of losers (competitive environment).

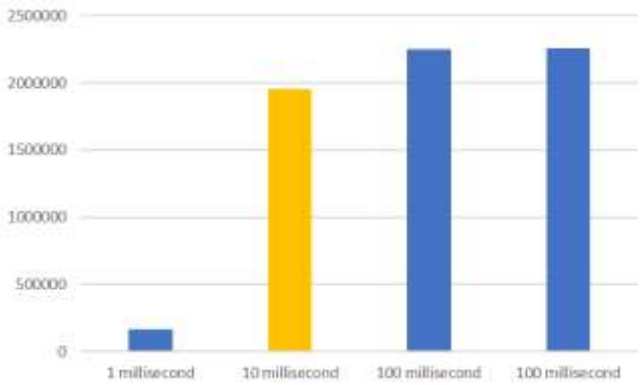
61 Starting from the point of time of order placement of the loser who failed in the "IOC order attempt" or "cancellation order attempt," prior to the placement of such "IOC order attempt" or "cancellation order attempt," a contract (or cancellation) is established by placing an order and a search is made for the winner who has quickly won (or avoided) the order subject to the "IOC order attempt" or "cancellation order attempt." In this case, it is assumed that there are three losers against such winner. In other words, it can be said that the same winner has been identified as a result of searching three times starting from each of the three losers.

is three, while if there are three winners and one loser in one race, the number of races will be three (as there will be one loser in each race) and the number of combinations will also be three. Basically, there will be more cases of multiple losers in one race than multiple winners in one race, and there will be more combinations of winners and losers than there will be the number of races.



Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 4.4.2 Number of Winners and Losers in Competitive Environment (A)
(Frequency table with time difference between winners and losers)



Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 4.4.3 Number of combinations of winners and losers by search time for competitive environment

4.4.1. Percentage of Other Investors Unintentionally Participating in Speed Competition

This section considers the situations of winners and losers in the three categories (six categories) described in Section 3.1 and by other investors (Figure 4.4.4). First, the overall trend is that the number of failed cancellation races is higher than the number of successful snipes because, by definition, each failed cancellation must have a matching winner, but as noted above, there are often multiple losers in one race. Conversely, the amount of failed cancellation races is lower than the amount of successful snipes on a per amount basis. It can be considered that the take-orders that constitute the amounts of successful snipes are mixed with large-sized market-orders, etc. and some of the failed cancellations that correspond to those orders constitute the race.

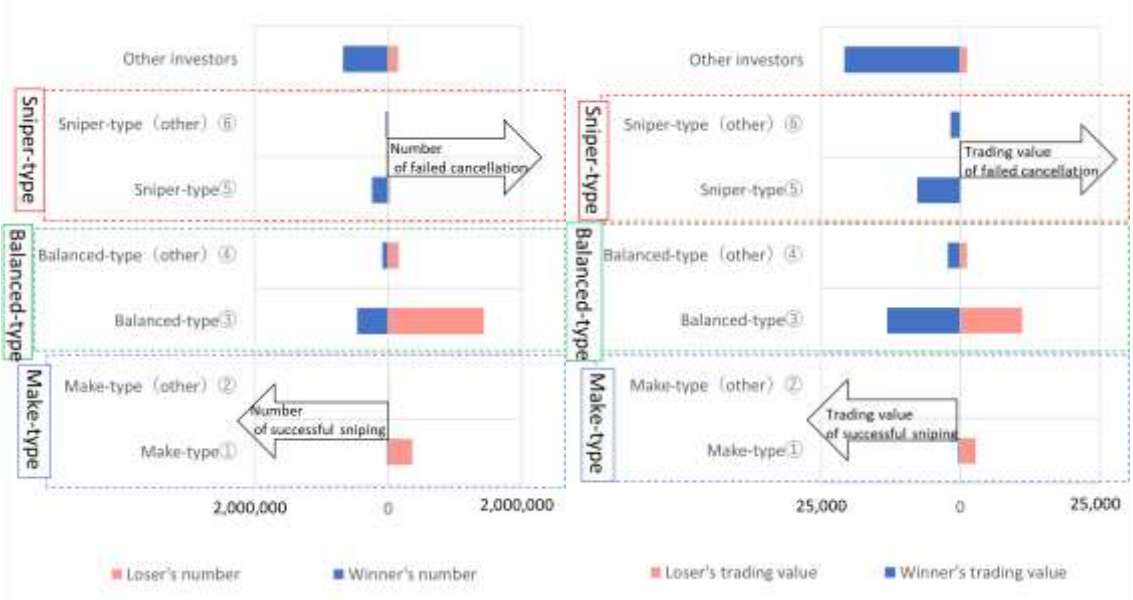
Based on the number of races shown in Figure 4.4.4 (the left figure), approximately 44% of the winners were other investors who are not registered HFTers. These are assumed to include not only other investors who unintentionally participate in races but also institutional investors[62] who are sufficiently fast to place and cancel orders, though not as fast as registered HFTers. In other words, competitive environment(A)(failure to cancel) includes at least two patterns: a race among registered HFTers based on changes in market conditions, and a race in which a registered HFTer detected orders from other investors and tried to avoid it. Further analysis is necessary, including other factors, but for now, we would like to add another point where other investors unintentionally participate in speed competition. For example, if there is a registered HFTer that provides liquidity (display quotes) to multiple markets, including dark pools and PTS at the same price for the same issue, if there is an order execution in a market, it is necessary to cancel quotes in other markets due to price volatility and price links.[63] However, if there is advanced SOR (Smart Order Routing),[64] such as simultaneous execution of best quotes in multiple markets, the cancellation order of the registered HFTer that was providing liquidity will fail. It is assumed that other investors became unintentional winners, including those caused by

[62] They are institutional investors such as securities firms. In particular, electronic trading that have the same level of technology as HFT can be assumed.

[63] There is also literature (Degryse, Winne and Gresse (2021)) that refers to the practice of HFTers to cancel all the order book provided to multiple markets as Ghost liquidity.

[64] A system which searches for best execution opportunities on multiple trading venues.

