



Comprehensive Delineation of Algorithmic High-Frequency Trading

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Abstract. This paper reviews past research on high-frequency trading (HFT) and analyzes the impact of HFT on market players. The development prospect of HFT is evaluated considering the relevant regulatory measures. In light of the economic proliferation, HFT has stationed a matured stage through the coordinating regulatory supervisors and sophistication of rapid-changing technology. From the perspective of macroeconomic structure, despite noticing certain downsides, HFT altered the main features and further enhanced the comprehensive quality of the market. With the implementation of appropriate, much more complicated regulations over ambiguous places, HFT will benefit the market and vitalize the economy in the foreseeable future.

Keywords: high-frequency trading, liquidity, volatility, market-making, arbitrage, directional trading, algorithmic trading

1 Introduction

Assume an individual investor wants to buy 100,000 shares of Intel, which are scattered among the New York Stock Exchange (NYSE), the National Association of Securities Dealers Automated Quotations Stock Market (NASDAQ), and the Better Alternative Trading System (BATS). Almost immediately after an investor enters a buy order (if it arrives at the exchange), the HF trader can access the order (as if the trading plan is already in the hands of the HF trader) and buy the stock before an individual investor can. A few milliseconds later, HF traders sell the shares to individual investors at a markup.

The financial activities that use programs instead of traders to participate are called High-frequency trading, also known as algorithmic trading. Generally, HFT can be classified into four different sectors, market makers, proprietary statistical arbitrageurs, predatory trading, also known as directional trading, and reverse trading involving particular financial institutions, the fourth sector will be ignored herein. Distinctive fea-

tures of HFT, improving the efficiency of both information transmission and the velocity of processing information or relative material in the sub-second level, have enabled participants open and close their positions in a very short time interval.

Despite the popularity of HFT in the market today, its history from its inception to the present is not long. One of the theories is that in the late 1980s, HFT took off at the same time as program trading took off in the US. The more widely held view in the market is that HFT took off around 1999.

At that time, most of the orders in the US stock market were indirectly sent to the market for matching, while the NYSE was still dominated by manual matching, while the NASDAQ market transferred the trading orders to the market makers, who then decided how to complete the transaction. As a result, the market could not truly reflect the orders of large orders or retail investors. During the unprecedented "stock market crash" in 1987, the problem of "ignoring the big and the small" (being too busy dealing with large customer orders to pay attention to small and medium investors) was highlighted, making small and medium investors suffer heavy losses and was criticized.

After hearing the arguments, the SEC decided to strengthen protections for retail investors, one of which was to set up a Small Order Entry System (SOES) on NASDAQ. The first automated trading system in the U.S. market, the system can only be used as a client brokerage, not a proprietary business, and there are limits on the number and frequency of orders traded. At the same time, as the only automated trading system, its speed and efficiency led many people to use it for trading. Due to the outbreak of the Internet economy around 2000, more and more people found it profitable to take advantage of SOES to participate in this enterprise trading, and intra-day trading proliferated in the market.

With the collapse of the dot-com bubble and the introduction of the percentile quotation reform, the bid-ask spread narrowed and day trading became much less profitable. Most day traders and day trading companies quit. But a small number of day trading firms have stayed behind and are using computer programs to make day trading possible. The companies' earliest trading strategies were basically day trading done by hand using computers. Some of these strategies, similar to those of market makers, have attracted the attention of these firms because they are less risky, require less capital, and are more cost-effective.

Due to the reform of market regulation policy and the progress of computer and communication technology, high-frequency trading has rapidly blossomed in the American capital market, extending from the stock market to futures, options, foreign exchange, bonds, and other diversified markets.

HF traders capture information from the market and use it to judge possible changes in stock prices. They then buy and sell at high speed and close their positions in a very short time. The capital appreciation or transaction fee of each transaction HFT make may be comparatively small, the entire P&L, however, can be mounted up to a terrible scale.

2 What is HFT?

HFT is a trading practice by powerful computers with high-speed connections to exchanges and the ability to execute large numbers of orders at an extremely high speed. Technically speaking, HFT employs specific algorithms to analyze different markets and execute trading orders in the most profitable manner. The Securities and Exchange Commission (SEC) attributes certain features to "high-frequency trading": (1) the use of extraordinarily high-speed and sophisticated computer programs for generating, routing, and executing orders; (2) the use of co-location services and individual data feeds offered by exchanges and others to minimize network and other types of latencies; (3) very short time-frames for establishing and liquidating positions; (4) the submission of numerous orders that are canceled shortly after submission; and (5) ending the trading day in as close to a flat position as possible [1]. Market making, arbitrage, and directional trading are the most frequently used HFT strategies.

