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Computerized and High-Frequency Trading

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Abstract

The use of computers to execute trades, often with very low latency, has increased over time, resulting in a variety of computer algorithms executing electronically targeted trading strategies at high speed. We describe the evolution of increasingly fast automated trading over the past decade and some key features of its associated practices, strategies, and apparent profitability. We also survey and contrast several studies on the impacts of such high-speed trading on the performance of securities markets. Finally, we examine some of the regulatory questions surrounding the need, if any, for safeguards over the fairness and risks of high-speed, computerized trading.

Keywords: high-frequency trading, HFT, algorithmic trading, market liquidity, market efficiency, price volatility, market regulation

JEL Classifications: G10, G12, G14, G15, G18, G19, G20, G23, G28, G29

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1. Introduction

Rapid, computerized trading refers to the execution of electronic trading strategies involving extremely fast order submissions, cancellations, and executions. Such trading is characterized by the use of computer algorithms to analyze quote data and detect and exploit short-lived trading opportunities. The needed response time is fleeting: U.S. Securities and Exchange Commission (SEC; 2010, p. 3605) notes "For example, the speed of trading has increased to the point that the fastest traders now measure their latencies in microseconds." Such rapid transactions can be undertaken with the intent to hold securities for various durations, depending on the motivation for pursuing them in the first place. One possibility is that firms use rapid computer programs to acquire and hold securities for quite a while, until new information or valuation signals indicate it is time to (rapidly) exit.

However, much of the attention focuses on high-speed trading by proprietary trading firms using computer algorithms. When such trading is deemed "high-frequency trading," or HFT, it involves the use of fast, sophisticated computers and computer algorithms to submit and cancel orders rapidly (and frequently) and to trade securities quickly, often resulting in very short holding periods.[1] Some of this trading is done in anticipation of expected momentum shifts, or it may be pursued because of perceived arbitrage across the prices of related securities.

Regardless of the reason or strategy, the increase in high-speed, computerized trading is controversial. Some suggest that such rapid in/out trading is a benign activity relatively independent of fundamental market values, market efficiency, and fair access to new information about companies and their securities—like the frothy turbulence or foam on the longer, slower and deeper surface waves seen at the beach—and not fundamentally affecting large-scale patterns of movement.[2] However, if/when fast trading induces large aberrations in value, perhaps due to failed position limits

[1] Although the distinction between different kinds of computerized trading (such as algorithmic trading and HFT) is blurred, SEC (2010, p. 3606) suggests that "One of the most significant market structure developments in recent years is high frequency trading ('HFT'). The term is relatively new and is not yet clearly defined. It typically is used to refer to professional traders acting in a proprietary capacity that engage in strategies that generate a large number of trades on a daily basis. . . . Other characteristics often attributed to proprietary firms engaged in HFT are: (1) The use of extraordinarily high-speed and sophisticated computer programs for generating, routing, and executing orders; (2) 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 cancelled shortly after submission; and (5) ending the trading day in as close to a flat position as possible (that is, not carrying significant, unhedged positions over-night)."

[2] A related question is whether orders submitted by HFT and the resultant trades are notably different than those from non-HFTs. Using a NASDAQ HFT database, Davis, Van Ness and Van Ness (2014) find that HFT trades notably cluster less on prices that end in zeros or fives (i.e., prices that are end in $xx.x0 or $xx.x5—dimes and nickels) than do non-HFTs, particularly when HFTs are on both sides of the transaction (liquidity provider and liquidity demander), providing at least some indication that the nature of trading changes with increased HFT participation.

in algorithms or due to unforeseen feedback loops among competing trading models, fundamental values may be affected, especially if the market has moved on and transactions may not be reversed rapidly. Others, such as SEC (2010), question the inherent fairness of such fast trading and whether brokers are using as sophisticated order routing mechanisms for their clients as they are for their proprietary trades.[3] Rapid, high-speed trading also brings up potential regulatory questions, including whether such rapid trading and order submission and cancellation adversely affect brokers' ability to perform affirmative obligations, such as best execution. In this paper, we examine very rapid, computer-mediated trading with a particular emphasis on high-speed trading strategies often used by HFT firms and cite several examples of when the character of that trading has different implications for market performance.

High-speed traders (those looking for low latency) and high-frequency traders compete on the basis of speed for an abundance of very small margins per transaction. The average estimated net profit margin for high-frequency traders in the U.S. equity market is only around 0.1 cents per share traded, thus necessitating very rapid, high-volume turnover to cover fixed costs (see, e.g., Narang, 2010). Since HFT firms generally unwind all of their positions before the end of each trading day, HFT firms do not tend to place substantial amounts of capital at risk, or require or use high levels of leverage.[4] As a result, HFT firms tend to have very large, short-term intraday trading volumes. In fact, the majority of volume which trades on U.S. exchanges across all financial markets are HFT transactions, and HFT is rapidly becoming prevalent on international exchanges, foreign exchange (FX) markets, and derivative markets as well.[5]

Although the margins are typically quite small per traded share, HFT firms try to make it up on volume. Brogaard, Hendershott and Riordan (2013) observe 26 high-frequency firms who traded on NASDAQ during 2008 and 2009, and find that these HFTs earned an average net trading revenue of approximately \$174 per company per day for medium-size stocks (the corresponding figures are \$6,651 for large stocks and \$30 for small stocks). Obtaining these margins depends on being faster than other HFT participants, which it appears is becoming increasingly difficult. Speed of trading has now become so critical to success that the length of wire between the exchange and

[3] SEC (2010, p. 3605) notes "Is it necessary or economically feasible for long-term investors to expend resources on the very fastest and most highly sophisticated systems or otherwise obtain access to these systems? If not, does the fact that professional traders likely always will be able to trade faster than long-term investors render the equity markets unfair for these investors?"

