High-Frequency Trading: Review of the Literature and Regulatory Initiatives Around the World*

Kee H. Chung**

School of Management, State University of New York at Buffalo
School of Business, Sungkyunkwan University

Albert J. Lee

School of Management, State University of New York at Buffalo

Abstract

This paper provides a review of the literature on high-frequency trading and discusses various initiatives taken by regulatory authorities around the world to address its potential detrimental effects on market quality and investor welfare. Empirical evidence to date generally suggests that high-frequency trading has improved market quality during normal times. What is not clear is the role of high-frequency traders during episodic periods of market crash and extreme volatility. A fruitful area of future research may be a comparative analysis of the role of high-frequency traders and the efficacy of various regulatory initiatives across periods of varying market conditions.

Keywords High-frequency traders; Market quality; Market volatility; Market regulation; Algorithmic trading

JEL Classification: G14, G18, G23

Forthcoming in the *Asia-Pacific Journal of Financial Studies*

---

* This work was supported by the Korean Securities Association and the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2014S1A3A2036037).

** Corresponding author: Kee H. Chung, Louis M. Jacobs Professor, Department of Finance, School of Management, State University of New York (SUNY) at Buffalo, Buffalo, NY 14260. Tel.: 716-645-3262; E-mail address: keechung@buffalo.edu.

1. Introduction

High-frequency trading (HFT) is one of the most significant developments in the securities markets around the world in recent years. HFT is a program trading platform that uses powerful computers to transact a large number of orders at very fast speeds. HFT uses complex algorithms to analyze multiple markets and execute orders based on market conditions. High-frequency traders include proprietary trading firms, proprietary trading desks of a multi-service broker-dealer, and hedge funds.

With the widespread use of electronic trading, automatically generated quotes (autoquotes), and colocation services, traders now can respond to new information at a rate that has never been possible.[1] The Staff of the U.S. Securities and Exchange Commission (SEC, 2010) notes that "the speed of trading has increased to the point that the fastest traders now measure their latencies in microseconds" (p. 41). Hasbrouck and Saar (2013) report that the fastest traders in their study sample react to new market events within two to three milliseconds. Given that the speed advantage can translate into profitable trading opportunities, high-frequency trading, equipped with state-of-the-art technologies to submit and cancel orders instantaneously, is rapidly gaining attention and popularity. A survey by the Authority for the Financial Markets (AFM, 2010) indicates that HFT accounted for about 20% to 40% of trading volumes in different European trading venues, and that the HFT shares are likely to continue to escalate. Gomber et al. (2011) suggest that estimated market shares of HFT in the United States range from 40% to 70%.[2]

[1] See Jain (2005) for an international survey of electronic trading, Hendershott, Jones, and Menkveld (2011) for a study of NYSE autoquotes and rise of algorithmic trading, and O'Hara (2015) for a discussion of colocation services and their impact on the speed of transferring information.

[2] Market share of HFT during mid-2000's was less than 25% (source: http://blogs.wsj.com/marketbeat/2009/06/19/rise-of-the-market-machines).

Researchers have found that HFT is profitable. For instance, Menkveld (2013) shows that high-frequency traders in Dutch stocks earn a gross profit of 9,542 euros per day after deducting exchange and clearing fees, enjoying an annualized Sharpe ratio of up to 23.43. Similarly, Brogaard, Hendershott, and Riordan (2014a) find that high-frequency traders in large cap NASDAQ stocks earn a daily average profit of $5,642. The profit increases to $6,651 after trading fees and rebates are considered, since high-frequency traders that supply liquidity receive a sizeable amount of rebates.[3]

Given the prevalence of HFT, researchers and market regulators have analyzed the impact of HFT on market quality. When equity and equity futures prices rapidly oscillated during the Flash Crash in 2010, a great deal of media blamed high-frequency traders as a cause of the extreme volatility. However, a thorough investigation following the crash revealed that, while HFT may have exacerbated the market condition during the event, it did not trigger the crash. In fact, many academic studies conclude that HFT generally improves market quality. However, it is unclear whether HFT improves market quality even when the market is experiencing tumultuously high volatility such as during the Flash Crash.

Regulators and trading venues have found it necessary to devise a plan to moderate potentially pernicious effects of HFT. For example, financial transaction taxes have been proposed or implemented primarily to discourage traders from engaging in excessively speculative activities and to raise additional tax revenue, while order-to-trade taxes are being used to curb soaring number of messages submitted by high-frequency traders. However, academic studies have generally concluded that such regulations targeted at HFT do not necessarily improve market

[3] Also see Kearns, Kulesza, and Nevmyvaka (2010), Litzenberger, Castura, and Gorelick (2012), and Carrion (2013) for discussions of HFT profits.

quality. Nevertheless, there is a dearth of evidence concerning whether such regulations can prevent sudden market failures such as the Flash Crash.

The rest of the paper is organized as follows. The next section provides descriptions of HFT and lists HFT datasets that have been used in the literature. We then review the impact of HFT on market quality in Section 3. Section 4 reviews regulatory and microstructure changes targeted at HFT and their effects on market quality. We provide concluding remarks in Section 5.

2. High-Frequency Trading: Definition, Data, and Types

2.1. Definition and Data

While the term high-frequency traders is often referred to "professional traders acting in a proprietary capacity that engage in strategies that generate a large number of trades on a daily basis" [Staff of SEC (2010), p. 45], there is no clear definition of the term. To better understand the behavior and effects of HFT, various regulatory agencies around the globe have attempted to define or characterize HFT, as summarized in Table 1. While specific details differ to some extent, the agencies generally agree that the most salient features of HFT are automation of trading process, high speed of receiving information and submitting orders, and generation of numerous messages. In fact, as we will discuss further in Section 4, a considerable number of legislations have been proposed or implemented internationally to discourage the practice of submitting an exorbitant number of orders by high-frequency traders, out of fear that such actions may crumble market quality.

[INSERT TABLE 1 ABOUT HERE]

Since HFT is not clearly defined, researchers are bound to use datasets with different definitions of HFT. Some scholars have come up with their own method to categorize HFT activities within traditionally-available datasets. For example, Zhang (2010) defines HFT broadly as all short-term trading activities of institutional investors that are not covered in Form 13F, the quarterly holdings report of large institutional investors in the United States.[4] Kirilenko et al. (2014) define high-frequency traders as any market participants with extremely high trading volume and well-balanced inventory. According to the Staff of SEC (2014), this definition is extremely narrow and therefore fails to identify a large block of HFT activities. Conrad, Wahal, and Xiang (2015) devise a high-frequency quoting activity metric, which is measured as the number of changes at best bids and asks and of depths at the inside quotes. Hasbrouck and Saar (2013) estimate 'strategic run,' which is a "series of submissions, cancellations, and executions that are linked by direction, size, and timing, and which are likely to arise from a single algorithm" (p. 660), to examine the effect of HFT.[5] However, as the Staff of SEC (2014) cautions, using proxies developed from datasets naturally comes with a danger of including algorithmic and computer-assisted trading activities that are not HFT in the scope of research.[6]

Other researchers have used datasets that are designed specifically to examine the consequence of HFT activities. While these datasets allow researchers to clearly identify HFT activities, as Conrad, Wahal, and Xiang (2015) argue, since the datasets are usually compiled by stock exchanges, the data are limited to those exchanges. Thus, using such datasets may not be

[4] Jones (2013) expresses concerns over this definition because it is difficult to attribute the ensuing result purely to HFT activities.
[5] Also see Gomber et al. (2011) for a survey of HFT definitions used in academic studies.
[6] It is also possible that datasets do not contain all the relevant information. For example, O'Hara, Yao, and Ye (2014) document a tendency of high-frequency traders to use odd lots, or small trades, which are not recorded in databases such as TAQ. HFT is also increasing its presence in dark trading venues (see, for example, Comerton-Forde and Putniņš, 2015).

appropriate in thoroughly investigating the effects of HFT activities in countries with many fragmented markets such as the United States.

First of the HFT-specific datasets, the NASDAQ Data identify 26 HFT firms based on their trading and quoting activities, and indicate whether any of the classified HFT firms took the aggressive (liquidity taking) or passive (liquidity providing) sides of each transaction.[7] Some of the limitations of the NASDAQ Data are that 1) researchers cannot distinguish different types of HFT, 2) the NASDAQ Data failed to include certain HFT activities, such as those by HFT firms that also offer brokerage services, and 3) trading activities in corporate stock-related products are not covered in the NASDAQ Data.