A market maker is a firm that stands ready to buy or sell a stock at publicly quoted prices [2]. Basically, market making is creating liquidity. In an order-driven market, market makers take several different forms: an exchange may agree with a designated market maker, who must bid at the opening and closing and guarantee a certain percentage of bids within a specified period, to provide more bid-ask quotes in a fair and orderly market. Non-designated market makers are exempt from such obligations and simply act as liquidity providers. This is the case for HF traders who adopt market-making strategies. Based on HFT data, they put up limit orders at different prices around the price of the underlying asset. When the underlying asset price fluctuates continuously, the market maker will put up low-price buy orders and high-price sell orders, so that the market maker can buy low and sell high to earn the difference. In quote-driven markets, market makers are dealers who offer to provide liquidity to other market participants through quotes. Market makers profit by earning bid-ask spreads, and each market maker acts like a small exchange.

Of course, market-makers bear the risk that they trade with, and lose money to an informed counterparty [3]. In order to limit their losses to their counterparties, they intend to ensure that their limit orders to buy and sell integrate as much current information as possible as rapidly as possible. HF market makers are therefore required to keep updating the quote continuously in response to other order submissions or cancellations. This continuous updating of the quote can be based on the type of model they follow. In this process, the HF market makers tend to submit and cancel a large number of orders for each transaction.

Arbitrage strategies are often defined as riskless profit opportunities. They consist of the simultaneous purchase and sale of two assets that are substantially similar or related, but that have different prices [4]. One of the most well-known uses of this trading approach is to try to profit from the discrepancy between the stated prices of the S&P500 Index and the market pricing for the S&P500 futures. Basis trading is another name for the S&P500 Index arbitrage. The difference between cash and futures market prices serves as the basis.

Theoretically, the price of the index is supposed to be accurate when calculated as a capitalization weighting of all 500 stocks. Any discrepancy between that figure and the

price of futures trading in real-time should be viewed as an opportunity. If the component prices were lower, a risk-free transaction would be to immediately execute a buy order on all 500 stocks and sell an equal number of higher-priced futures contracts.

Naturally, such a strategy would necessitate substantial capital, accelerated trading, and few commissions or other costs. Taking all these factors into consideration, arbitrage strategies are more likely to be profitable when implemented by large-scale banking and brokerage operations. Such institutions can execute significant trades while still profiting from minor differences. The likelihood that some index components may be mispriced increases with the number of components, which also increases the potential for arbitrage. As a result, it is less likely that arbitrage on an index of a select few equities can present profitable possibilities.

When HF traders detect external information that a move is imminent, positions are established in advance, and profit closing is completed when the market reacts to the event and it is reflected in the price. The core idea of directional strategy is basically to obtain the direction of short-term large probability price fluctuation after studying and judging the order flow information or specific events, then build positions in advance with the speed advantage, and close out positions after the price fluctuation reaches the expected point. This strategy is profitable because it studies the microstructure of the trading market (order book information), understands events, and executes faster than other participants. And it is less susceptible to volatility due to order placing.

3 The importance of market liquidity

Liquidity, one of the most valuable features in the financial market, measures the extent of how hard it is to switch one asset to cash. Liquidity is subject to 3 dimensions, price, volume, and time. Normally, when one talks about the liquidity of a certain type of asset, one can think of bid-ask spread, transaction cost, order handling fees, brokerage commission, and so on. All of these become authentic obstacles for liquidating the underlying assets. The three properties mentioned above are greatly subject to the underlying assets. We primarily focus on the listed stocks.

3.1 Impact of HFT on liquidity

As mentioned above, HF traders act as informal market makers. By exploiting extraordinarily complicated computing codes and co-location services as a result of a sub-second level of trading, HF traders and participants forward a large number of limit orders in both the long and short side of the limit order book over the security market simultaneously, by filling these orders with different transactions conductors and thus ultimately providing liquidity for investors. HF traders earn the bid-ask spread. With a tiny spread for each trade on a large scale, it is rather profitable.

There is no doubt that in this sort of market making, HFT does not play a fundamental role in trading and securities exchanging. However, it greatly increases the liquidity of each type of asset. HFT generates a huge amount of buy limits and sells limits in the sub-second level, contributing to matching one trader and another trader much more

quickly and acutely. As a result, it lowers the bid-ask spreads and the matching time. HF market makers greatly enhance the overall market structure, depth of trading as well as the most important feature, liquidity.