[4] Many suggest that HFT firms liquidate nearly their entire portfolios on a daily basis rather than carrying positions overnight, to remove the high risk of overnight positions (see SEC, 2010). Recent conversations with market participants indicate, however, that many HFT firms do actually carry substantial inventory positions overnight (see Jones, 2013a).

[5] See Kirilenko and Lo (2013). Cardella, Hao, Kalcheva, and Ma (2014) also discuss the many markets in which HFTs trade, including equity, FX, derivatives and fixed income. See, in addition, King and Rime (2010) for discussion of HFT in the FX market.

the trader is a strategic consideration in trade priority and information arbitrage.[6] Technological improvements are constantly introduced, raising operating costs and reducing competitive advantage differences across traders. This trend results in HFT margins eroding over the past few years. According to Jones (2013a), technology and labor costs have reduced trading intermediaries' net trading revenue levels per stock per day to a fraction of the levels earned by market specialists and market-makers 15 years ago.

Because computerized trading has become more prevalent but is not generally available to average, retail investors, it has attracted controversy. HFT has been an area of particular debate. In the view of proponents of HFT, the faster speed and higher volume due to computerized trading is just another stage in the evolution of financial transacting that has taken place over the past several decades. During that time, financial markets have evolved from floor-based outcry trading (NYSE or old derivatives pits), to over-the-counter (OTC) virtual markets (NASDAQ), to hybrid or electronic markets accessed almost entirely by computers (electronic communication networks [ECNs]), and now to HFT programs executing in concert across multiple product and geographic markets.[7] Coincident with most of these improvements, including the recent increase in computerization, transaction costs and bid–ask spreads have generally declined, and some studies find that liquidity improves as high-speed algorithmic trading market participation broadens.[8]

Others, however, question this view. Biais, Foucault and Moinas (2011) demonstrate mathematically that while HFTs and other high-speed traders may generate gains-from-trade, they also can increase adverse selection, price impact, and generate negative externalities, so that there may be more investment in HFT than is societally optimal. Menkveld (2014) notes that while HFTs might promote welfare when they act as market-makers, they reduce "welfare when HFTs pick off investors' quotes at superhuman speed on information that would have been revealed to investors anyway at a lower frequency" and suggests that "high-frequency traders might be engaged in a socially wasteful arms race ... Overall, high-frequency traders overinvest in

[6] SEC (2010, p. 3610) notes "Speed matters both in the absolute sense of achieving very small latencies and in the relative sense of being faster than competitors, even if only by a microsecond. Co-location is one means to save micro-seconds of latency." See Laughlin, Aguirre and Grundfest (2014) for an analysis of the time saved by co-location. Ding, Hanna and Hendershott (2014) demonstrate the differences between the nationally distributed National Best Bid and Offer (NBBO) and those calculated by proprietary feeds co-located near trading centers. Garvey and Wu (2010) show that distance matters—orders take longer for those further away from market centers, resulting in higher costs.

[7] Aspects of electronic markets can mimic those of older, open outcry markets. Harris and Saad (2014) note that electronic message traffic on NASDAQ can mimic the information carried by sound in the older open outcry futures pits examined in Coval and Shumway (2001).

[8] Angel, Harris and Spatt (2011) note that by providing very fast and inexpensive systems, computerized markets allow dealers to offer liquidity via electronic proprietary trading systems, either acting as market-makers who commit capital to connect buyers to sellers, or as arbitrageurs who connect buyers in one market to sellers in another correlated market.

technology relative to a social optimum if the main motivation is to be ahead of rival HFTs when trading on a publicly observed signal." Likewise, Anand and Venkataraman (2013) note that endogenous liquidity providers (similar in nature to market-making HFTs) on the Toronto Stock Exchange withdraw from the market in the face of unfavorable conditions.

In addition, as Menkveld (2014) notes, "The migration to electronic trading coincided with a gradual decline in the average transaction cost ... [and] with the occasional disappearance of liquidity supply." As a result, rapid, computerized trading has caught the attention of the general public due in large part to a few extreme and dramatic, albeit fairly brief, price drops or spikes that have occurred over the past few years, such as the flash crash in May 2010 (see U.S. Securities and Exchange Commission and the Commodity Futures Trading Commission [SEC/CFTC], 2010). Biais, Foucault and Moinas (2011, p. 2) note their model suggests one possible reason for such market disruptions is that switching across multiple equilibria could result in "a period of miscoordination during which HF traders submit aggressive orders which trigger excessive price changes, that will be reverted later."