The E-Mini Data contain transaction information of the E-Mini, including who the buyer and seller were and whether they took aggressive or passive sides of each transaction. Therefore, researchers can manually decide how to classify HFT activities based on the data. For example, Clark-Joseph (2013), Baron, Brogaard, and Kirilenko (2014), and Kirilenko et al. (2014) classify a trading account as a high-frequency trader if its trading volume is relatively high but end-of-day inventory position is low compared to its trading volume. However, the studies differ in specific cutoff points for classifying HFT accounts, hence the identified HFT accounts do not overlap exactly across the studies.

Two datasets are available to study the role of HFT during the Flash Crash.[8] The first dataset, which the Staff of SEC (2014) refers to as the FINRA Dataset, contains the minute-by-minute total trading volume of 12 largest HFT firms on May 6, 2010, when the Flash Crash occurred. The HFT firms are manually identified by FINRA. Another dataset, dubbed the Lit

[7] See the Staff of SEC (2014) for a detailed discussion of the datasets dedicated to the research of HFT.
[8] See Section 3.2 for a discussion of the Flash Crash.

Venue Dataset by the Staff of SEC, contains the trading volume data of 17 manually classified HFT firms during May 3-10, 2010.

Lastly on the datasets, researchers have also used international datasets to understand the effects of HFT in foreign markets. Some researchers have used quantitative standards to classify HFT activities. For example, the Investment Industry Regulatory Organization of Canada (IIROC, 2012) classifies HFT firms as those with high (11.20 in the study) order-to-trade ratio to analyze HFT activities in the Canadian equity markets. Alternatively, others have manually classified HFT activities based on trade identifiers provided by the datasets and information of the associated traders.

2.2. Types of High-Frequency Trading

Adding to the complexity of identifying HFT activities, not all high-frequency traders behave similarly; that is, objectives and strategies differ for each type of high-frequency traders. First of all, market-making high-frequency traders maintain limit orders on both sides of trades and thereby provide liquidity to the market. These traders earn profit from the bid-ask spread, and use their speed advantage to instantly update quotes.[9] Second, arbitrage trading strategy is used to instantaneously take advantage of price discrepancies, or arbitrage opportunities, that arise between two portfolios of assets. Since the fastest trader who spots such opportunities and trades on them will take most, if not all, of the profits from the strategy, high-frequency traders of this type are immensely motivated to invest a huge amount of resources to constantly revamp their

[9] In addition, this type of high-frequency traders receive rebates from certain trading venues for providing liquidity. See Section 4.3 for more details.

technological capabilities.[10] Third and last, directional trading involves rapidly trading on new information. The strategy exploits any news related to economy or even order flows that will have a significant impact on asset prices.[11]

3. Effects of High-Frequency Trading on Market Quality

Given the technological dominance and strategies of high-frequency traders, it would be of significant interest to marker regulators, investors, and academic researchers to find out whether and how HFT activities influence market quality. If we construe the speed advantage of high-frequency traders merely as an informational advantage, HFT is just another form of informed trading which improves the price discovery process in the sense of Kyle (1985).[12] However, the speed of HFT may be used for other purposes as well. According to Harris (2013), HFT can take one of three forms: valuable, harmful, and very harmful. The valuable function of HFT includes decline in transaction costs due to extensive utilization of technologies. By letting machines oversee everyday trading activities, human traders can enhance attention spans and reduce errors in implementing their trading strategies. The harmful HFT activities take advantage of new information as soon as it arrives, consuming limit orders of traders who did not have enough time to process the new information and modify their outstanding orders accordingly.[13] The very harmful HFT anticipates order flows and front-run them or engage in quote matching. These

[10] In fact, the technology arms race among high-frequency traders to gain a slight edge in speed has raised concerns for extravagant spending of money without meaningful improvements in market quality. See Section 4.7.
[11] Also see Jones (2013), the Staff of SEC (2014), and O'Hara (2015) for a discussion of HFT types and strategies.
[12] See Foucault, Hombert, and Roşu (2015), who find that the behavior of fast and informed speculator in their model matches that of directional high-frequency traders.
[13] Brogaard, Hendershott, and Riordan (2014a), who document an improvement in price discovery process due to HFT activities, remain skeptical of the societal benefit of HFT. As the authors state, "the information [high-frequency traders] use is short lived at less than 3-4 seconds. If this information would become public without [high-frequency traders], then the potential welfare gains may be small or negative if [high-frequency traders] impose significant adverse selection on longer-term investors. Our evidence on [high-frequency traders'] liquidity demand immediately following macroeconomic announcements may fall into this category" (p. 2,302).

activities impose larger trading costs to other traders, without making a significant contribution to the price discovery process.

Our review of recent studies indicates that HFT can be helpful in improving market quality. Although some studies argue otherwise, there is ample evidence suggesting that spreads and short-term volatility declined while price efficiency increased with the rise of HFT activities during normal market conditions. However, the market impact of HFT during times of extremely high market volatility is unclear. Furthermore, even if there is evidence of a harmful behavior of high-frequency traders during such times, it remains a puzzle whether the behavior of high-frequency traders is materially different from that of other traders during volatile times. After all, market failures and extreme volatilities existed even before the prevalence of HFT.

3.1. General Effects of High-Frequency Trading

With a few exceptions, researchers have found that HFT activities decrease spreads. After analyzing the effects of HFT activities in the Dutch equity market, Jovanovic and Menkveld (2015) conclude that passive HFT activities lower effective spreads. Bershova and Rakhlin (2013) show that HFT activities are negatively related to bid-ask spreads using international datasets from Tokyo and London. Malinova, Park, and Riordan (2013) find that effective spreads increased significantly when trading activities of intensive algorithmic traders (iATs) decreased using data from the Toronto Stock Exchange.[14] Stoll (2014) also reports that the advent of HFT is associated with narrower spreads, which he attributes to decline in trade sizes.

[14] The authors classify traders with the highest order-to-trade ratios and the most total number of messages submitted as iATs.

Riordan and Storkenmaier (2012) analyze 98 stocks listed on Deutsche Boerse's HDAX segment of Germany, which had recently upgraded its system to reduce the latency of electronic trading, and show that effective spreads shrunk after the technological upgrade. The authors further document that price impact dropped after the upgrade. Boehmer, Fong, and Wu (2015) analyze 42 equity markets and document a fall in effective spreads for 69% of the markets when colocation services were introduced.

However, HFT activities do not always reduce spreads. After analyzing HFT's role in KOSPI 200, a Korean index futures market, Lee (2015) reports that HFT activities do not boost liquidity or improve market quality in general. Similarly, Gai, Yao, and Ye (2013) examine the impact of two technological upgrades on NASDAQ during 2010 that enabled faster transfer of messages and conclude that the upgrades did not have significant effects on quoted and effective spreads. Lastly on spreads, using the short sale ban of September 2008 as an instrument and the NASDAQ Data, Brogaard, Hendershott, and Riordan (2014b) show that HFT activities cause an increase in quoted and effective spreads. According to their finding, liquidity supplying activities of high-frequency traders positively affect liquidity, but their liquidity demanding activities more than offset the positive effect.

Breckenfelder (2013) analyzes the NASDAQ OMXS 30 index and finds that competition among HFT firms induces more liquidity consuming trades, as measured by the Amihud illiquidity ratio, thereby draining available liquidity in the market. In contrast, Australian Securities & Investments Commission (ASIC, 2013) examines the Australian equity market and shows that HFT activities are not associated with changes in quoted depths at the inside spread, suggesting that liquidity is not deteriorated by HFT activities. On the other hand, Brogaard, Hendershott, and Riordan (2014a) show that, although aggressive HFT activities incur adverse selection costs on

passive non-high frequency traders, the liquidity supplying activities of high-frequency traders offset the harmful activities, reducing the overall adverse selection cost. This finding is consistent with the result of Jovanovic and Menkveld (2015) that HFT activities are negatively associated with the adverse selection risk.

Researchers have also examined the impact of HFT activities on price efficiency. Carrion (2013) shows that price efficiency is positively associated with HFT aggressiveness using the NASDAQ Data. Brogaard, Hendershott, and Riordan (2014a) find that aggressive high-frequency traders tend to trade towards the direction of permanent changes and opposite of the direction of transitory movements, thereby improving overall price efficiency. Conrad, Wahal, and Xiang (2015) show that high-frequency quoting activities are positively associated with price efficiency. According to Chaboud et al. (2014), algorithmic trading is associated with higher price efficiency, as measured by the frequency of triangular arbitrage opportunities and the autocorrelation of high-frequency returns, in three foreign exchange markets: euro-dollar, dollar-yen, and euro-yen.