Conversely, the HF market makers create endless electronic limit orders sub-secondly, and the market exposure position is rather huge. For either a traditional market maker or an HF market maker, the exposure must be hedged to a great extent. And apparently, HFT being the counterpart of the underlying trade, taking the assets of the immediate seller and being the buyer temporarily is not sensible to have a huge exposure. Those electronic limit orders are then withdrawn. A great deal of cancelation is taking place sub-secondly accordingly. That is, the liquidity HF traders provide are fake, with a tiny portion of them can be traded appropriately. The increased liquidity is not tradable. This could lead to a unilateral trend in the market, effectively taking out the liquidity. Not to mention that when a time of crisis happen, HF traders leave immediately and take away liquidity faster than anyone else could.

In terms of liquidity, the HFT is also creating information asymmetry. As market makers, HF traders gain a lot of private information in the "price impact" situation. As institutional investors, hedge funds, and such make a large order to close their position or else, they tend to suppress the intention, hiding it from the public, while the HF traders and market makers know all about it and have the incentive to sell the underlying assets first beforehand, to lower the price. To a certain extent, this could lead to an increase in the bid-ask spread. In a long run, this sort of information asymmetry could deteriorate the quality of the exchange market and force small investors out of the investment market.

3.2 Transaction cost tendency

As one can easily notice, the bid-ask spreads are indeed reducing over the given years. And the certain volatile market and uncertainty like the financial crisis in 2007-2008 increased the bid-ask spread in the short-term rapidly due to decreasing trades, and worse liquidity [5]. To see it in 10 decades or even longer, the bid-ask spread, or the main transaction cost are doubtlessly reducing due to the electronic automated matching systems, which replace the traders in exchange markets with low latent and high accuracy machines. Also, the impact of restrictions on brokerage commissions should be taken into account to a great extent. It is clear that the bid-ask spread, also known as the quoted spread herein, is indeed dropping with information exchanging systems developing faster than ever. However, one can hardly tell the portion of how these HFTs market makers or, HFTs arbitrage seekers have helped, along with so many other indispensable factors.

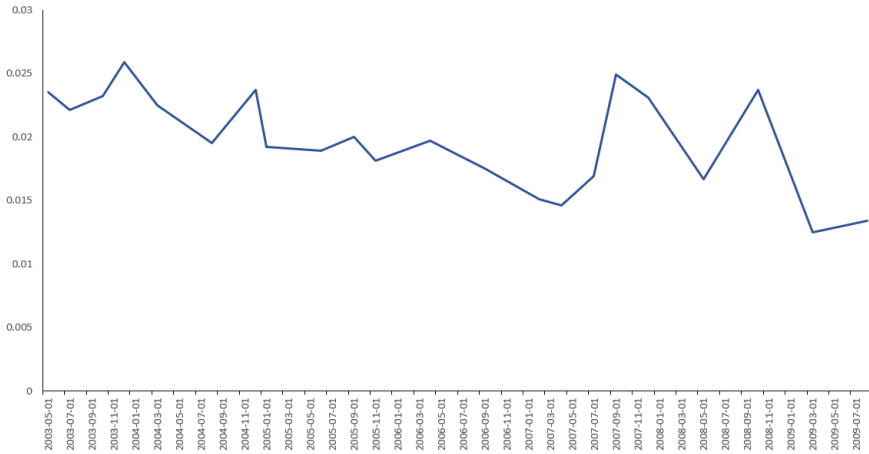


Fig. 1. Median SP500 Bid-Ask Spread in 2003-2009. [Owner-draw] Source: Knight Securities

4 Volatility

4.1 Impact of HFT on volatility

Volatility is a concept of simply the price of the underlying asset's fluctuations over a given period, subject to multi-dimensions factors. Academically, people sorted 4 kinds of volatility to quantitatively measure volatility, historical volatility, realized volatility, expected volatility, and implied volatility.

As the main function role, HF traders' role as market makers, though putting forward endless limit orders on both sides, does not enlarge the long position or short position according to the academic estimation. In other words, it efficiently lowers the fluctuations of securities, for having low latent matching and trading.

However, firstly, the main feature of HF traders is that they are not taking interest rate risk, that is, their market exposure has to be hedged. Generally, HFTs must sell all their position when the market is closed. This will also potentially create unstable factors, increasing unnecessary volatility [6].