Other examples of computerized trading glitches include the Knight Trading error in August 2012 (which resulted in $460 million in losses, a $12 million fine from the SEC, and the sale of the firm to Getco), the NASDAQ Securities Information Processor (SIP) trading glitch on August 22, 2013 (which shut down trading in all NASDAQ stocks for three hours), and the recent 10-minute shutdown of the entire U.S. options market due to computer issues from NYSE Euronext. Such events raise questions about the risks of HFT and whether it needs constraints or oversight.[9] The Financial Industry Regulatory Authority ([FINRA] 2014, p. 9) has identified HFT as an enforcement priority for 2014, and notes: "Although many HFT strategies are legitimate, some are not and may be used for manipulative purposes. Given the scale of the potential impact these practices may have, the surveillance of abusive algorithms remains a high priority for FINRA." In particular, concerns arise regarding the potentially disruptive or destabilizing effect of HFT on markets, given the immense volumes it can generate. For example, in a notable "mini flash crash" on January 25, 2013, Apple's stock plummeted nearly 2% in the last minute of trading with roughly 1 million shares changing hands. As Farrell (2013) notes "That's nearly 10 times the volume during any other time that day, and the move briefly wiped out as much as $7 billion of Apple's market value. Apple managed to recover more than half of that in the final few seconds of trading." Farrell (2013) goes on to note that in the first quarter of 2013 alone, mini-crashes with high volume also occurred in Berkshire Hathaway, Aon Plc, Hanesbrands (which "dropped 3% in less than half a second

[9] FINRA (2014, p. 9) notes "In recent years, there have been a number of algorithmic trading malfunctions that caused substantial market disruptions. These malfunctions raise concern about firms' ability to develop, implement and effectively supervise these systems." See also Bunge (2013), Massoudi (2012), and Lopez (2013).

before quickly rebounding"), and U.S. Silica Holdings (a $1.2 billion company, whose stock "dropped 9% in less than two seconds").[10]

Another line of public concern arises from whether or not access to the financial markets has become unfairly biased in favor of those with faster, closer access—in essence, as in Arnuk and Saluzzi (2010), becoming a members-only game. Smythe (2013) notes the New York Attorney General described early access to "market-moving information" as "Insider Trading 2.0," citing as an example Thomson Reuters providing information regarding the early release of the University of Michigan's consumer survey index to HFT traders who paid to receive an early look. Lattman (2013) further notes that Thomson Reuters had, in addition, "accidentally released a manufacturing survey from the Institute of Supply Management to a small group of traders milliseconds before others received it. Those traders used computer models to process and trade on the data." Laughlin, Aguirre and Grundfest (2014) also describe that "$4.939M of SPY shares traded with a single nanosecond time stamp of 2:00:00.000390009," just after the announcement by the Federal Reserve on September 18, 2013 that it would not start to taper its purchases of bonds.

2. The evolution of computerized and high-frequency trading

Rapid, computerized trading started to take flight after 1998, when the SEC introduced regulations for alternative trading systems (ATS), including electronic exchanges.[11] At the beginning of the 2000s, HFT represented less than 10% of all equity trades in the United States, whereas by late 2012, HFT firms accounted for approximately 50% of all U.S. equity-exchange trading volume, and between 40% and 60% of trading activity across all U.S. financial markets for stocks, options and currencies.[12] As reported in Popper (2012b), HFT is also rapidly growing in Europe and Asia, accounting for approximately 45% of stock trading volume in the European Union, 40% in Japan, and 12% in the rest of Asia as of late 2012. Trading speeds are

[10] The SEC suggested single-stock circuit breakers to reduce the minicrashes in individual stocks. The benefit of such a circuit breaker system is to give liquidity providers a chance to collect more information, limit the possibility of extreme adverse selection for market-makers, and then resume trading via an auction where buyers and sellers can meet directly with less need for an intermediary. The disadvantage of single-stock circuit breakers, however, is that they are sometimes triggered by a single erroneous trade on one trading venue, at a time when the market in that stock is operating normally on all other venues. Therefore, on April 8, 2013, the SEC and the major U.S. exchanges initiated a new program called "limit up-limit down," that will pause trading in a particular stock for 15 seconds if its price falls outside of a normal range of 5–10% from the last trading price. If trading does not revert to a normal range within 15 seconds, trading will be paused for another five minutes. There are also circuit breakers which shut down the entire market, but they have been triggered only once (see Goldstein and Kavajecz, 2004).

[11] The SEC adopted Regulation ATS in 1998. This regulation permitted ECNs (or alternative electronic trading systems that collect and match brokerage client orders automatically, outside of stock exchanges) the option of registering as stock exchanges or else being regulated under a separate set of standards.

[12] See Iati (2009), Popper (2012c), and Kirilenko and Lo (2013).

increasing dramatically over this 15-year interval. In the early 2000s, high-frequency trades had an average round-trip order execution time of several seconds, whereas in recent years, latency has decreased to milli- and even microseconds (see Haldane, 2010; SEC, 2010).