Hasbrouck and Saar (2013) develop a HFT proxy called 'strategic run,' which they describe as a "series of submissions, cancellations, and executions that are linked by direction, size, and timing, and which are likely to arise from a single algorithm" (p. 660). Using the proxy, the authors find that the short-term volatility of NASDAQ stocks, defined as the mid-quote range scaled by the mid-quote average during a 10-minute interval, declines as HFT activities increase. However, the authors caution that their result does not imply that HFT activities can help prevent sudden market failures such as the Flash Crash. Consistent with the result of Hasbrouck and Saar (2013), Hagströmer and Nordén (2013) find evidence that market-making HFT activities reduce short-term volatility (measured by one-minute midpoint quote changes) using the data of 30 stocks from the NASDAQ-OMX Stockholm. On the other hand, the international analysis of 42 equity

markets by Boehmer, Fong, and Wu (2015) shows that short-term volatility (measured by standardized intraday price ranges) increases when the intensity of algorithmic trading rises. Furthermore, the authors note that the increase in volatility cannot be attributed to faster price discovery or to the penchant of algorithmic traders for entering volatile markets.

Bershova and Rakhlin (2013) find that HFT activities are negatively associated with the transaction costs of long-term investors, which is consistent with the result of Conrad, Wahal, and Xiang (2015) that high-frequency quoting activities in the United States help reduce trading costs.[15] On the other hand, Brogaard et al. (2012) fail to observe a direct relation between HFT activities and the trading costs of institutional investors. Moreover, Tong (2015) finds that HFT activities are positively related to execution shortfall costs of institutional investors.

Studies suggest that HFT firms are associated with order anticipation activities. Hirschey (2013) finds that aggressive selling activities of high-frequency traders are generally followed by those of non-high-frequency traders, and the pattern persists up to five minutes. The author concludes that the phenomenon is due to order anticipation strategies of high-frequency traders. Similarly, Clark-Joseph (2013) also suggests that high-frequency traders employ order anticipation strategies in the E-mini S&P 500 futures market.

3.2. High-Frequency Trading and Market Glitches

The Australian Securities & Investments Commission (2013) finds that HFT activities are not harmful to market liquidity under normal market conditions. However, it is nonetheless "concerned that liquidity may evaporate in periods of extreme volatility" (p. 9), consistent with a

[15] Long-term investors are defined as users of traditional direct market/strategy access, smart order routers, and dark pools.

caution from Conrad, Wahal, and Xiang (2015). Indeed, although not many academic studies find HFT to be detrimental to market quality, several market glitches have been attributed to HFT.

During the Flash Crash of May 6, 2010, nearly one trillion U.S. dollars' worth of equity value vanished within a matter of minutes, with the Dow Jones Industrial Average temporarily plunging by more than 9%.[16] Although it did not take long for the market to recover from the crash, the event has raised concerns for the market stability and for the cause of such a sudden market failure.[17] Brogaard, Hendershott, and Riordan (2014a) remark, "the substantial, largely negative media coverage of [high-frequency traders] and the [Flash Crash] raised significant interest and concerns about the fairness of markets and the role of [high-frequency traders] in the stability and price efficiency of markets" (p. 2,268). To examine the role of HFT activities during the Flash Crash, the Staffs of the U.S. Commodity Future Trading Commission and the U.S. Securities and Exchange Commission (CFTC and SEC, 2010) analyze two datasets, the FINRA and the Lit Venue Datasets.

An investigation of the FINRA Dataset shows that six of the 12 high-frequency traders have reduced their involvement in the market sometime after the crash, which caused decline in overall market liquidity. Hence, high-frequency traders did accelerate the rate of crash. In addition, the Staffs of CFTC and SEC examine the Lit Venue Dataset and find that high-frequency traders engaged in aggressive selling activity during the crash, and their trading activities fell during the recovery period that followed the crash. Kirilenko et al. (2014) also conclude that HFT was not

[16] See http://www.bloomberg.com/news/articles/2015-10-19/before-u-s-called-igor-oystacher-a-spoofer-he-was-known-as-990 and http://www.montrealgazette.com/business/fp/markets+wild+ride/2994890/story.html.
[17] See Barrales (2012) for a review of the Flash Crash and regulatory responses concerning HFT.

responsible for sparking the Flash Crash, although, as previously mentioned, their definition of HFT is not deemed broad enough by the Staff of SEC (2014).

In addition, HFT has caused or was related to several recent market glitches.[18] Erroneously placed orders, or the 'fat finger' glitch, by China Everbright Securities on August 16, 2013, triggered a 6% irrational increase in the Shanghai Composite Index within two minutes, costing the brokerage firm about three billion yuan.[19] Similarly, poorly tested algorithms employed by Knight Capital generated massive unintended orders that resulted in a temporary surge in prices of multiple stocks on August 1, 2012. For example, the stock price of Wizzard Software Corp, which closed at $3.50 the day before the event, once spiked to $14.76 due to the accidentally submitted orders.[20]

It is natural to question whether the current market structure is more susceptible to events like the Flash Crash or recent market glitches given the prevalence of HFT. At the very least, it would be fair to say that a possibility of such events existed before the rise of HFT as well. As Conrad, Wahal, Xiang (2015) explain, "while dislocations are harmful to market integrity, it is important to recognize that some discontinuities have always occurred in markets (even before the age of electronic trading), just as flickering quotes have existed well before the advent of high-frequency quotation … if liquidity provision is not mandated by law, liquidity providers can always exit without notice, exposing marketable orders to price risk" (p. 290). To illustrate, an event similar to the Flash Crash also occurred on May 28, 1962, during which stock markets in the United States experienced a sudden turbulence and some stocks fell by more than 9% within 12

[18] See, for example, Jones (2013) and Goldstein, Kumar, and Graves (2014) for a review of recent market glitches.
[19] See http://www.scmp.com/business/companies/article/1297123/china-everbright-securities-shares-suspended-amid-fat-finger.
[20] See http://www.reuters.com/article/2012/08/01/us-usa-nyse-tradinghalts-idUSBRE8701BN20120801.

minutes due to an unknown cause.[21] On the other hand, a clerk during the 1990s was fired for mistakenly trading two million U.S. dollars' worth of a stock, instead of the intended two million shares, suggesting that trade mistakes among skilled traders existed even before the advent of HFT.[22]

4. Changes in Regulations and Market Structure in Relation to High-Frequency Trading

Out of suspicion that certain HFT activities may be detrimental to financial markets, a number of proposals and laws have been introduced around the world to discourage such activities. Some of the HFT-related legislations in place or under discussion by authorities around the world include financial transaction taxes, fees based on excessive order-to-trade ratios (or similarly, order cancellation fees), and minimum resting time, among others. However, according to a model developed by Aït-Sahalia and Saglam (2014), regulations targeted at HFT activities would not be beneficial to the market. In the model, high-frequency traders, who act as market makers, have order-flow driven information and speed advantages, while uninformed low-latency traders arrive randomly according to a Poisson process. Based on its assumptions, the model predicts that financial transaction taxes do not improve liquidity. On the other hand, minimum resting times and order cancellation fees result in enhanced liquidity when the market conditions are normal, although liquidity dissipates rapidly when the market is highly volatile, hence failing to induce high-frequency traders to supply liquidity when it is most needed. Empirical results in general support the result of Aït-Sahalia and Saglam (2014) that HFT regulations do not necessarily

[21] See http://www.wallstreetandtech.com/exchanges/take-heed-the-lessons-from-the-1962-flash-crash/a/d-id/1263651.
[22] See http://www.reuters.com/article/2012/08/01/us-usa-nyse-tradinghalts-idUSBRE8701BN20120801.

improve market quality, but fail to offer sufficient evidence pertaining to sudden market failures such as the Flash Crash.

4.1. Financial Transaction Taxes

The European Union (EU) and some of its member states have already started collecting financial transaction tax (FTT) or are considering doing so.[23] According to the Staff of the International Monetary Fund (IMF, 2010), FTTs can be used for the purpose of raising extra tax revenue by compelling the financial sector to "make a fair and substantial contribution toward paying for any burden associated with government interventions to repair the banking system" (p. 4). Furthermore, Jones (2013) notes that "some policymakers … have proposed a transaction tax on financial instruments as a way of limiting HFT and other 'excessive' trading while raising revenue for the government" (p. 48). Supporting the taxing scheme, Goldstein, Kumar, and Graves (2014) claim that "at the right level, [FTT] could pare back HFT without undermining other types of trading, including other forms of very rapid, high-speed trading" (p. 196). Recently, the Business, Innovation and Skills Committee (2013) of the United Kingdom recommended the British government to evaluate suitability of a FTT on equities "at a level which is the average profit made on a High Frequency Trade in the UK" (p. 47), to curb short-termism often associated with HFT.[24]

[23] In some literature, the term 'financial transaction tax' is associated with taxes on transactions of foreign currencies, or 'Tobin tax.' Our use of FTT only includes taxes on transactions of equity securities and derivatives. Some studies call it a 'securities transaction tax,' or simply STT.