Secondly, particularly those event-driven HF traders, who seek information at the fastest level to earn an arbitrage premium, by noting the sudden huge orders posted by large investors or institutions, would have an incentive to follow and therefore create huge increment or decrement in a single stock, enlarging uncertainty and volatility for normal investors. This also leads to an exacerbating quality of exchanging market.

5 HFT's development

5.1 HFT's impact and development

Peter Gomber and Martin Haferkorn (2012) studied HFT technologies and their implications for electronic securities trading in 2012. Authors hinted that the overall market quality has been further improved by HFTs, no matter in the way of electronic market makers, arbitragers, liquidity-detection, or event-driven strategies. Market quality is now normally and extensively measured based on the metrics of liquidity, volatility, and explicit and implicit transaction cost. HFT strategies are both statistically and empirically proven that they are indeed causing the overall trading frequency, namely liquidity, to extend when volatility accordingly to be stabilized to a certain extent. As for the new regulations on HFTs, the revision of the Market in Financial Instrument Directive (MiFIDII) plays the most important role. The HFTs are required to construct matured systems including risk position as well as eligible information unveiled. A crucial excuse justified for the Flash Crash in the United States in 2010, is argued that the intention of rapidly and radically selling was completely reasonable, even without such technology the result would not be any different [7].

5.2 Using artificial stock market and STGP model to demonstrate the HFT scalping strategy

Viktor Manahov (2015) studied whether HFT strategies can constantly beat the market in 2015. The Paper begins with a statement of the significance of the study, contributing to regulators with legal and macroeconomic aspects. HFT investors are separated into a scalping strategy and an aggressive one, and their way of investing is successfully replicated in the author's artificial stock market. Additionally, since only computers can handle huge amounts of orders' generation and execution at a sub-second level, the author quoted in the paper that the financial market "mixed human machine" was transformed into an "all-machine ecology". This outstanding feature of HFT, unimpeachable exchanging rate and completion of the complicated algorithm coding, earns itself an unparalleled advantage in both scalping strategy and aggressive way. By accurately computing the cumulative return of HFT in the artificial stock market, the paper finally concludes that the scalping strategy can grasp a frontier opportunity faster and more accurately than other market undertakers and therefore generate a larger profit. That is, via advanced and unpatrolled algorithm codes, HFT scalpers can earn a certain amount of capital gains in anticipating and front-running the order flow, leaving the low-latency investors in a rather awkward position in the marketplace. As stated in the paper, low-latency investors could impose server picking-off risks for private trading orders and inefficient markets [8].

5.3 HFT's development in China

China's institution is not attractive for HFT practices mainly for several reasons listed below: 1. The regulatory environment is not favorable for HFT practices. 2. The major

obstacle to suppressing such practices is that the T+1 rule was implemented in China, which forces investors to sell their assets the day after the day they bought. 3. The internet latency in China is not conducive to cultivating HFT. 4. The explicit transaction cost in China is not contributing to promoting such practices. Some countries in Asia, otherwise, have a relative matured system [9].

Table 1. The portion of HFT activities in several countries

Country	Estimate	Information Source
Japan	45% of equity trading	Bank of Japan
Australia	27% of equity trading	Australian Securities and Investments Commission
Hong Kong	20% of equity trading	Hong Kong Securities and Futures Commission
Singapore	30% in derivatives	Singapore Stock Exchange

Source: Kauffman et al. 2015

5.4 Very-Short-Time-Price-Change Theory

Gianluca P. M. Virgilio (2022) studied the very short-time price change in 2022. To maximize the profits gained from fluctuations in securities, institutional investors or high-frequency trading investors always tend to search for driven factors behind price changes at a sub-second level. Herein, the paper filled the gap academically, that has generally been missed by previous studies that concentrated on exclusively exogenous factors, for instance, business and macroeconomics news, fundamental analysis like the financial statement across sectors, corporate, accounting and tax policies, market regulations, the correlation between securities, technical analysis, arbitrage and so on. Also, such paper may enhance the overall financial stability.

The endogenous factors that the paper focuses on are previous volatility, scarce liquidity, high quantity exchanged, and stop-loss orders. Particularly, the stop-loss orders factor is quite an innovative thought. Methodology exploited here are (1) newly established theoretical foundation, (2) Granger-causality tests (3) ABM, that is, agent-based modeling, and simulation. By roughly discussing 4 types of relations between the underlying factors, Direct, Indirect, Behavioral, and Indirect behavioral, the paper concluded that the combination of previous volatility, scarce liquidity, and stop-loss orders is the prerequisite to high volatility in a very short period. Whereas, the high quantity of trading, though reasonable, is not to be proven [10].