Recent evidence suggests that HFT activity is starting to decline, especially in the United States, where volumes and profits are declining in the past few years. Popper (2012c) reports that HFT volume is down from approximately six billion shares (61% of volume) in 2009 to approximately three billion shares (51% of volume) in 2012, and the brokerage firm Rosenblatt Securities estimates that total HFT profits were "at most, $1.25 billion [in 2012], this year, down 35 percent from [2011] and 74 percent lower than the peak of about $4.9 billion in 2009." One of the reasons for this decline in profits is that costs of rights and hardware for keeping computers close to the major exchanges and maintaining high-speed data streams have become much higher than they were in 2008–2009. Many HFT firms feel pressure to sign up for new technologies to keep up with their competitors. While there are no official data available on employment at HFT firms, Popper (2012c) suggests that several HFT firms around the globe have recently been cutting staff or shutting down operations.

These trends toward lower volumes and profits could be transitory and circumstantial, or they could be durable due to a combination of technological upgrades that have increased costs and fostered greater parity and competitiveness among participants. It is also possible that market conditions themselves have become less auspicious for HFT strategies and algorithms. In the past two to three years, major U.S. stock indices have risen quite steadily with lower volatility than in the past, interest rates have been low, and some major commodities are also less volatile than in the mid 2000s. This relative monotonicity and stability may be adverse to HFT, to the extent that the latter involves capturing profits through rapid responses to short-term, shifting momentum and volatility, as suggested by Anand and Venkataraman (2013).

One interesting consequence of the recent contraction of high-speed U.S. equity trading, noted in Cardella, Hao, Kalcheva and Ma (2014), is that HFT firms have begun to increase trading in other financial assets, such as international stocks and currencies. Popper (2012c) reports that high-speed firms accounted for approximately 12% of all currency trading in 2010, but for 2012, Celent estimates this share to be around 28%. However, executives at several HFT firms state that the increase in trading in currencies and other assets is not compensating for the large declines in their traditional profit-making areas of U.S. stocks, futures, and options.

3. HFT firms, strategies and practices

HFT strategies typically involve firms trading mostly their own capital, with the major participants being broker-dealer proprietary trading desks, hedge funds (such as Renaissance Technologies, Worldquant, DE Shaw, and Millennium) and proprietary trading groups (including Getco LLC, Allston Trading LLC, Infinium

Capital Management LLC, Hudson River Trading LLC, Quantlab Financial LLC, and others).

Due to the latency issues with information flows across markets, HFT firms are concerned about transmission speed across geographic distances.[13] Not surprisingly, many HFT firms are located in the cities of New York, Connecticut, London, Singapore and Chicago, and utilize strategies that capitalize on their geographic location. For instance, several Chicago-based firms (such as Getco LLC) exploit their proximity to the Chicago Mercantile Exchange (CME) to develop faster trading strategies for futures, options and commodities, while New York-based firms (such as Hudson River Trading LLC) tend to have a preference for U.S. equities. European time zones give London-based firms an advantage in trading currencies, and Singapore-based firms often specialize in Asian markets (see Aldridge, 2010).

In most rapid trading strategies, orders only last for a few milli- or microseconds and thus are not actionable by the majority of market participants (only by other computerized participants). Furthermore, there is evidence that some HFT systems deliberately cancel many of their orders almost immediately after placing them, as they do not intend the trades to carry through.[14] These false orders are used instead as a "pinging" tactic to discover the price other traders are willing to pay or to discover undisplayed liquidity.[15] While moving quotes to find appropriate prices may be part of a price search mechanism as in Leach and Madhavan (1992, 1993), these practices, known as "flickering quotes" or "quote stuffing," have been claimed to generate an overload of data to market centers, potentially increasing systemic risk. Quote stuffing can also degrade market quality: Egginton, Van Ness and Van Ness (2013, p. 2) find that "stocks experience decreased liquidity, higher trading costs, and increased short-term volatility during periods of intense quoting activity."

[13] Garvey and Wu (2010) show that geographical distances matter. While co-location can solve issues related to a single market, one cannot literally co-locate in two places at once. (A firm can co-locate at each place, but that is two computers, not the same computer.) Since the U.S. equity and futures markets are separated by hundreds of miles, distance, transmission speed, and the speed of light become limiting issues. See Laughlin, Aguirre and Grundfest (2014) and Angel (2014) for a discussion about transmission issues and the speed of light as they relate to the New York/New Jersey equity markets, the Chicago derivatives market, transmission, trading, and co-location.

[14] For example, on September 25, 2012, the SEC issued a cease-and-desist order against Hold Brothers On-Line Investment Services, an electronic broker-dealer which had been involved in such manipulative trading activities though offshore HFT accounts. See Kirilenko and Lo (2013).

[15] SEC (2010, p. 3607) notes questions regarding "pinging": "A 'pinging' order is an immediate-or-cancel order that can be used to search for and access all types of undisplayed liquidity, including dark pools and undisplayed order types at exchanges and ECNs. The trading center that receives an immediate-or-cancel order will execute the order immediately if it has available liquidity at or better than the limit price of the order and otherwise will immediately respond to the order with a cancellation . . . [T]here is an important distinction between using tools such as pinging orders as part of a normal search for liquidity with which to trade and using such tools to detect and trade in front of large trading interest as part of an 'order anticipation' trading strategy." SEC (2010, p. 3607) also asks "Should the use of 'pinging' orders by all or some traders to assess undisplayed liquidity be prohibited or restricted in all or some contexts?"