[24] Interestingly, the United Kingdom is already levying stamp duty, a type of FTT, as we will discuss shortly, which is why the new FTT proposed by the committee "was met with backlash from industry experts." See http://www.taxationinfonews.com/2013/07/transaction-tax-proposed-for-high-frequency-trading-in-uk.

The notion of collecting taxes from financial transactions is not entirely new.[25] As Dieter (2002) remarks, the United Kingdom has been levying a form of FTT called stamp duty since 1694, which charges 0.5% to the buyer of a stock. The legislation has been quite lucrative, as the British government raised more than five billion euros from the tax during the fiscal year of 1999-2000. The renowned economist John Maynard Keynes also argued in 1936 that FTTs should be used to subdue speculative activities in the United States.[26] However, the stamp duty policy has been challenged as being ineffective in reducing market volatility. Consequently, opponents of FTTs argue that the taxing scheme is not adequate in counteracting speculative trading activities.[27] After conducting a survey of FTT literature, Matheson (2011) contends that FTTs are unlikely to reduce the risk of bubbles given a lack of "convincing evidence" (p. 37) that FTTs reduce short-term volatility. Perhaps one of the most discussed historical cases of FTT is that of Sweden, which was implemented during 1984-1991 in the hope to rake in some additional tax revenue and rein financial markets. However, the 50-basis-point tax on equity transactions introduced by the Swedish government spurred migration of more than half of equity trading volume from Sweden to London, proving itself to be a poor source of revenue and an inadequate mechanism to regulate the equity market.[28]

Despite the skepticisms surrounding the efficacy of FTTs, in 2011, the European Commission (EC) proposed a continent-wide FTT with rates of 0.1% for shares and 0.01% for

[25] See Matheson (2011) for a survey of current and past international FTT legislations.
[26] See http://biblioeconomicus.googlepages.com/KeynesJohnMaynard-TheGeneralTheoryOfEmploymentInterestAndMoney.pdf.
[27] See Green, Maggioni, and Murinde (2000) for a survey of stamp duty literature, and Becchetti, Ferrari, and Trenta (2013) for a survey of arguments for and against FTT.
[28] For example, the average annual revenue from the tax on fixed-income securities was about 50 million Swedish kroner, compared to the originally anticipated amount of 1,500 million per year. See http://publications.gc.ca/collections/Collection-R/LoPBdP/BP/bp419-e.htm.

derivatives, initially scheduled to be launched by 2014.[29] According to the EC, the European FTT is not only expected to raise an additional 30 to 35 billion euros per year from the 11 EU member states that are in favor of the legislation, but also "[encourage] the financial sector to engage in more responsible activities, geared towards the real economy."[30] In order to ensure that the FTT does not harm the economy, the tax will not be applied towards ordinary financial activities of citizens and businesses and towards capital raising and restructuring activities. However, the proposed FTT was not met with enough approval, and despite an ongoing support from France, Germany, Italy, and Spain, it is unclear when or even whether the European FTT will be put into effect.[31]

Since August 2012, the French government has been levying a 0.2% tax on all financial transactions of French stocks with over one billion euros in market capitalization to suppress speculative trading activities and raise additional tax revenue. When the new tax legislation was carried out, the government expected to collect additional 170 and 500 million euros of tax revenue in 2012 and 2013, respectively. It also predicted that the euro volume of stock purchases will drop by nearly 40%.[32] While studies indeed report that trading volume decreased due to the tax, they present somewhat contradicting results on liquidity, among other market quality measures.

Colliard and Hoffmann (2015) show that the French FTT had a negative impact on overall French market quality after studying two months before and after the implementation of the tax legislation, excluding August 2012. The authors find that, although quoted and effective spreads, intraday price range, and realized volatility are generally not significantly affected by the French

[29] See http://ec.europa.eu/taxation_customs/resources/documents/taxation/com_2013_71_en.pdf.
[30] See http://europa.eu/rapid/press-release_IP-13-115_en.htm.
[31] See http://www.ft.com/cms/s/0/8569047e-a251-11e4-9630-00144feab7de.html.
[32]See http://www.independent.ie/business/world/france-becomes-the-first-in-europe-to-levy-a-transaction-tax-26882429.html.

FTT, stocks with no market making activities by HFT firms have experienced a decrease in liquidity as institutional investors with long-term investment horizon contracted their trading activities within those stocks. As a result, less sophisticated investors began to assume more role in providing liquidity, which in turn elevated adverse selection risks in stocks with no HFT market making activities. In addition to the deterioration of liquidity in certain stocks, overall market depth and informational efficiency (as measured by five-minute mid-quote return autocorrelations) significantly declined after the FTT was put into effect.

Becchetti, Ferrari, and Trenta (2013) find that liquidity has not been affected significantly, although trading volume has decreased significantly in general after the introduction of the FTT in the French stock market. Furthermore, intraday volatility has decreased significantly for about 30% of the stocks within the scope of the FTT. The authors attribute this phenomenon to the decline in HFT activities, although they do not support it with any empirical evidence. Capelle-Blancard and Havrylchyk (2014) show that the French FTT did not affect market volatility or liquidity, as measured by the bid-ask spread and inverse of the Amihud illiquidity ratio. In addition, they show that their result is robust to the choice of time periods from one to six months before and after the tax scheme. The authors interpret their result as a failure of the government on regulating speculative trading activities.

Gomber, Haferkorn, and Zimmermann (2015) analyze the stock market data of firms from CAC 40 index for period that encompasses six months before and after August 2012.[33] Their result indicates that liquidity has declined after the French FTT, as relative spreads of the largest companies' stocks rose by 12% and quoted depths fell by 17% when using German stocks as a

[33] CAC 40 is a value-weighted index of 40 largest firms from NYSE Euronext Paris. The authors note that three of the index constituents are not located in France, hence are exempt from the FTT legislation. Therefore, a total of 37 stocks are analyzed for the study.

benchmark. On the other hand, the authors find a negative impact of the FTT on the price coordination between NYSE Euronext Paris and Chi-X Europe, leading to a conclusion that informational efficiency has worsened due to the taxation, consistent with the result of Colliard and Hoffmann (2015). Results presented by Meyer, Wagener, and Weinhardt (2013) also suggest that the French FTT may have deteriorated market liquidity.

Italy also has put a similar legislation into effect in March 2013, in which transactions of equities of companies that are headquartered in Italy and are more than 500 million euro in market capitalization are subject to taxation. This Italian FTT initially levied 0.22% for over-the-counter and 0.12% for regular market transactions, but in 2014 the rates were lowered respectively to 0.2% and 0.1%. The FTT was extended to transactions of equity derivatives in September 2013.[34]

Capelle-Blancard (2014) analyzes the effect of the tax scheme on Italian firms' stocks with a difference-in-differences approach, using comparable German firms and smaller Italian firms as control groups. The author finds that the overall market quality decreased slightly after the initial introduction of the Italian FTT, but the effect was reversed when the FTT was extended to the derivatives later in 2013. As a result, the overall effect of the FTT on market quality remains insignificant. The author posits that the initial negative effect was due to the migration of trading activities from the spot to the derivatives market, a pattern that was reversed when the derivatives market also became a subject to the tax legislation.

The United States is also considering ways to implement its version of FTT. For example, Congressman Peter DeFazio proposed a bill titled 'Let Wall Street Pay for the Restoration of Main

[34] See http://www.lseg.com/markets-products-and-services/post-trade-services/unavista/regulation/italian-ftt and Capelle-Blancard (2014).

Street Act of 2009' to "fund job creation and deficit reduction."[35] If passed, the bill will levy a transactions tax of 0.25% of the value for stocks and of 0.02% of the value for futures and swaps. It is expected to collect $150 billion as tax revenue.[36]

4.2. Regulations on Excessive Order Submissions and Cancelations

As noted earlier, one of the most prominent characteristics of HFT is submission and cancellation of a large amount of orders during a very short time period. In fact, high-frequency traders are among the market participants who submit the largest number of orders.[37] Some of those activities may deteriorate market quality by engaging in quote stuffing, in which traders send and instantly cancel a large number of orders to cause delays in execution of the orders of their rivals, or spoofing, which involves sending a massive amount of buy (sell) orders to make it look as if the demand (supply) of a particular stock is substantial and lure potential buyers (sellers), with intentions to eventually trade on the sell (buy) side, among others (O'Hara, 2015). Both activities are illegal in the United States. A chairman of the Italian Securities and Exchange Commission (CONSOB), Giuseppe Vegas, once remarked that rapid placement and cancellation of orders "can generate a misleading representation of the actual depth of the order book, creating favorable conditions for market manipulation" [see Friederich and Payne (2015, p. 215)].