6 Market glitches and regulatory measures associated with HFT

6.1 Flash Crash

The “Flash Crash” of May 6th, 2010, comprised an unprecedented, rapid decline in the Dow Jones Industrial Average (DJIA) that was followed by a rapid, disorderly recovery of prices [11].

The crash occurred in the equities markets; the S&P 500, the NASDAQ, and the DJIA. The DJIA, for instance, dropped nearly 1,000 points from its opening value in just several minutes. This amounted to about 9% of the total value. The subsequent recovery is even stranger. The majority of the price decrease had recovered by just after 3 PM. The price returned to its pre-crash range after another 30 minutes.

However, HFT was not the only cause of this disaster. How much HFT and other factors contributed to the crash has been the subject of considerable inquiry and discussion in the years following the incident. When the dust settled, the CFTC concluded that while HFT did not initiate the flash crash, it did exacerbate it.

6.2 Knight Capital

On August 1, 2012, at 9:30 am, the New York Stock Exchange (NYSE), immediately after the market opened, discovered that it had received an abnormally large influx of trading orders involving a variety of stocks. A tsunami of orders flooded the NYSE 20 minutes after the market began, triggering circuit breakers that limit stock price changes to 10% and immediately suspending trading in several equities.

At first, the NYSE was unable to identify the origin of the orders. It was 9:50 p.m. when it was eventually established that the strange directives came from Knight Capital. At this time Knight capital had also fallen into unprecedented chaos. Top executives hurried to the trading floor as soon as it became apparent that the company's trading system was sending an unusually high volume of orders to the NYSE. It was not until 10 o'clock, more than 30 minutes after the NYSE opened, that Knight Capital's trading system stopped sending any trading orders to the NYSE in a joint effort with the NYSE. Following the closing of trading, the NYSE revealed that it had spent 45 minutes from 9:30 to 10:15 inspecting 140 anomalous equities affected by the incident and had chosen to halt trade in only six stocks. 397 million shares were exchanged for a total volume of \$6.65 billion during these 45 minutes on Knight Capital's trading system. It has 80 long positions worth around \$3.5 billion and 74 short positions totaling approximately \$3.15 billion. Noting from a report in the Financial Times, direct consequence of these dreadful incidents, the underlying corporate suffered a significant loss of approximately \$461 million, contributing to the fact that the Knight Capital was later bought by the other financial institutions through merger and acquisition [12].

6.3 Regulatory measures for HFT

In 2016, the SEC approved plans for a Consolidated Audit Trail (CAT) system. The original idea of establishing the CAT system was merely to classify and store the financial transaction information from various equity markets within the database framework set under the CAT [13]. Under this approach, the stock exchange institutions and other self-regulatory organizations (SRO) are required to disclose all order dynamics of the preceding trading day, from issuance through execution or cancellation, by 8:00 a.m. on each trading day. The SEC has been able to follow and monitor trading activity in the American stock market swiftly and thoroughly, conduct pertinent research, identify, and investigate criminal actions more efficiently than it could have in the past given the information's complete opacity. The regulation of high-frequency trading has benefited from this.

The Market Information Data Analytics System (MIDAS) is another tool the SEC employs to gather more thorough stock transaction data. MIDAS may gather information about each stock trade order, including its report, cancellation, and execution, from 13 American stock exchanges. The timing of trading information is precise to the microsecond, making it ideal for supervision and analysis of HFT.

7 Conclusions

High-frequency trading can be delineated as an algorithms coding system, that mainly serves three separate roles. In light of the understanding of traditional finance, HFT practitioners developed (1) market making (2) arbitrage (3) directional trading. Compacting current literature, along with empirical statistics, HFT has substantially subtracted the bid-ask spread, denoting the market liquidity, and therefore decreased the major transaction cost. Academically it is extensively acknowledged that the overall market liquidity has been tremendously enhanced. Additionally, HFT's positive impact on volatility outweighs the negative ones. It increases competition in the market as trades are executed faster in the sub-second level and the volume of trades is significantly increased. Given the lower transaction cost, HFT, to a certain extent and with other unignorable factors, makes the stock exchange market more price-efficient. Consequently, stock prices are bound to be higher because of the continuously dropping transaction costs, and eventually benefit long-term investors. A higher stock price also has a beneficial influence on a company's capital cost of equity, causing the director of the board to have a greater incentive to issue its shares in the primary market. Ultimately, with a more efficient market and a more prosperous fund-exchanging world, the overall economy can be significantly promoted.

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