In general, most algorithmic strategies using HFT fall within one or more of the following four categories, described in Aldridge (2010).

3.1. Automated liquidity provision

This strategy, also described as "passive market-making" in SEC (2010), involves buying and selling securities to provide two-sided markets on exchanges and smooth out temporary imbalances in supply and demand. High-frequency market-makers rapidly place, cancel, and replace bid (buy) and offer (sell) limit orders, and they derive profits from the resulting bid-offer spreads.[16] As a result of automation of the market-making process, the rewards from these activities generally accrue to those with the best connectivity, algorithms, and access to customer order flow (see Kirilenko and Lo, 2013; and Ding, Hanna and Hendershott, 2014).[17]

Within this category, "Rebate trading" is a special case of market-making. Many markets now offer rebates or fees for making or taking liquidity; see Malinova and Park (2013) for a discussion related to the Toronto Stock Exchange, and Battalio, Shkilko and Van Ness (2013) and Anand, McCormick and Serban (2013) regarding U.S. option markets. On U.S. equity markets, exchanges and ECNs, stock market-makers now receive liquidity rebates of up to 0.25–0.30 cents a share for each share that is sold to, or purchased from, each posted bid or offer.[18] Rebate traders often trade for free: because they are considered to be adding liquidity, exchanges and ECNs cover their commission costs and exchange fees.[19] Arnuk and Saluzzi (2008) suggest these rebates make it worthwhile for rebate traders to buy and sell shares at the same price, in order to generate their liquidity rebate on each trade. Many buy-side investors do not receive the maximum liquidity rebates from exchanges and ECNs,

[16] Jones (2013a) notes that due to this continuous updating process, HFT market-makers generally submit and cancel a large number of orders per transaction. These strategies tend to generate a high amount of message traffic relative to the number of trades that result. SEC (2010, p. 3607) notes that passive market-making strategies "... can generate an enormous volume of orders and high cancellation rates of 90% of more. The orders also may have an extremely short duration before they are cancelled if not executed, often of a second or less." Hendershott, Jones and Menkveld (2011) and Viljoen, Westerholm and Zheng (2014) use this fact to generate estimates of the amount of algorithmic trading.

[17] SEC (2010, p. 3608) also notes that it is possible that the short duration of these orders may cause other issues: "Does the very brief duration of many of their orders significantly detract from the quality of liquidity in the current market structure? For example, are their orders accurately characterized as phantom liquidity that disappears when most needed by long-term investors and other market participants?"

[18] The NYSE offers rebates of up to $0.0022 (see http://www.nyse.com/pdfs/nyse_equities_pricelist.pdf), NYSE Arca offers rebates of $0.0030 (see http://www.nyse.com/pdfs/nysearcaMarketplaceFees112011-Clean.pdf) and NASDAQ offers rebates as high as $0.00295 (see http://www.nasdaqtrader.com/content/ProductsServices/PriceList/pricesheet.pdf).

[19] SEC (2010, p. 3608) notes possible issues with rebates: "For example, are there risk-free trading strategies driven solely by the ability to recoup a rebate that offer little or no utility to the marketplace? Are these strategies most likely when a trading center offers inverted pricing and pays a liquidity rebate that is higher than its access fee for taking liquidity?"

however, given that market centers typically tier their rebates based on trade volume. SEC (2010) notes that although it is possible that buy-side investors may benefit from higher liquidity or smaller spreads, it is the higher volume, high-frequency traders who have an advantage in capturing the highest rebates.

3.2. Market microstructure trading (“trading the tape”)

Under this category of strategies, HFTs analyze the flow of quotes in order to extract price information and reverse-engineer trading party order flow to try to predict likely future volumes of buy and sell orders and thereby anticipate price momentum trends. SEC (2010) refers to these strategies as “order anticipation strategies.”[20] One type of strategy within this class, described as “filter trading” by Rowley (2010), involves monitoring large amounts of stocks for abnormal price changes or volume activity.

3.3. Event arbitrage

Certain ad hoc events, such as company announcements of earnings or other economic figures, tend to generate abnormal price movements among affected securities.[21] High-frequency and other rapid traders capture such opportunities to generate short-term profits. In a world with rapid, computerized trading, speed is essential. Scholtus, van Dijk and Frijns (2012) show that high-speed responses on the order of milliseconds are crucially important for HFT strategies based on U.S. macroeconomic news releases, and Laughlin, Aguirre and Grundfest (2014) describe transactions nanoseconds after an announcement by the Federal Reserve. Some HFT firms electronically parse news releases and apply textual analysis to trade on the inferred news. For example, an algorithmic program might search for words such as “raise,” “higher” or “increased” adjacent to the phrase “earnings forecast,” identify the subject company, and then submit orders. Some news providers also sell summary news measures to HFT firms, saving traders the effort of performing their own analysis (see Jones, 2013a). In addition, some HFT firms have paid for advance information regarding the filing of market moving reports, such as the University of Michigan

[20] SEC (2010, p. 3609): “One example of an order anticipation strategy is when a proprietary firm seeks to ascertain the existence of one or more large buyers (sellers) in the market and to buy (sell) ahead of the large orders with the goal of capturing a price movement in the direction of the large trading interest (a price rise for buyers and a price decline for sellers) ... After a profitable price movement, the proprietary firm then may attempt to sell to (buy from) the large buyer (seller) or be the counterparty to the large buyer’s (seller’s) trading. In addition, the proprietary firm may view the trading interest of the large buyer (seller) as a free option to trade against if the price moves contrary to the proprietary firm’s position.”