Market regulators have considered charging a fee for traders with high order-to-trade ratio (OTR) to scale down harmful behaviors of HFT firms. If successful, an OTR tax may hinder manipulative activities and encourage slower traders to trade more actively, which would improve

[35] See http://www.gpo.gov/fdsys/pkg/BILLS-111hr4191ih/pdf/BILLS-111hr4191ih.pdf.
[36] See Page (2010) for more details.
[37] See http://www.ft.com/intl/cms/s/0/1bbcc370-5bb5-11e1-a447-00144feabdc0.html.

liquidity in general.[38] However, if HFT activities are mostly devoted to providing liquidity by sending numerous orders, depressing the number of orders from high-frequency traders would lead to decline in liquidity. After analyzing ten FTSE 100 stocks, van Kervel (2015) argues that levying a cancellation fee (i.e., higher OTR traders will need to pay more fees) will discourage competition across trading venues and result in decline in liquidity.

Italy is among the first to tax traders with high OTR to curb HFT activities. Since April 2012, Borsa Italiana, Italy's main stock exchange located in Milan, has been charging a fee to traders with OTR higher than 100:1 (0.01 euro per order), 500:1 (0.02), or 1000:1 (0.025). Fees are computed daily with a maximum of 1000 euros, so that traders cannot balance out their ratio across several days. According to Caivano et al. (2012) and Friederich and Payne (2015), the introduction of the Italian OTR fee structure resulted in lower average Italian OTRs. Using a group of stocks from the Stoxx Europe 600 index, Friederich and Payne (2015) show that the Italian OTR fee has deteriorated market quality. In contrast, Capelle-Blancard (2014) finds that the Italian OTR fee did not have any significant impact on the Italian market quality using a difference-in-differences approach with a control sample of German firms. The author explains that his contradictory finding with that of Friederich and Payne (2015) is due to the difference in time frame of the data; the data used by Capelle-Blancard span three-year period from 2011 to 2013, while those by Friederich and Payne only cover four months. Therefore, the author conjectures that the significant impact of OTR fee documented by Friederich and Payne is only transient, to

[38] Even though spoofing and other manipulative trading strategies are prohibited in the United States, it has been difficult to enforce the law since government agencies would have to provide definitive evidence that a suspected lawbreaker indeed had an intent to manipulate the market. Even though the enactment of the Dodd-Frank Act brought about a new era of financial law enforcement, it remains to be seen whether the law successfully discouraged manipulative activities. Such predicaments may be one reason why an OTR tax can be a simple but powerful instrument to protect investors in general. See http://www.bloomberg.com/news/articles/2015-10-19/before-u-s-called-igor-oystacher-a-spoofer-he-was-known-as-990.

be vanished over a longer time horizon. Capelle-Blancard also notes that all of the proxies of market volatility have risen statistically significantly after the implementation of the OTR fee.

In France, an OTR tax law was put into effect in August 2012, on the same day that the country's FTT legislation was launched. The law levies a tax of 0.01% of the notional amount of modified or cancelled orders of French high-frequency traders whose OTR is higher than five while trading French stocks of all sizes. Furthermore, activities pertaining to market making, smart order routing, and automated execution of large orders are not subject to the tax. According to a study by Colliard and Hoffmann (2015), the French OTR tax did not have any significant effect on market quality, which include trading volume in euro, realized volatility, quoted spread, depth at inside quotes, effective spread, price impact, realized spread, speed of mean reversion for market depth, and informational efficiency (as measured by 5-minute mid-quote return autocorrelations).

In May 2012, Norway also announced that it will introduce a new OTR fee structure on September of the same year to the Oslo Stock Exchange (Oslo Børs). The OTR fee structure incurs a fee of 0.05 Norwegian krone (NOK) per order to traders with OTR higher than 70 to 1. The ratio is calculated monthly to estimate the amount of fees due, and it is intended to include only the orders that are perceived to be harmful to the market. Hence, orders that stay in the market for more than a second, that improve price or volume, or that are either Execute and Eliminate (ENE) or Fill or Kill (FOK) are not counted towards the OTR.[39] Jørgensen, Skjeltorp, and Ødegaard (2014) use a difference-in-differences method with the same Norwegian stocks from other exchanges that were not in the scope of the Norwegian OTR fee used as a control group. They show that the relative spread has decreased for the treated stocks from the Oslo Stock Exchange, while depth

[39]http://www.oslobors.no/ob_eng/obnewsletter/download/e4ed8c104a183dd253000ccc332dbdbf/file/file/Order%20to%20Executed%20Order%20Ratio%20(OEOR).pdf.

and turnover remain unchanged. To that end, the authors conclude that the OTR fee cannot be said to have had a negative impact on the market quality.

An effort to reduce the market OTR was also found in the United States. Before it was merged with BATS Global Markets in 2014, Direct Edge briefly introduced Message Efficiency Incentive Program in June 2012, in which its members with average monthly OTR greater than 100 to 1 would have their rebate lowered by $0.0001 per share, to "protect … markets from excessive message traffic."[40] However, the program was rescinded within months, after the exchange acknowledged the fact that the program may had discouraged trading activities that were beneficial in providing liquidity.[41]

Germany launched a comprehensive regulation of HFT firms in 2013, of which one of the main objectives is to limit OTR of HFT firms. The regulation, dubbed the 'German HFT Act,' requires HFT firms to obtain registration from the German Federal Financial Services Supervisory Authority (BaFin) in order to trade financial instruments in a German regulated market.[42] Then, trading venues compute the OTR of each registered HFT firm, which is used to determine the amount of fees incurred to each firm. Hafterkorn and Zimmermann (2014) find that the introduction of the German HFT Act has resulted in decline in the number of orders, with the number of executed trades exhibiting little change. They further point out that the reduction of the number of orders is mainly evident among HFT firms that were liquidity providers, leading to rise in relative spreads. However, the overall effect is negligible in magnitude, hence the authors conclude that the legislation did not have a significant effect on the market quality. On the other

[40] http://www.mondovisione.com/media-and-resources/news/direct-edge-introduces-message-efficiency-incentive-program).
[41] See https://www.sec.gov/rules/sro/edgx/2012/34-67820.pdf.
[42] The German HFT Act classifies a trading firm as a HFT firm based on its low trading latency, use of algorithmic trading technology, and high intraday trading message volume. See Haferkorn and Zimmermann (2014) for details.

hand, Hafterkorn (2015) shows that price dispersion between trading venues has increased after the implementation of the German HFT Act, implying that the market efficiency has improved due to the regulation.

The Canadian government introduced regulatory fees in April 2012 which charged fees to traders based on the number of messages. As briefly mentioned earlier, Malinova, Park, and Riordan (2013) show that the introduction of such fee was followed by decline in the total number of messages from iATs by more than 30% and escalation of quoted and effective spreads. However, since retail and institutional traders are able to gain more profit in their passive orders, trading costs of the traders did not change significantly.

4.3. Rebate Structures

Various rebate structures can be set up by trading venues to either entice or ward off HFT activities. The widespread practice of maker-taker pricing, in which market order traders are charged with fees while limit order traders are compensated with rebates, was first introduced by Island ECN to encourage traders to submit limit orders, thereby providing liquidity to the market. Since the pricing scheme provides less risk to limit order traders, it is particularly attractive to traders who submit a massive number of limit orders; as a matter of fact, high-frequency traders enjoy a hefty amount of profit from such rebates. The United Kingdom's London Stock Exchange and the United States' BATS BZX, among others, are currently using this structure. An opposite fee structure, called taker-maker pricing, of providing rebates to market order traders and charging fees to limit order traders is also used in certain markets. In contrast to the maker-taker pricing, such structure will be less favorable to high-frequency traders in general.

In 2008, the German exchange Deutsche Boerse offered fee rebate to algorithmic traders, given the belief that such traders are beneficial to trading volume and liquidity. The rebate program even provided financial support to technological investments to encourage automation of trades. Indeed, Hendershott and Riordan (2013) find that algorithmic traders are more active in providing liquidity than human traders. Furthermore, algorithmic traders generally take liquidity when spreads are relatively narrow but supply it when spreads are wider.

In March 2015, the Aequitas NEO Exchange was launched by the support of the Royal Bank of Canada, Barclays Corp, OMERS Capital Markets, and others, with an explicit goal to restrain HFT activities.[43] Specifically, the exchange imposes trading fees under maker-taker pricing and favors 'non-speed advantaged traders' for its Lit Book trading, while traders of the exchange's Neo Book platform face speed bumps that delay messages by five milliseconds each to take liquidity and to post.[44] A total of 45 stocks were listed when the exchange officially initiated operation, with a trading volume of 6.1 million recorded on its first day.