SOR.[65] In such a case, the success or failure of the HFTers which execute before other investor's order is executed depends on the structure and accuracy of the SOR. But even if an HFTer successfully cancel before other investor's order is executed, the orders of other investors are partially executed at the best execution price in any market, and it is unlikely that all orders of HFTer will be cancelled except under special circumstances. However, it can be said that from the viewpoint of best execution obligations, it is important to check whether the structure of the SOR is such that the SOR always arrives at one of the markets earlier and whether the arrival time of SOR is not significantly different between the markets (whether there is a sufficient time difference to use to execute latency arbitrage).[66]



Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 4.4.4: Competitive environment

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[65] If an order is placed with the TSE, PTS, etc. at the same time, it will arrive first at the exchange that is physically close. There are also sophisticated SORs that adjust the timing of orders according to the physical distance from the TSE, PTS, etc. so that orders arrive at each exchange at the same time.

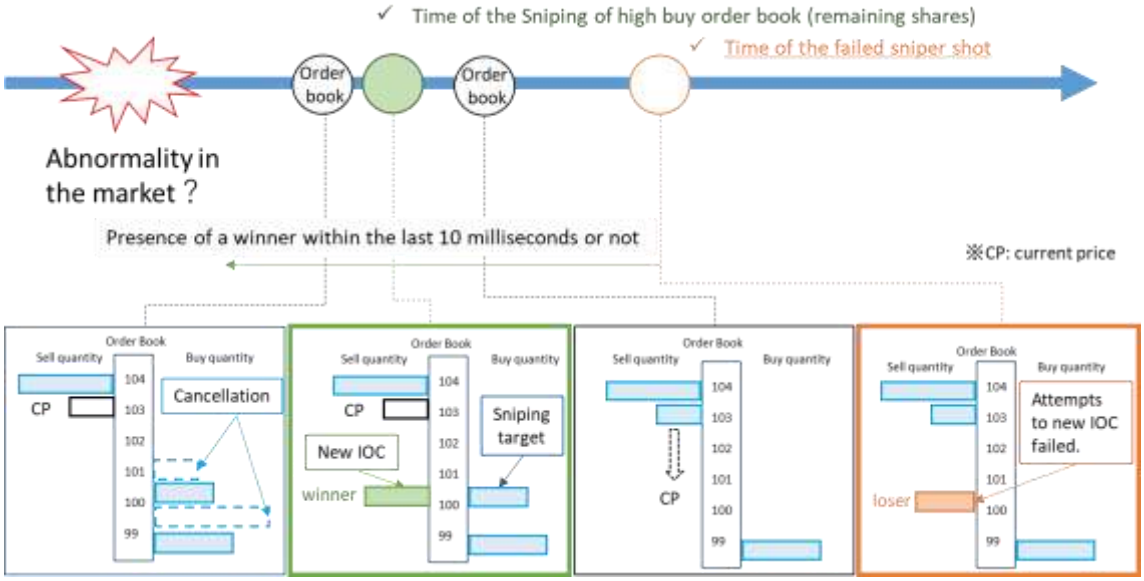
[66] The result of this analysis is the percentage of winners, and as mentioned in the previous section, other investors by definition in this paper are very rarely losers in the race. However, as described in the main text, the use of SOR by other investors may create a racing environment (in the case of an IOC order to the TSE). If the number of cases in which other investors become losers increases, it is possible to grasp the situations of inferior prices by setting an appropriate search time starting from all orders of individual investors (defined as losers).

Number of winners and losers (left figure) and amount (right figure; unit: billion yen)

4.4.2. Degree of risk aversion to providing liquidity to the market

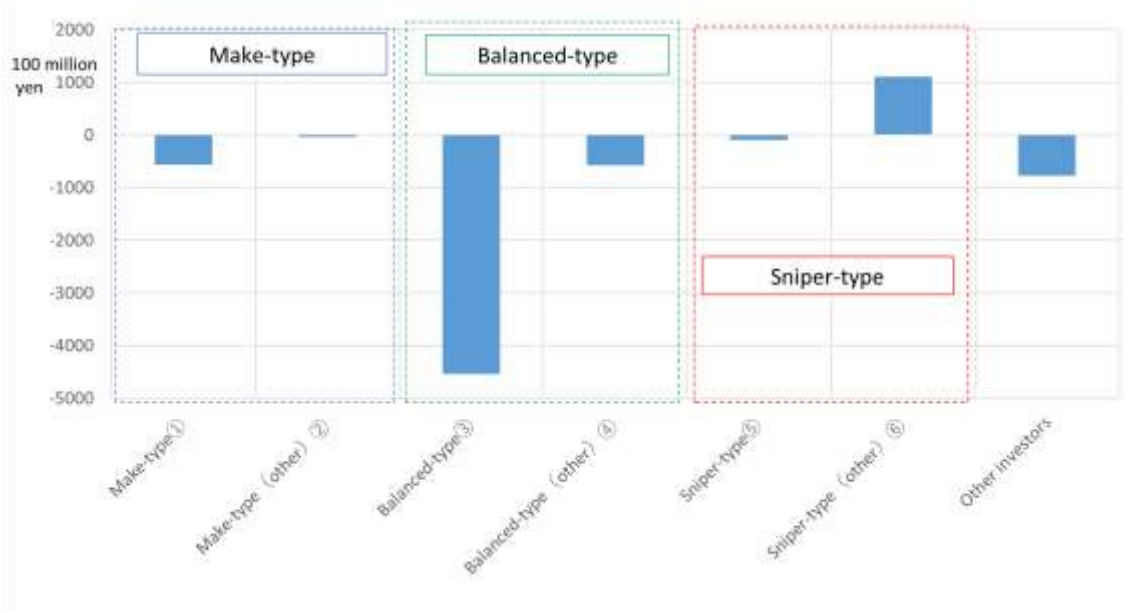
From the perspective of the degree of avoidance of the risk of providing liquidity to the market, Figure 4.4.4 shows that there is a large number of failed cancellations for balanced-type and make-type, except the sniper-type, but on a per-amount basis (right-hand side of Figure 4.4.4), the amounts of successful sniping are larger than the amounts of failed cancellations for the balanced-types (iii) and (iv). This suggests that even if all cancellation orders cannot be successful as desired, the amount of money attributable to successful sniping of inferior limit-orders may compensate for the loss attributable to unsuccessful cancellation. On the other hand, the make-type cannot be expected to make up for this loss because it does not snipe at all.