[21] Interestingly, recent papers suggest retail trades anticipate such news; see, for example, Kelley and Tetlock (2013) or Kaniel, Liu, Saar and Titman (2012).

Consumer Sentiment Index.[22] Advance trading in this issue or the early release of analyst reports has led to increased attention from regulators (see, e.g., Lattman, 2013; Smyth, 2013).

3.4. *Statistical trading*

These rapid trading strategies exploit temporary and potentially fleeting discrepancies inferred from unusual or lagging statistical relationships among liquid securities across different markets, including equities, futures, and FX. Statistical arbitrage opportunities arise due to the fact that long-term investors sometimes create a price impact in the securities they accumulate or sell, and because these securities are correlated with other securities, the price impact is propagated across markets. (Intentional "spoofing" of the market through "momentum ignition strategies" is considered market manipulation and is illegal; see SEC, 2010.) Strategies in this category typically function by specifying a "maximum range of variance" of price differentials between a given set of securities, and taking a "counter trade when that range is exceeded" (Rowley, 2010). This approach is used to exploit covered interest rate disparities in the FX market, price discrepancies between highly correlated stocks and also between derivatives and their underlying assets, although, as Laughlin, Aguirre and Grundfest (2014) demonstrate, distances between these markets and the speed of light are limiting factors. Position-holding periods for these strategies can last as long as a day, but again, rapid initiation of positions is helpful. In general, such arbitrage strategies play two key roles in the financial system: liquidity provision, and price discovery or informational efficiency.

4. The very high speed of computerized trading

As a result of the proliferation of high-speed and particularly HFT, exchanges are now competing with each other to support faster trade execution times, or lower latencies. Hasbrouck and Saar (2013, p. 647) note that "[e]xchanges have been investing heavily in upgrading their systems to reduce the time it takes to send information to customers." For instance, MacDonald (2007) reports that in June 2007, the London Stock Exchange began a new system called TradElect, which promised to deliver an average 10 millisecond (ms) turnaround time from placing an order to final confirmation (or a 10-ms latency) while processing 3,000 orders per second. Likewise, the length of time it takes to execute a trade on the NYSE's most popular platform dropped from 3.2 seconds to 48 ms, according to Celent as of late 2012. Today, however, latencies down into the microseconds are available

[22] Javers (2013) notes: "In the ultra-fast world of high-speed computerized markets, 500 milliseconds is more than enough time to execute trades in stocks and futures that would be affected by the soon-to-be-public news. Two seconds, the amount promised to 'low latency' customers, is an eternity."

in several U.S. exchanges and OTC markets.[23] Decreases in latency matter to HFT firms: Brogaard, Hendershott, Hunt and Ysusi (2014) show that the level of HFT increased with each technology upgrade that reduced latency on the London Stock Exchange.

While Garvey and Wu (2010) show that geographically more distant traders are at a disadvantage, the implication is that trading is now so fast that HFT brokers in a given financial center, such as Chicago, may not be able to know what the most recent quote is in a sufficiently remote financial center, such as New York, before another high-speed trader has already acted on it. As noted by Laughlin, Aguirre and Grundfest (2014) and Angel (2014), the limiting factor is the speed of light. Therefore, in order to realize greater benefits from implementing low-latency strategies, HFT and other algorithmic trading firms often engage in the practice of "co-location," by moving the servers that execute their trading strategies into co-located facilities, that is, data centers that are located as close as possible to (or often within) exchanges' and their ECNs' "matching engines."[24] In response to this demand from HFTs, and in order to attract new sources of revenue, exchanges and other market centers, as well as global co-location specialists, have been opening up new data centers to offer co-location services around the world. Bowley (2011) reports that a recent example of a co-location project has been the creation of a 428,000-square-foot data center in Chicago, to house the CME's Globex electronic futures and options trading platform.

Given the currently fragmented nature of the markets, and with HFT firms sometimes utilizing several trading venues simultaneously, it is not enough to just co-locate next to the primary exchange on which they provide liquidity. Rather, these trading firms require connections to their other related trading venues as well, since there can be temporary delinking of certain markets, such as the New York equity and the Chicago futures markets. Recent research efforts focus on techniques to minimize delays in data transmission when HFT firms trade securities in different locations around the world. For instance, Wissner-Gross and Freer (2010) examine pairs of the 52 largest global exchanges in order to calculate the optimal locations where trading between the financial centers should be centered at any point in time to minimize such transmission delays. Alternatively, Laughlin, Aguirre and Grundfest (2014) consider the optimal location of transmission towers between Chicago and

[23] Algo Technologies, a U.S. trading system technology company, offers AlgoM2, its latest exchange trading platform, which is the industry's fastest exchange matching engine with an average round trip latency of 16 microseconds (http://www.algotechnologies.com/AlgoM22). See also Grant (2010).