4.4. Monitoring of Trade Activities

The Markets in Financial Instruments Directive (MiFID) II, proposed by the European Parliament and the Council of the EU, requires algorithmic traders to report to relevant authorities on the traders' strategies, trading parameters or limits, key compliance, and risk controls. The proposed law, which is expected to be in effect by January 2017, also mandates high-frequency traders to appropriately store records of all placed orders, including those that are cancelled, and

[43] See http://www.thestar.com/business/personal_finance/investing/2015/03/27/trading-begins-on-aequitas-neo-exchange.html.
[44] See https://www.aequitasneoexchange.com/en/trading/trading-fees.

have the records available to relevant authorities upon request.[45] As Foresight (2012) points out, this notification requirement can better educate the authorities of how high-frequency traders operate, and can help the authorities devise a plan to reduce the risk of sudden market upheavals caused by malfunctioning algorithms. However, it remains to be seen whether the additional cost of adequately analyzing all high-frequency traders' strategies, which includes tasks of examining complex codes and software used, is manageable to the authorities.[46] Similarly, in July 2012, the U.S. SEC passed Rule 613 under Regulation NMS, which prompted all U.S. stock exchanges and securities associations to construct a plan to "develop, implement, and maintain a consolidated audit trail that must collect and accurately identify every order, cancellation, modification, and trade execution for all exchange-listed equities and equity options."[47]

In Canada, the National Instrument 23-103, or formally 'Electronic Trading and Direct Electronic Access to Marketplaces,' has been in effect since 2014. The legislation requires users of automated order systems to ensure that their use of the systems "does not interfere with fair and orderly markets," to test their systems at least annually, to acquire sufficient knowledge of their systems to "identify and manage the risks associated with the use of [the systems]," and to be able to immediately halt their systems if necessary.[48] In January 2014, Hong Kong has also begun implementing a similar legislation which requires traders using algorithmic trading system to "effectively manage and adequately supervise" and to keep "proper" records of "the design,

[45] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.173.01.0349.01.ENG.
[46] Jones (2013) also argues that consolidated order- and trade-level data can be useful for regulators to assess the impact of high-frequency traders. However, since collecting such data would require costly deployment of common reporting standards and formats across exchanges, he warns that a thorough cost-benefit analysis needs to be performed.
[47] See http://www.sec.gov/News/PressRelease/Detail/PressRelease/1365171483188.
[48] See https://www.osc.gov.on.ca/documents/en/Securities-Category2/ni_20140301_23-103_unofficial-consolidated.pdf).

development, deployment and operation of the electronic trading system," to regularly monitor risks related to their activities, and to test their systems.[49]

4.5. Minimum Order Resting Times

Given the tendency of high-frequency traders to send and instantly cancel orders, minimum order resting times can be used to force all orders to stay in the market at least for some time periods. Foresight (2012) and Jones (2013) argue that decreeing minimum order resting times will suppress the proliferation of 'flickering orders,' thereby providing assurances to market participants of available terms of trade. However, both studies caution that, as a consequence, market participants will be discouraged to submit limit orders given the inability to withdraw their orders before the required minimum resting time periods pass even when a material event arises. Therefore, market liquidity may decline if minimum order resting times are established.[50] In the United States, the NASDAQ OMX PSX exchange had offered the 'minimum life orders,' which could not be cancelled within 100 milliseconds after submission. In return, those who submit the minimum life orders were compensated by higher liquidity rebate at 0.0026 cent per share, compared to 0.0024 cent for basic orders.[51] However, the order type is no longer available in the exchange.

[49] See http://en-rules.sfc.hk/net_file_store/new_rulebooks/h/k/HKSFC3527_1868_VER50.pdf.
[50] Brewer, Cvitanic, and Plott (2012) run simulations under various market microstructure conditions and conclude that, when a flash flood of orders occurs, switching to call auctions is more beneficial in terms of liquidity and short-term volatility than setting up a minimum order resting time. Therefore, they do not recommend using minimum order resting times.
[51] See http://www.bloomberg.com/news/articles/2011-10-28/nasdaq-omx-plans-minimum-life-orders-on-psx-stock-exchange.

4.6. Circuit Breakers

Circuit breakers are being used to forestall extreme market volatilities. In order to prevent market crashes such as those in October 1987 and October 1989, the NYSE has introduced circuit breakers for the exchange, which pauses market-wide trading when stock prices fall below a threshold, hoping that "investors are given time to assimilate incoming information and the ability to make informed choices during periods of high market volatility."[52] According Rule 80B, which governs the use of circuit breakers and was amended and put into effect on April 8, 2013, if the Dow Jones Industrial Average and S&P 500 fall below certain thresholds, the market halts trading for 15 minutes.[53] If the values of the indices reach even lower thresholds after the trades resume from the previous circuit breakers, trading for the entire market is closed for the remainder of the day. Similarly, the U.S. SEC has approved the Limit Up/Limit Down (LULD) Plan, which sets price bands outside of which individual securities cannot be traded, to "address the type of sudden price movements that the market experienced on the afternoon of May 6, 2010."[54]

4.7. Structural Delays in Order Processing

To counteract the technology arms race and the winner-takes-all nature of some HFT strategies, scholars have proposed implementing random delays in processing of orders by certain milliseconds. For example, Harris (2013) notes that messages sent by a trader with one-millisecond advantage over another will outrun those by a slower trader only 59.5% of the time if all messages are delayed randomly by 0 to 10 milliseconds. Consistently, a model by Hasbrouck (2015) suggests that the advantage of faster traders declines significantly under random delays. Therefore, while

[52] See https://www.nyse.com/markets/nyse/trading-info.
[53] The 'distance' to a threshold is different for each quarter.
[54] See http://www.finra.org/industry/trf/limit-uplimit-down-luld-plan.

traders may still have motivations to improve their trading speed, the benefits of doing so would diminish tremendously, thereby discouraging high-frequency traders to engage in fruitless arms race.

Also to discourage the technology arms race, Budish, Cramton, and Shim (2015) propose using a frequent batch auctions design instead of the continuous limit order book market structure that is being widely used now. Since the batch auctions system processes orders received during a fixed time interval simultaneously, instead of sequentially handling incoming messages, the authors explain that even orders submitted by faster traders may be treated concurrently with those by slower traders, hence reducing the benefit of marginal superiority in speed.

5. Concluding Remarks

Technology has drastically changed the landscape of stock market trading. Transactions are now handled by high-powered computers running sophisticated software. Computers are making the decisions to buy and sell based on preset parameters provided by professional traders. High-frequency traders rely on technology because it has the capability to react quickly, completing thousands of transactions within a very short period of time. The technology-driven trading could be one of the reasons behind the high level of market volatility in recent years. Market regulators around the world have been trying to keep up with the high-speed environment of automated trading by taking various regulatory initiatives.

While a number of academic studies have documented the positive ramifications of the high-speed trading for market quality (such as lower spreads, faster execution speed, and higher informational efficiency of prices), there are many areas of concerns that arise from the proliferation of high-frequency trading. For those traders who do not have an access to high-

frequency trading technologies (e.g., individual investors), the market is no longer a level playing field because they are simply unable to compete with high-speed computers run by professional traders. In turn, they may find the market unfair and inequitable and, as a result, shy away from it altogether. The continuing trend of decreasing market trading volume in recent years might be at least one manifestation of this fear. If true, this trend should be of significant concerns to market regulators because it could seriously hinder the capital supply function of the market by reducing capital flows from these investors.

While empirical evidence generally suggests that high-frequency trading tends to improve market quality, there are many anecdotal observations that suggest potentially detrimental impacts of high-frequency trading on market quality. First of all, there have been a number of aberrant stock market behaviors that occurred in the high-frequency trading era. For instance, extreme intraday price volatility has been observed even for stocks of large and well-known companies with large trading volumes such as Apple, IBM, and McDonalds which seems to be driven by computer algorithmic trading. Also, there is evidence that high-frequency traders have contributed to the Flash Clash of May 6, 2010.

Although there are many liquidity-providing high-frequency traders, they are fundamentally different from traditional market makers in one important aspect. While traditional market makers (such as NYSE specialists and NASDAQ dealers) had an affirmative obligation (individually or collectively) to maintain a fair and orderly market in a given stock, high-frequency traders do not have such obligation. As a result, high-frequency traders are likely to provide liquidity opportunistically and shut down liquidity provision when they perceive large adverse selection risks. These considerations suggest that the role of high-frequency traders is likely to vary with market conditions. A fruitful area of future research would be a comparative analysis of

the role of high-frequency traders and the efficacy of various regulatory initiatives taken to address the potential detrimental effect of high-frequency trading across periods of differing market conditions.