Next, we examine whether the registered HFTers of make-type or balanced-type are able to quickly cancel inferior limit orders from the order book by comparing a competitive environment (A) in which failure to cancel is a condition for a loser with a competitive environment (D) in which successful cancellation is a condition for a winner. As shown in Figure 4.4.5, the Competitive Environment (D) starts from the time of the failed sniping attempt, and searches back up to 10 milliseconds to the time when the order to snipe was preempted(D).



Source: Prepared by the author

Figure 4.4.5 Overview of IOC Order vs. Cancellation Order Race



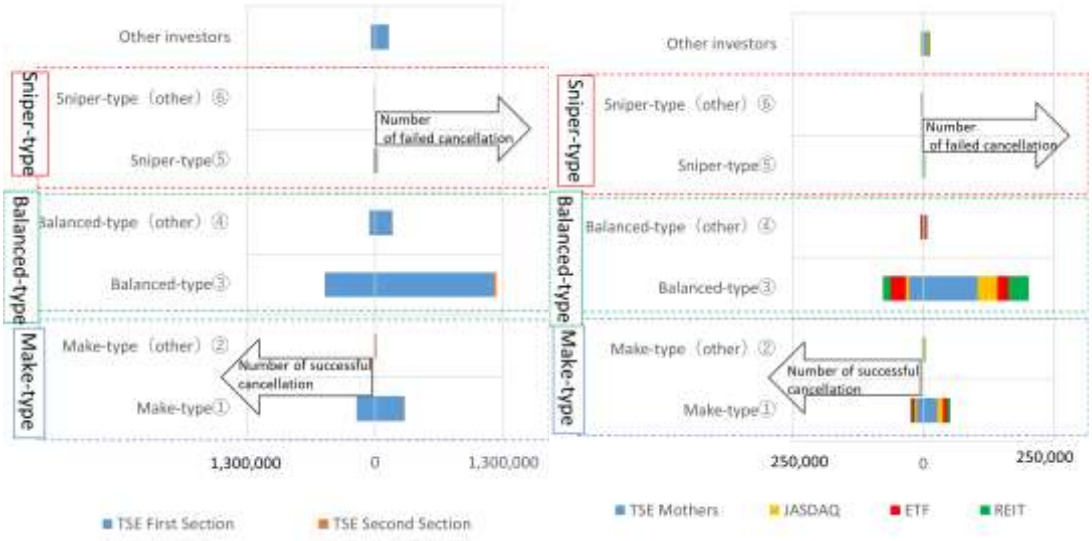
Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 4.4.6 Successful Cancellation Amount of Competitive Environment Minimum (D) - Unsuccessful Cancellation Amount of Competitive Environment (A)

When calculating the net amount obtained by subtracting the amount that failed to cancel from the amount that succeeded in cancellation for each of the six categories, it can be seen that the amount that failed to cancel was larger for all categories except for the sniper-type category (6) (Figure 4.4.6). In the case of balanced-type (3), cancellation was particularly likely to fail, and as mentioned above, it was assumed that successful snipers compensated for losses[67] to some extent. On the other hand, it is important for a make-type HFT to see whether the net amount in Figure 4.4.6 can be recovered by profits of the BBO spread. However, at least in the current situation, there are many cases where orders cannot be cancelled as desired, and it may be appropriate to consider that losses caused by BBO spread deviations cannot be recovered for races. These circumstances suggest that earnings competition among make-type of registered HFTers is intensifying. However, since market-making strategies are not limited to races, further examination is necessary in order to grasp the earnings situation of make-type of registered HFTers.

[67] The total amount of the loss itself varies depending on the point in time at which the loss is measured. Loss compensation here means the possibility that the loss caused by the failure to cancel (provisional value) is eventually partially covered by the success of the snipes.

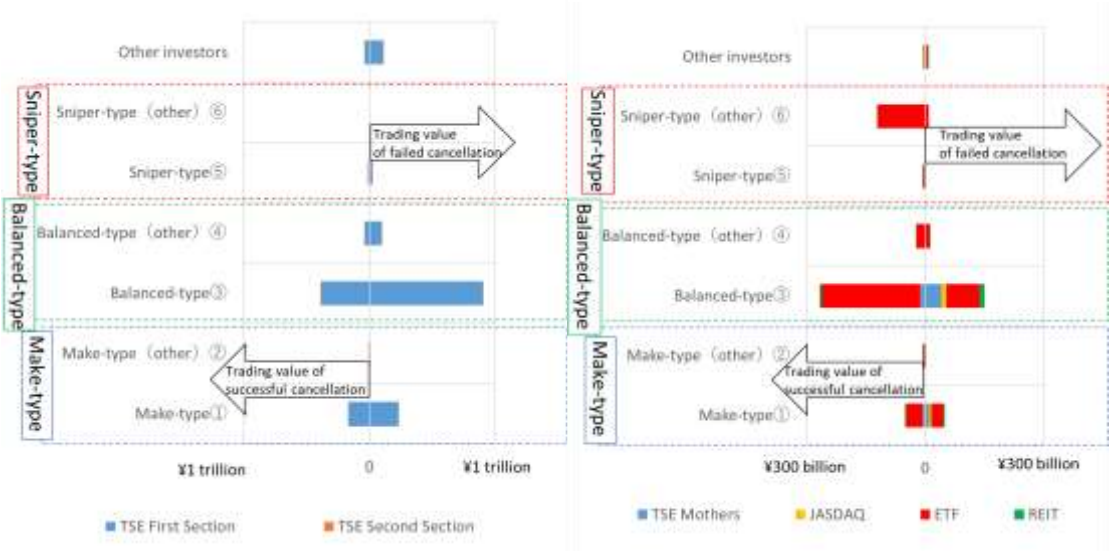
Next, Exhibit 4.4.7 and Exhibit 4.4.8 examined whether registered HFTers belonging to each category differ in the successes or failures of cancellation by market division. As a result, it can be seen that registered HFTers generally fail in each market except for ETFs in terms of amount. In addition, it is the sniper-type category (6) of registered HFTers that place take-orders, so the number of cancellation successes/failures shown in Exhibit 4.4.7 is much smaller than that of other categories. However, looking at the amount of races in Figure 4.4.8, it can be seen that the sniper-type category (6) participated in the race of ETFs and succeeded in cancelling orders for large amount of races with a high probability.[68] It is necessary to consider whether there is a remarkable feature in the timing of successful cancellation, based on the trading characteristics of registered HFTers, for each type and product attribute of ETFs, including market makers who quote obligation under the market-making system (market making incentive scheme of the TSE).



Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 4.4.7: Successful Cancellation of Competitive Environment (D) and Unsuccessful Cancellation of Competitive Environment (A)
Number of races by market segment and by six categories (Left: TSE 1st and 2nd Sections, Right: other)

68 As a prerequisite, this section discusses successful and unsuccessful order cancellations that satisfy the conditions for the race to occur. Since either success or failure of cancellations depends on considering orders near the BBO, it is unlikely that a high success rate is achieved at least in cancellation away from the BBO.



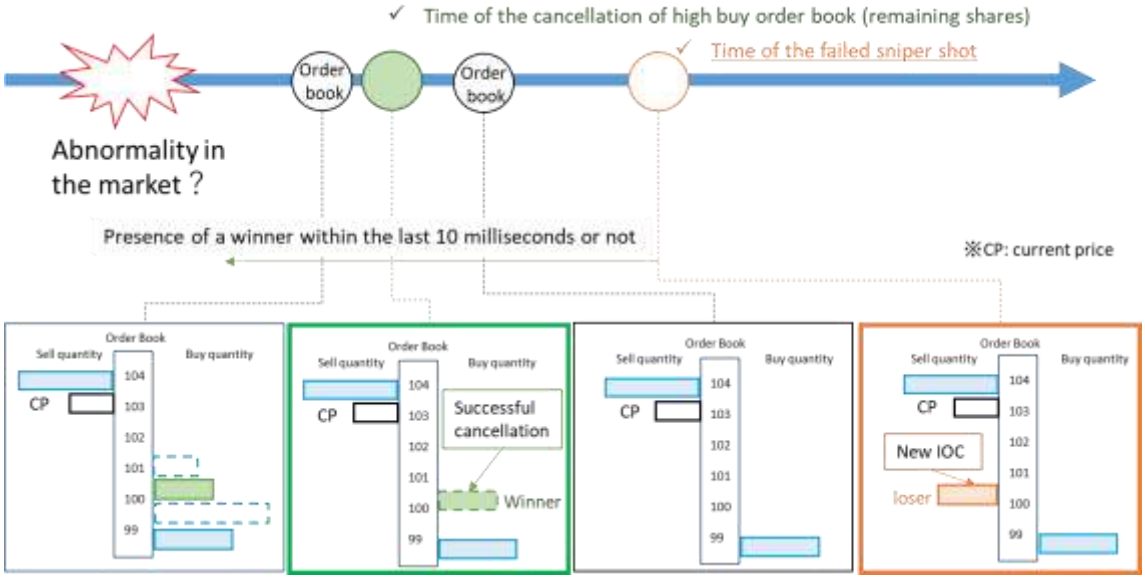
Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 4.4.8: Successful Cancellation of Competitive Environment (D) and Unsuccessful Cancellation of Competitive Environment (A)

Race amounts by market segment and by six categories (left: TSE 1st and 2nd Sections, right: other)

4.5. Discussion on Competitive Environment(C):Take-Orders vs. Take-Orders

In this section, we consider competitive environment (C), which is a race between snipers. In addition, as set out in Section 4.3.1, we try to minimize the presence of other investors who unintentionally participate in the race by limiting the conditions for the winner of snipers to "IOC order trade" rather than "take-order trade," thereby trying to grasp the reality of pure speed competition among registered HFTers. As in the past, as shown in Figure 4.5.1, the time when the sniper failed is the starting point, and the time when the order for sniper was preempted is searched up to 10 milliseconds in advance.



Source: Prepared by the author

Figure 4.5.1 Overview of Race between Take-Orders and Cancellation Orders for Competitive Environment (C)

As noted in Section 4.1, the style of sniping quickly at targeted orders is not limited to snipers with one shot. In particular, in the race in this section, which specializes in speed, it is assumed that there may be a style of sniping at specific orders multiple times from multiple virtual servers in order to reduce latency even slightly. Therefore, we analyzed not only a per virtual server basis but also a per firm basis[69] for the race. This means that a company with multiple virtual servers will not satisfy the definition of a race within one company, such as satisfying the winner condition for one virtual server and the loser condition for another virtual server. In addition, the specification was changed so that only the fastest order among multiple orders placed via multiple virtual servers owned by the same company will not be counted as a loser multiple times in one race.