[24] As described in SEC (2010, p. 3610): "Co-location is a service offered by trading centers that operate their own data centers and by third parties that host the matching engines of trading centers. The trading center or third party rents rack space to market participants that enables them to place their servers in close physical proximity to a trading center's matching engine. Co-location helps minimize network and other types of latencies between the matching engine of trading centers and the servers of market participants." See also Schmerken (2009).

New York to minimize transmission latency between these two markets, and show that even with the fastest transmissions, the latency cannot be less 3.92 ms, the speed of light between these two financial centers.

5. The market consequences of rapid computerized trading

High-speed trading has a variety of effects on various aspects of market performance, such as liquidity, transaction costs, profitability, and volatility, as discussed below.

5.1. Effects of HFT on market liquidity and transaction costs

One of the main claims in support of HFT activity is that it can improve the liquidity of markets, by creating more rapid adjustments that allow smaller bid–ask spreads within a market and by strengthening the linkage and activity across related markets. It is not immediately obvious that an increase in volume by algorithmic trading should per se lead to an increase in market liquidity, because HFT could generate more activity in either supply or demand for trades, and a dominance of the latter could actually decrease liquidity and result in wider spreads.

Biais, Foucault and Moinas (2011), Menkveld (2014), Budish, Cramton and Shim (2013) and Schwartz and Wu (2013), among others, note that high speeds and a continuous limit order book could lead to a "socially wasteful arms race" among high-frequency traders and could disadvantage other ordinary investors. The resulting adverse selection issues could then reduce market quality, as measured by liquidity and price informativeness. Hendershott and Moulton (2011) find that the introduction of the automated "Hybrid" market by the NYSE in 2006 led to an increase in bid–ask spreads due to an increase in adverse selection, but also find a reduction in the noise in prices, making prices more efficient. Others suggest that high-frequency traders generate greater liquidity and efficiency by acting as market-makers and as statistical arbitrageurs, by ensuring that information is quickly propagated from securities traded by long-term investors to other correlated securities. For example, Jarnecic and Snape (2014) examine HFT activity on the London Stock Exchange and suggest "that high-frequency participants resolve temporal liquidity imbalances in the limit order book."

While HFT activity and general market liquidity have both improved over the past decade, correlation does not necessarily imply causation, especially given the changes in equity market structure (such as the tick size reductions, Regulation NMS, and other developments) as well as the increase in the use of technology overall during this same period. Studies such as Hendershott, Jones and Menkveld (2011), Hendershott and Riordan (2013), Brogaard, Hendershott and Riordan (2013) and Baron, Brogaard and Kirilenko (2012), attempt to disentangle the incremental effect of algorithmic trading and HFT from other changes in the equity markets by isolating market structure changes that facilitate HFT. This effort is difficult because it is not possible to directly observe whether a particular order is generated by an HFT computer algorithm, as opposed to just being any other kind of automated trade that does not rely on human intermediaries. Therefore, proxies for algorithmic trading and the HFT portion thereof have been developed. These include the rate of electronic message traffic normalized by trading volume as used by Hendershott, Jones and Menkveld (2011) and Viljoen, Westerholm and Zheng (2014), the use of proprietary data to identify specific HFT firms in the data as in Brogaard, Hendershott, Hunt and Ysusi (2014), or the use of account-level trade-by-trade data on certain contracts and schemes for classifying traders into various high-frequency categories, based on their trading volume and inventory management (see Baron, Brogaard and Kirilenko, 2012; Brogaard, Hendershott and Riordan, 2013; and Hendershott and Riordan, 2013).

Recent evidence from these proxy metrics suggests that when a market structure change results in more HFT, liquidity and market quality typically improve, though results are mixed. For example, Boehmer, Fong and Wu (2012) find that co-location increases the volume of HFT and improves market quality, and Brogaard, Hendershott and Riordan (2013), who analyze the impact of HFT on U.S. equity trading on the NASDAQ and BATS exchanges, find that high-frequency trades are positively correlated with permanent price changes and negatively correlated with temporary pricing errors, thus improving the price discovery process. McInish and Upson (2013) find mixed evidence, however, showing that when the NYSE decreased latency by 600 ms in March 2008, execution quality improved for fast liquidity demanders (i.e., HFT traders), but only minimally for slow liquidity demanders. Brogaard, Hendershott, Hunt and Ysusi (2014) examine multiple latency decreases on the London Stock Exchange and find an increase in HFT activity, but do not find notable evidence of changes in institutional execution costs.