To the extent that a significant portion of trades and quotes are made by computers according to preset parameters, the proliferation of high-frequency trading may reduce or eliminate certain market anomalies that arise from human behavioral biases, such as inattention, over confidence, and regret avoidance. Another area of future research would be an investigation of the relation between market anomalies and high-frequency trading.

References

Aït-Sahalia, Yacine, and Mehmet Saglam, 2014, High frequency traders: Taking advantage of speed, Available at SSRN: http://ssrn.com/abstract=2331613.

Australian Securities & Investments Commission (ASIC), 2010, Report 215: Australian equity market structure.

Australian Securities & Investments Commission (ASIC), 2013, Report 331: Dark liquidity and high-frequency trading.

Authority for the Financial Markets (AFM), 2010, High frequency trading: The application of advanced trading technology in the European marketplace.

Baron, Matthew D., Jonathan Brogaard, and Andrei A. Kirilenko, 2014, Risk and return in high frequency trading, Available at SSRN: http://ssrn.com/abstract=2433118.

Barrales, Edgar O., 2012, Lessons from the Flash Crash for the regulation of high-frequency traders, Fordham Journal of Corporate & Financial Law 17, pp. 1195-1262.

Becchetti, Leonardo, Massimo Ferrari, and Ugo Trenta, 2013, The impact of the French Tobin tax, CEIS Working Paper No. 266, Available at SSRN: http://ssrn.com/abstract=2226983.

Bershova, Nataliya, and Dmitry Rakhlin, 2013, High-frequency trading and long-term investors: A view from the buy-side, Journal of Investment Strategies 2, pp. 25-69.

Boehmer, Ekkehart, Kingsley Y. L. Fong, and Juan Wu, 2015, International evidence on algorithmic trading, AFA 2013 San Diego Meetings Paper, Available at SSRN: http://ssrn.com/abstract=2022034.

Breckenfelder, Johannes H., 2013, Competition between high-frequency traders, and market quality, NYU Stern Microstructure Meeting 2013.

Brewer, Paul, Jaska Cvitanic, and Charles R. Plott, 2012, Minimum resting times vs. call markets and circuit breakers, Government Office for Science Economics Impact Assessment EIA3.

Brogaard, Jonathan, Terrence Hendershott, Stefan Hunt, Torben Latza, Lucas Pedace, and Carla Ysusi, 2012, High-frequency trading and the execution costs of institutional investors, U.K. Foresight Project Working Paper.

Brogaard, Jonathan, Terrence Hendershott, and Ryan Riordan, 2014a, High frequency trading and price discovery, Review of Financial Studies 27, pp. 2267-2306.

Brogaard, Jonathan, Terrence Hendershott, and Ryan Riordan, 2014b, High frequency trading and the 2008 short sale ban, Available at SSRN: http://ssrn.com/abstract=2509376.

Budish, Eric, Peter Cramton, and John Shim, 2015, The high-frequency trading arms race: Frequent batch auctions as a market design response, Quarterly Journal of Economics 130, pp.1547-1621.

Business, Innovation and Skills Committee, 2013, The Kay Review of UK Equity Markets and Long-Term Decision Making, House of Commons: Third Report of Session 2013-2014.

Caivano, Valeria, Salvatore Ciccarelli, Giovanna Di Stefano, Marco Fratini, Giorgio Gasparri, Monica Giliberti, Nadia Linciano, and Isadora Tarola, 2012, High frequency trading: Definition, effects, policy issues, Commissione Nazionale per le Società e la Borsa Discussion Paper No. 5.

Capelle-Blancard, Gunther, 2014, Curbing the growth of stock trading? Order-to-trade ratios and financial transaction taxes, BAFFI CAREFIN Centre Research Paper No. 2015-6, Available at SSRN: http://ssrn.com/abstract=2603587.

Capelle-Blancard, Gunther, and Olena Havrylchyk, 2014, The impact of the French securities transaction tax on market liquidity and volatility, Available at SSRN: http://ssrn.com/abstract=2378347.

Carrion, Allen, 2013, Very fast money: high-frequency trading on the NASDAQ, Journal of Financial Markets 16, pp. 680-711.

Chaboud, Alain P., Benjamin Chiquoine, Erik Hjalmarsson, and Clara Vega, 2014, Rise of the machines: Algorithmic trading in the foreign exchange market, Journal of Finance 69, pp. 2045-2084.

Clark-Joseph, Adam D., 2013, Exploratory trading, job market paper.

Colliard, Jean-Edouard, and Peter Hoffmann, 2015, Financial transaction taxes, market composition, and liquidity, Paris December 2014 Finance Meeting EUROFIDAI - AFFI Paper, Available at SSRN: http://ssrn.com/abstract=2215788.

Comerton-Forde, Carole, and Tālis J. Putniņš, 2015, Dark trading and price discovery, Journal of Financial Economics 118, pp. 70-92.

Committee of European Securities Regulators (CESR), 2010, Call for evidence: Micro-structural issues of the European equity markets.

Conrad, Jennifer, Sunil Wahal, and Jin Xiang, 2015, High-frequency quoting, trading, and the efficiency of prices, Journal of Financial Economics 116, pp. 271-291.

Dieter, Heribert, 2002, Reshaping globalisation: A new order for international financial markets, Working Paper, University of Warwick Centre for the Study of Globalisation and Regionalisation (No. 103).

Foresight, 2012, The Future of Computer Trading in Financial Markets, The Government Office for Science, London.

Foucault, Thierry, Johan Hombert, and Ioanid Roşu, 2015, News trading and speed, Journal of Finance, forthcoming.

Friederich, Sylvain, and Richard Payne, 2015, Order-to-trade ratios and market quality, Journal of Banking and Finance 50, pp. 214-223.

Gai, Jiading, Chen Yao, and Mao Ye, 2013, The externalities of high frequency trading, Available at SSRN: http://ssrn.com/abstract=2066839.

Goldstein, Michael A., Pavitra Kumar, and Frank C. Graves, 2014, Computerized and high-frequency trading, Financial Review 49, pp. 177-202.

Gomber, Peter, Björn Arndt, Marco Lutat, and Tim Uhle, 2011, High-frequency trading, Available at SSRN: http://ssrn.com/abstract=1858626.

Gomber, Peter, Martin Haferkorn, and Kai Zimmermann, 2015, Securities transaction tax and market quality: The Case of France, European Financial Management, forthcoming.

Green, Christopher J., Paolo Maggioni, and Victor Murinde, 2000, Regulatory lessons for emerging stock markets from a century of evidence on transactions costs and share price volatility in the London Stock Exchange, Journal of Banking and Finance 24, pp. 577-601.

Haferkorn, Martin, 2015, High-frequency trading and its role in fragmented markets, Proceedings of the 23rd European Conference on Information Systems (ECIS 2015).

Haferkorn, Martin, and Kai Zimmermann, 2014, The German high-frequency trading act: Implications for market quality, Available at SSRN: http://ssrn.com/abstract=2514334.

Hagströmer, Björn, and Lars Nordén, 2013, The diversity of high-frequency traders, Journal of Financial Markets 16, pp. 741-770.

Harris, Larry, 2013, What to do about high-frequency trading, Financial Analysts Journal 69, pp. 6-9.

Hasbrouck, Joel, 2015, High frequency quoting: Short-term volatility in bids and offers, Available at SSRN: http://ssrn.com/abstract=2237499.

Hasbrouck, Joel, and Gideon Saar, 2013, Low-latency trading, Journal of Financial Markets 16, pp. 646-679.

Hendershott, Terrence, Charles M. Jones, and Albert J. Menkveld, 2011, Does algorithmic trading improve liquidity?, Journal of Finance 66, pp.1-33.

Hendershott, Terrence, and Ryan Riordan, 2013, Algorithmic trading and the market for liquidity, Journal of Financial and Quantitative Analysis 48, pp. 1001-1024.

Hirschey, Nicholas, 2013, Do high-frequency traders anticipate buying and selling pressure?, Available at SSRN: http://ssrn.com/abstract=2238516.

Investment Industry Regulatory Organization of Canada (IIROC), 2012, The HOT Study: Phases I and II of IIROC's Study of High Frequency Trading Activity on Canadian Equity Marketplaces.

Jain, Pankaj K., 2005, Financial market design and the equity premium: Electronic versus floor trading, Journal of Finance 60, pp. 2955-2985.

Jones, Charles M., 2013, What do we know about high-frequency trading?, Columbia Business School Research Paper No. 13-11, Available at SSRN: http://ssrn.com/abstract=2236201.