When the race was on a per virtual server basis, the number of winners and losers for the five day period under analysis was approximately 4.8 million. When the race was on a per-firm basis, the number of winners and losers for the five-day period under analysis was approximately 2.4 million, a decrease of approximately 52%.[70]

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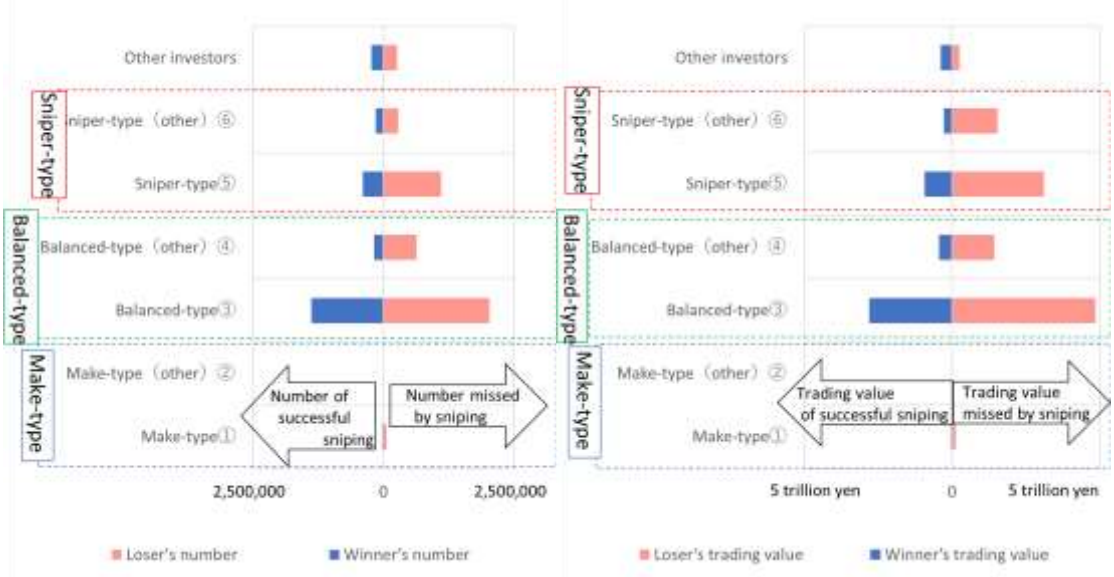
69 "Firm unit" is the unit for each registered HFTer and other investor. All participants other than registered HFTers are grouped under "other investors." Therefore, it does not satisfy the definition of a race among other investors (because it does not satisfy the definition of a race, that is, there are two or more participants).

70 Let us briefly consider alternative competitive environments (A) and (D). As for competitive environment (A), it is a situation where a participant succeeds in sniping its own order and fails to cancel its own order. It is a precondition that such transactions are cross-trade transactions and are basically not conducted. It should be noted that STP (Self-Trade Prevention) function, which was introduced by the TSE in July 2021, made it possible to prevent the occurrence of cross-trades by the same investor.

4.5.1. Order Styles and Sniper Rates by Category

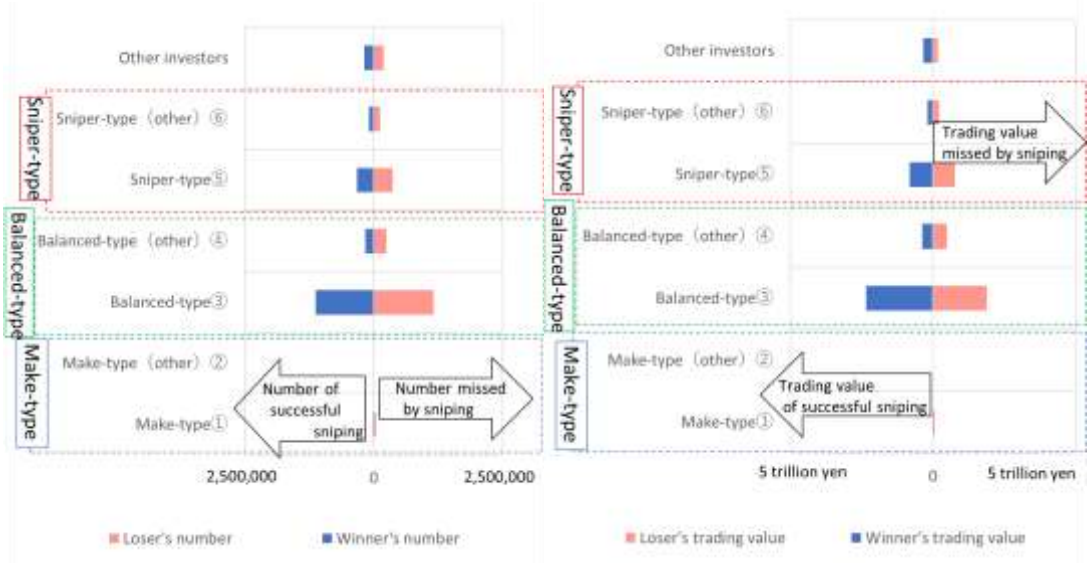
Next, we consider winners and losers by three categories (including six categories) and other investors, both by virtual server and by firm. Capturing races by company has reduced the number of races by 18% and the number of combinations of winners and losers by approximately 52% as mentioned above. As a result, there is no indication of a significant trend for the success rates of snipers to be extremely high in the specific categories (1) to (6) [Figure 4.5.3]. In the course of our analysis so far, we have caught a glimpse of various order styles by category, so we would like to sort out the order styles of each category by summarizing take-orders (the potential number of races), the number of successful snipers in the races, and the success rates.



Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 4.5.2 Competitive Environment (C) (per virtual server):
Number of winners and losers (left) and amount (right) for each of the six categories.

As for competitive environment (d), it is a situation where a participant fails to snipe its own order and succeeds in cancelling its own order. It is assumed that there are multiple trading strategy teams within a single firm. Defining the race on a "company unit" reduced the number of races by around 7% and the number of winner / loser combinations by around 24%.



Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 4.5.3: Competitive Environment (C) (Corporate Unit)

Number of winners and losers (left) and amount (right) for each of the six categories.

object	All orders		Competitive Environment(C)			
Calculation Methodology	Nums of take orders / (Nums of take orders + Nums of IOC expirations)		Nums of race winners / (Nums of race winners + Nums of race losers)			
Subject of the race			per virtual server		per corporate	
Item	sniping rate	Nums of take orders (ten thousands)	sniping (target) rate	Nums of successful sniping attempts (ten thousands)	sniping (target) rate	Nums of successful sniping attempts (ten thousands)
Balance-type③	55%	316	41%	139	50%	113
Balance-type(other)④	38%	53	22%	18	40%	16
Snip-type⑤	24%	109	26%	39	47%	33
Snip-type(other)⑥	2%	22	34%	14	44%	10
Calculation Results	Percentage of take orders that led to execution		Race sniping (target) rate			
note			○The race definition must be met on a per virtual server. ●If a particular order is placed multiple times from one virtual server, it will be recorded multiple times as a loser.		○The race definition must be met on a per company-by-company. ●If a particular order is placed multiple times by a single firm, all but the fastest orders are excluded.	

Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 4.5.4 Target Rate and Number of Successful Sniping by Category

As mentioned in Chapter 3, the number of take-orders ("all orders" in Figure 4.5.4), which is the potential number of races for competitive environment (C), is larger for balanced-type than for sniper-type, and sniper-type (Other) (6) has a very low success rate (about 2%) because many IOC orders have expired.

When a race is defined in a per virtual server basis in Competitive Environment(C), approximately 2.1 million (1.39 million + 180,000 + 390,000 + 140,000), or approximately

42%, of the number of take-orders (approximately 5 million: 3.16 million + 530,000 + 1.09 million + 220,000) have developed into a race. The success rate of the balanced-type is generally lower than the take-order success rate (from 55% to 41%), while the success rate of the sniper-type (5) is slightly higher than the take-order success rate (from 24% to 26%), the success rate of the sniper-type (other)(6) is significantly higher than the take-order success rate (from 2% to 34%). In competitive environment (C) that captures a pure race among registered HFTers, naturally there are more races in which the sniper-type registered HFTers specialized in take-order strategies participate. Therefore, it can be inferred that the success rate of balanced-type registered HFTers will decrease, whereas the success rate of speed-focused, sniper-type registered HFTers, will not differ significantly. The significant increase in the success rate of the sniper-type (others) (6) is due to the fact that IOC orders have been repeatedly placed and many of them have expired in an environment that does not develop into a race. It can be inferred that repeated IOC orders are part of a strategy, but as long as they have not developed into a race, they are trading based on information that has not been detected by other registered HFTers.

Finally, defining a race on a per-firm basis shows that the success rate is higher for all categories of balanced-type and sniper-type of registered HFTers than on a per virtual server basis. Many registered HFTers have multiple virtual servers, so defining a race on a per-firm basis rather than on a per virtual server basis avoids the situations where winners and losers actually belong to the same firm and where a particular order that has been placed multiple times is counted as a loser multiple times. The rise in the success rate may have been due to the presence of multiple trading strategy teams within a HFTer and an intense competition within a single HFTer, or it may have been due to the style of placing multiple specific orders from a virtual server owned by the firm, which made the success rate appear lower than it was. Regardless of the cause (the former or the latter), when we summarize a per-firm basis success rate, which is considered close to the true success rate, we can see that the success rate of both balanced-type (3) and sniper-type (5) registered HFTers have a high success rate of 50% and 47%, so it can be said that the current race is a close contest. If the success rate of sniper-type registered HFTers increases overwhelmingly, it could increase the risk of market making strategies of the make-type or balanced-type registered HFTers, which could lead to a reduction in liquidity supply. Furthermore, the possibility that many of the registered HFTers will become specialized in sniper-type will warrant monitoring with additional analysis.

4.5.2. Specificity in ETF Issues

Looking at the status of races by market segment based on the assumption of races by virtual servers, it can be seen that both the number of races and the amount of races are dominated by those on the TSE 1st Section (Figures 4.5.5 and 4.5.6, left side). On the other hand, there is a characteristic difference in the number and amount of races for ETFs. Although the number of races for ETFs is not much different from those for JASDAQ and REITs, the amount of races for ETFs is about 11% of the total amount of successful snipes, and about 34% of the total amount of failed snipes. Each race is large and is more than five times larger than other market segments. From figures 4.5.7 and 4.5.8, when looking at each group, it can be seen that there are many races between registered HFTers of snipe-type in categories (3),(5) and (6) and those of balanced type.

Additionally, when we checked the trading status of each future linked to ETFs, we found that many registered HFTers participating in the speed competition in the ETF market were participating, and that they were arbitrage linked to ETF trading. In the past, it was considered that HFTers tended to refrain from taking large orders; however, with an arbitrage strategy for ETFs and futures, almost a perfect linkage can be expected. If they buy futures of the same size even if they sell large amounts of ETFs, market risk would be limited. Therefore, it was inferred that there was an unusual difference between ETF issues and other issues, and it was possible that trading based on such arbitrage strategies would dominate market-making strategies. We cannot examine whether price links between products and markets will be speeded up by intensifying speed competition because we need to extend the period covered by the analysis and secure sufficient data.

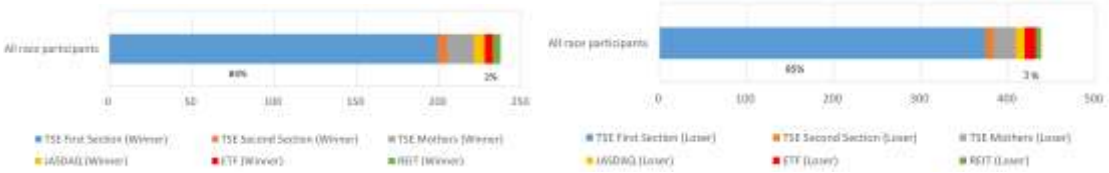


Figure 4.5.5 Competitive Environment (C) (per virtual server)