Jørgensen, Kjell, Johannes Skjeltorp, and Bernt Arne Ødegaard, 2014, Throttling hyperactive robots: Message to trade ratios at the Oslo Stock Exchange, Available at SSRN: http://ssrn.com/abstract=2399225.

Jovanovic, Boyan, and Albert J. Menkveld, 2015, Middlemen in limit order markets, Available at SSRN: http://ssrn.com/abstract=1624329.

Kearns, Michael, Alex Kulesza, and Yuriy Nevmyvaka, 2010, Empirical limitations on high frequency trading profitability, Available at SSRN: http://ssrn.com/abstract=1678758.

Kirilenko, Andrei A., Albert S. Kyle, Mehrdad Samadi, and Tugkan Tuzun, 2014, The Flash Crash: The impact of high frequency trading on an electronic market, Available at SSRN: http://ssrn.com/abstract=1686004.

Kyle, Albert S., 1985, Continuous auctions and insider trading, Econometrica 53, pp. 1315-1335.

Lee, Eun Jung, 2015, High frequency trading in the Korean index futures market, Journal of Futures Markets 35, pp. 31-51.

Litzenberger, Robert, Jeff Castura, and Richard Gorelick, 2012, The impacts of automation and high frequency trading on market quality, Annual Review of Financial Economics 4, pp. 59-98.

Malinova, Katya, Andreas Park, and Ryan Riordan, 2013, Do retail traders suffer from high frequency traders?, Available at SSRN: http://ssrn.com/abstract=2183806.

Matheson, Thornton, 2011, Taxing financial transactions: Issues and evidence, International Monetary Fund Working Papers 11/54.

Menkveld, Albert J., 2013, High frequency trading and the new market makers, Journal of Financial Markets 16, pp. 712-740.

Meyer, Stephan, Martin Wagener, and Christof Weinhardt, 2013, Politically motivated taxes in financial markets: The case of the French financial transaction tax, Available at SSRN: http://ssrn.com/abstract=2211748.

O'Hara, Maureen, 2015, High frequency market microstructure, Journal of Financial Economics 116, pp. 257-270.

O'Hara, Maureen, Chen Yao, and Mao Ye, 2014, What's not there: Odd lots and market data, Journal of Finance 69, pp. 2199-2236.

Page, Richard T., 2010, Foolish revenge or shrewd regulation? Financial-Industry Tax Law Reforms Proposed in the Wake of the Financial Crisis, Tulane Law Review 85, 191-214.

Riordan, Ryan, and Adreas Storkenmaier, 2012, Latency, liquidity, and price discovery, Journal of Financial Markets 15, pp. 416-437.

Staff of the International Monetary Fund (IMF), 2010, A Fair and Substantial Contribution: A Framework for Taxation and Resolution to Improve Financial Stability, Draft Report to the G-20 (Washington: International Monetary Fund).

Staffs of the U.S. Commodity Future Trading Commission and the U.S. Securities and Exchange Commission (CFTC and SEC), 2010, Findings Regarding the Market Events of May 6, 2010.

Staff of the U.S. Securities and Exchange Commission (SEC), 2010, Concept Release on Equity Market Structure 34-61358.

Staff of the U.S. Securities and Exchange Commission (SEC), 2014, Equity Market Structure Literature Review Part II: High Frequency Trading.

Stoll, Hans R., 2014, High speed equities trading: 1993-2012, Asia-Pacific Journal of Financial Studies 43, pp. 767-797.

Tong, Lin, 2015, A blessing or a curse? The impact of high frequency trading on institutional investors, Available at SSRN: http://ssrn.com/abstract=2330053.

van Kervel, Vincent, 2015, Competition for order flow with fast and slow traders, Review of Financial Studies 28, pp. 2094-2127.

Zhang, Frank, 2010, High-frequency trading, stock volatility, and price discovery, Available at SSRN: http://ssrn.com/abstract=1691679.

Table 1. Definition and Characterization of High-Frequency Trading by Regulatory Agencies

Agency	Definition or Characterization of HFT
Australian Securities & Investments Commission (ASIC, 2010)	"[Specialized] forms of high-speed algorithmic trading are emerging—that is, the use of high-speed computer programs to generate, route and execute orders. [HFT] is a subset of this. While there is not a commonly agreed definition of HFT, it is [characterized] by: (a) the generation of large numbers of orders, many of which are cancelled rapidly; and (b) typically holding positions for very short time horizons (i.e. ending the day with a zero position). HFTs employ high-speed, low-latency technology infrastructures: (a) they process direct market feeds to have access to the fastest market information available; (b) they co-locate their servers in the [data centers] with the exchange market's matching engine to reduce access times; (c) they develop their own sophisticated trading strategies to trade on a short-term basis; and (d) they typically end the trading day with no carry-over positions that use capital" (p. 46-47).
Authority for the Financial Markets (AFM, 2010)	"HFT is a form of automated trading based on mathematical algorithms … HFT is not a trading strategy in itself, but a means of applying certain strategies (market making and statistical arbitrage) in practice on trading platforms. These strategies concern only some of the strategies which may be deployed. In other words, HFT is certainly not the only way to operate successfully on trading platforms. The main feature of HFT is the importance of rapid calculation and execution speeds for the trading strategy in question. As a result of the increased efficiency of the market, opportunities for arbitrage and market-making are available for ever briefer periods of time. To be able to respond to these fleeting trading opportunities, HFT market parties have [optimized] their response times using sophisticated systems and efficiency of infrastructure. The earnings model for HFT consists of executing transactions with very small profit margins in very large volumes. HFT is [practiced] in most cases by proprietary traders" (p. 8).

Agency	Definition or Characterization of HFT
Committee of European Securities Regulators (CESR, 2010)	"HFT is a form of automated trading and is generally understood as implying speed. Using very sophisticated computers and IT programs, [high-frequency traders] execute trades in matters of milliseconds on electronic order books and hold new equity positions possibly down to a 'subsecond'. HFT generally involves getting in and out of positions throughout the day with a 'flat' position at the end of the day. [High-frequency traders] use their own capital and do not act on behalf of clients. [High-frequency traders] follow different strategies (e.g., arbitrage, trading on prices which appear out of equilibrium, trading on perceived trading patterns, etc.) but are generally geared towards extracting very small margins from trading financial instruments between different trading platforms at hyper fast speed. HFT is different from what is generally referred to as algorithmic trading or black-box trading, based on the use of computer programs for entering orders with the computer algorithm deciding on individual parameters of the order such as the timing, price, or quantity of the order" (p. 5).
The European Parliament and the Council of the European Union	In their proposed legislation Markets in Financial Instruments Directive (MiFID) II, the European Parliament and the Council of the European Union defined 'high-frequency algorithmic trading technique' as an 'algorithmic trading technique' that is associated with the following characteristics:[55] ▪ "Infrastructure intended to [minimize] network and other types of latencies, including at least one of the following facilities for algorithmic order entry: co-location, proximity hosting or high-speed direct electronic access. ▪ System-determination of order initiation, generation, routing or execution without human intervention for individual trades or orders. ▪ High message intraday rates which constitute orders, quotes or cancellations."[56]

[55] 'Algorithmic trading' is defined by the group as an act of "trading in financial instruments where a computer algorithm automatically determines individual parameters of orders such as whether to initiate the order, the timing, price or quantity of the order or how to manage the order after its submission, with limited or no human intervention, and does not include any system that is only used for the purpose of routing orders to one or more trading venues or for the processing of orders involving no determination of any trading parameters or for the confirmation of orders or the post-trade processing of executed transactions." See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.173.01.0349.01.ENG.

[56] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.173.01.0349.01.ENG.

Agency	Definition or Characterization of HFT
The Staff of SEC (2010)	The Staff of SEC lists few characteristics that are constantly associated with HFT, although not all of those characteristics must be satisfied for a trading activity to be classified as HFT: ▪ "Use of extraordinarily high speed and sophisticated programs for generating, routing, and executing orders. ▪ Use of co-location services and individual data feeds offered by exchanges and others to minimize network and other latencies. ▪ Very short time-frames for establishing and liquidating positons. ▪ Submission of numerous orders that are cancelled shortly after submission. ▪ Ending the trading day in as close to a flat position as possible (that is, not carrying significant, unhedged positions overnight)" (p. 45).
The U.S. Commodity Future Trading Commission (CFTC)	HFT is a "form of automated trading that employs: ▪ algorithms for decision making, order initiation, generation, routing, or execution, for each individual transaction without human direction; ▪ low-latency technology that is designed to minimize response times, including proximity and co-location services; ▪ high speed connections to markets for order entry; and ▪ high rates of orders or quotes submitted."[57]

[57] See http://www.cftc.gov/idc/groups/public/@newsroom/documents/file/tac103012_wg1.pdf.