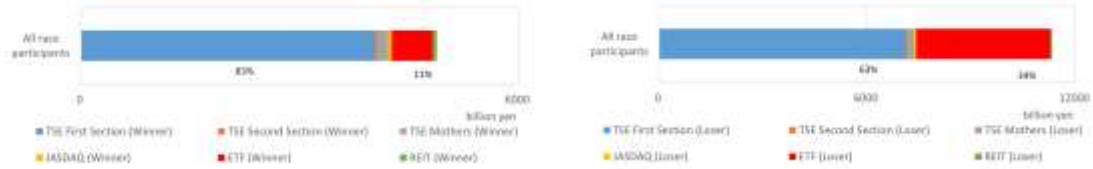
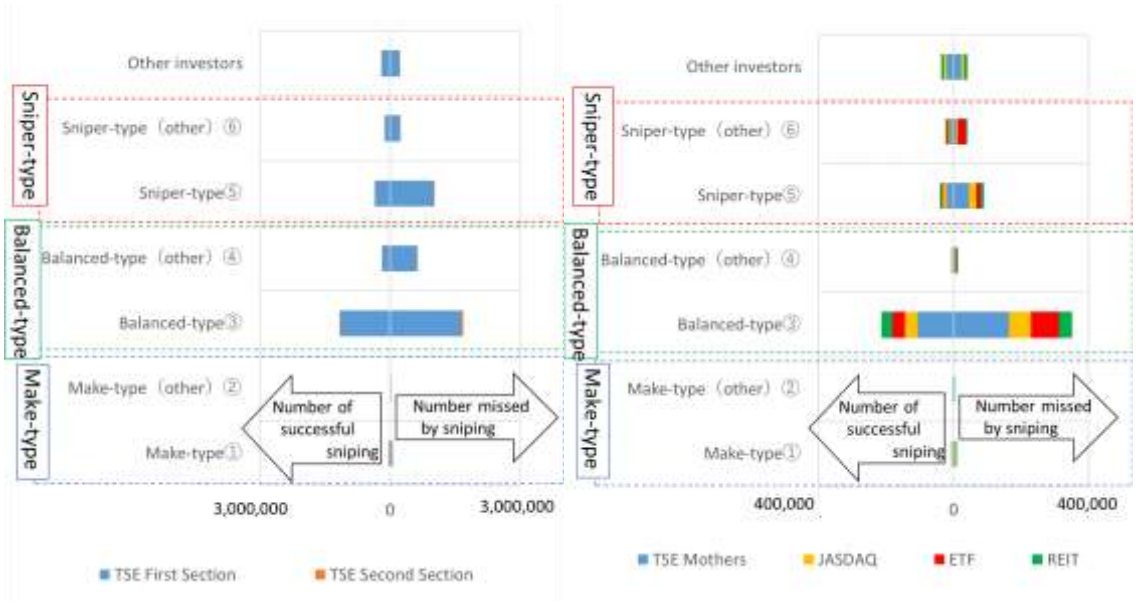
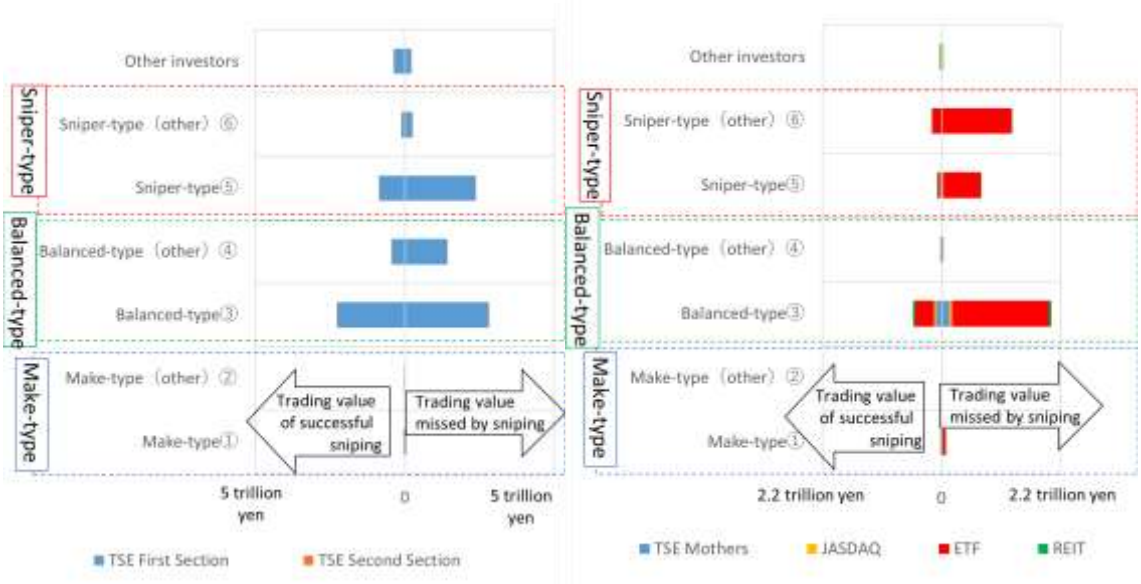


Figure 4.5.6 Competitive Environment (C) (Virtual Servers Market by Race Amount (Left: winner, Right: loser)



Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 4.5.7 Competitive Environment (C) (per virtual server): Number of races by market division and by six categories (left: TSE 1st and 2nd Sections, right: others)



Source: Prepared by the author based on data from the Tokyo Stock Exchange

Figure 4.5.8 Competitive Environment (C) (per virtual server):

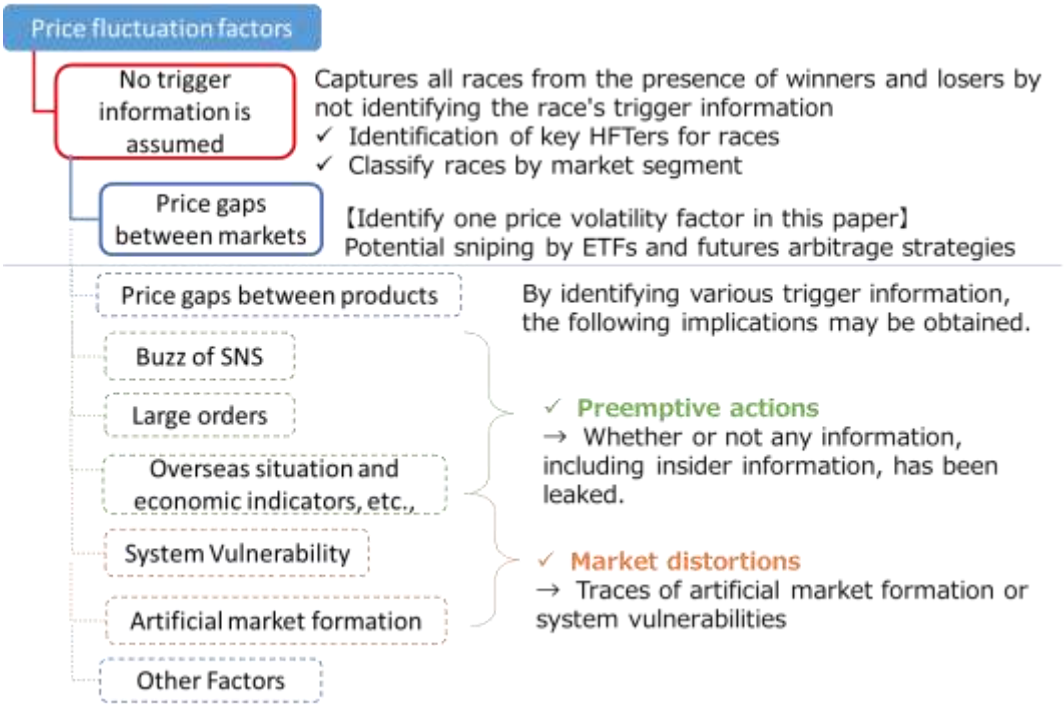
Race amounts by market segment and by six categories (left: TSE 1st and 2nd Sections, right: other)

4.6. Discussion on race results and future challenges

As can be seen from the definition of race in Section 4.1, this analysis has made it possible to capture the race comprehensively by not specifying the triggers of the race (market volatility, natural disasters, international affairs, price differences between markets/products, social media buzz, large-scale market-orders, etc.). Therefore, in order to conduct further in-depth analysis in the future, it is effective to conduct secondary analysis of the race that has been captured and on what grounds the race occurred. As appropriate, other analysis, such as analysis of trading data other than cash equities, may be effective, in addition to interviews with registered HFTers and exchanges. For example, although arbitrage strategies for ETFs and futures were briefly mentioned in this section, there may be a race that has been created due to system vulnerabilities or market distortions or a trading strategy that artificially generates a race that is not specified in this paper (Figure 4.6.1). It can be said that this analysis method is useful because there are many implications that can be obtained by examining the captured race from various angles, such as whether there is a race in which a particular registered HFTer continues to win, or whether there is a race in which only a particular HFTer can respond (or whether only a particular HFTer responds). Furthermore, within the framework of this approach, it is possible to analyze whether or not there is latency arbitrage trading across multiple exchanges of registered HFTers, for example, by directly originating from a specific execution (large-sized orders, market-orders, etc.) instead of originating from a loser in the speed competition (failure of a cancel attempt or an IOC order attempt). This is an approach with many uses, as it has the potential to reveal the entire trading of a race by extracting various races based on the issues related to HFT, not only speed competition.

As a future issue, the number of days subject to analysis was limited to five business days due to data constraints, and it cannot be completely denied that the results reflect the peculiarities of the five business days. Although this paper secures a certain amount of data by analyzing all of the cash equities (approximately 4,000 stocks), it does not analyze market conditions, such as the beginning of the month, the end of the month, the beginning of the year, the end of the year, or the trading days with high market volatility. Naturally, the outcome of the race will change depending on each such phase, and there is a possibility that registered HFTers will refrain from trading when the winning rate declines. In light of the possibility that a decline in liquidity could trigger sharp market fluctuations, it is necessary

to increase the number of days subject to analysis as much as possible and deepen the analysis, including consideration of trends and strategies of registered HFTers.



Source: Prepared by the author

Figure 4.6.1 Trigger Events and Implications

5. Summary and remaining issues

This paper's understanding of speed competition reveals that orders placed by investors are targeted by registered HFTers and inadvertently become winners in the race; that "make-type" registered HFTers are becoming increasingly exposed to risk from constant (or technical factors in electronic transactions) cancellation failures, while "balanced-type" registered HFTers may be able to make profits from sniper attacks that exceed cancellation failures; that "balanced-type" and "sniper-type" registered HFTers place IOC orders in a variety of ways (sniping placed not only once but also on a random basis, and sniping from multiple virtual servers, etc.); that the hit (success) rate of "balanced-type" registered HFTers is close to that of "sniper-type" registered HFTers: and that ETFs have characteristics (trends) that differ from those of other stocks.

The approach of Budish et al. (2021), which defines a race by the presence of losers and winners without identifying the race's triggers (market volatility, natural disasters, international affairs, price differences between markets/products, social media buzz, large sized market-orders, etc.), is extremely powerful in that it captures speed competition exhaustively. In addition to the approach of Budish et al. (2021), identifying the trigger information that triggered the race would enable a more in-depth analysis of speed competition among registered HFTers.

In any case, what is important in considering the pros and cons of HFT is to identify and discuss the reason for the speed competition, that is, the root cause of the race (trigger information or the event that triggered the transaction). As a side effect, it is possible to discover market distortions and vulnerabilities and gain various implications, such as measures to be taken and the framework for necessary laws and regulations.

In order to accurately grasp the actual situation of HFTers, it is vital to digest each of these implications and accumulate and examine wide-ranging data collection, including not only cash equities but also derivatives, commodities, PTSs, and dark pools, through further in-depth study.

Above all, in addition to the paper published by the UK's Financial Conduct Authority (Budish et al. [2021]), which forms the basis of this analysis, other authorities are actively disseminating information on HFTs and algorithms (Financial Industry Regulatory Authority [2015], Authority for the Financial Markets [2016], Financial Conduct Authority [2018], Australian Securities & Investments Commission [2018], Securities and Exchange Commission [2020], and Hong Kong Monetary Authority [2020]). It is interesting to note that races similar to those on UK exchanges (Budish et al. [2021]) are also taking place on

Japanese exchanges. In order to accurately understand the trading behavior of HFTers which are expanding globally, it is necessary to analyze the characteristics and structure of the race, the factors that cause the race, and the economic effects caused by it. Sharing the pros and cons of HFT across countries and conducting mutual verification may yield essential knowledge. International cooperation in this field, in particular, information sharing with exchanges and building close relationships with securities regulators in other countries will become increasingly important in the future.

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