On the other hand, Gai, Yao and Ye (2012) examine the impact of two 2010 NASDAQ technology upgrades that reduced the minimum time between order messages from 950 to 200 nanoseconds. These changes led to substantial increases in the number of cancelled orders without much change in overall trading volume, bid–ask spreads or depths. The authors interpret this as evidence of diminishing liquidity from faster exchanges. Cartea and Penalva (2012) also demonstrate that HFT strategies introduce "microstructure noise"; that is, in order to profit from intermediation, HFTs buy shares from one trader at a cheap price and sell them more dearly to another, generating price dispersion where before there was only a single price. Egginton, Van Ness and Van Ness (2013) note that quote stuffing results in higher costs and the worsening of market quality.

More recently, as the volume of HFT has decreased, a number of studies and market participants have suggested that the benefits of HFT in reducing trading costs for ordinary investors have stalled. For example, Popper (2012a) reports Abel/Noser estimates that the average cost for an investor to get into and out of a single share of stock fell by more than 50% between 2000 and 2010, to 3.5 cents (including both the bid–ask spread and broker commissions in their measure of transaction costs), but since then the cost has leveled off and subsequently ticked up by mid 2012 to 3.8 cents.

5.2. Profitability of HFT in relation to other (non-HFT) investors

In general, it is difficult to determine profitability across different traders, be they high-speed traders or not. One study that does so, Baron, Brogaard and Kirilenko (2012), suggests that high-frequency traders make an average profit of as much as $5.05 per trade each time they go up against small traders buying and selling one of the most widely traded financial contracts, the E-mini Standard & Poor's (S&P) 500 Futures contract. Using previously private data, Baron, Brogaard and Kirilenko (2012) find that from August 2010 to August 2012, HFTs were profitable, and generated high risk-adjusted performance, consistently outperforming the market. Baron, Brogaard and Kirilenko (2012) also observed that more aggressive traders, who do not engage in the provision of liquidity like traditional market-makers, account for the largest share of trading volume and made the largest profits. For example, the average aggressive high-speed trader earned a daily gross trading profit of $45,267 in August 2010, versus only $2,461 per day for passive HFTs (who simply take the other side of existing offers in the market).

Baron, Brogaard and Kirilenko (2012) further note that high-frequency traders generate their profits from all other market participants, and do so mainly in the short to medium run (seconds to minutes). The overall implication of the report is that the markets are effectively a "zero sum game," in which HFT profits are earned at the expense of other traders, and these profits are highly concentrated toward a small number of firms, in particular toward the fastest and most aggressive. A possible behavioral consequence of this pattern could be that smaller traders might leave the futures markets to operate in less transparent markets where they are better protected from HFT traders.

5.3. Effects of HFT on market performance and volatility

HFT may impact market performance in other ways beyond liquidity, such as affecting volatility or overall risk. Surveying approximately 30 theoretical and empirical papers on the topic of HFT, Jones (2013a) concludes that HFT and related technologies are making markets better, not destabilizing them. He notes that many of the regulatory discomforts associated with HFT are the same as those that arose in regard to improvements to manual markets previously; for example, the current claims that trading speed gives HFT an unfair advantage parallel the concerns in the floor-based era regarding the differential access of market participants to the trading floor.

Others, such as Hasbrouck and Saar (2013), Jarnecic and Snape (2010), and Credit Suisse (2012) study the impact of HFT on market quality and volatility. Credit Suisse (2012) finds that long-term volatility in recent years remained within historical norms, while short-term volatility declined, concluding that markets are "not worse" for the presence of HFT. Hagströmer, Nordén and Zhang (2014) note that the "aggressiveness" of orders submitted varies by HFT firm and by market situations, "adhere strongly to the tradeoff between waiting cost and the cost of immediate execution," and that HFT firms react less strongly to recent volatility than do non-HFT participants. Moreover, Lepone (2011), Hagströmer and Nordén (2013), and Bank for International Settlements (2011) provide global evidence that HFT firms have been active during both high- and low-volatility conditions, and that high-frequency traders have often been the primary providers of liquidity in periods of high uncertainty, as well as mitigating intraday pricing volatility. Finally, a recent study by Bollen and Whaley (2013), commissioned by the Futures Industry Association, shows that volatility in futures contracts remained largely stable in the face of an increase in HFT over the past five years or so.

It is possible there is a difference in HFT impacts under "normal" versus extreme conditions—possibly mostly helping but occasionally hurting the markets. Some researchers and regulators suggest that the ability of HFT firms to leave the market rapidly has made the markets more fragile. Kirilenko and Lo (2013) and others suggest that, under certain market conditions, the automated execution of large orders can create "feedback-loop" or vicious cycle effects. These could in turn generate systemic destabilizing market events, such as the May 2010 "flash crash."

The main impetus for these recent concerns about an increase in volatility may be a few "rogue" events that have captured public attention, especially over the past four years—some of which are still not well understood, despite considerable investigation by the SEC and others. One of the first and most dramatic examples of such a market-wide event was the sudden plunge in the Dow Jones Industrial Average on May 6, 2010 (now widely dubbed the "flash crash"). Kirilenko, Kyle, Samadi and Tuzun (2011) note that HFTs were among the buyers of the first batch of these sell orders, but then sold the contracts aggressively to reduce their inventories during the next few minutes, exacerbating the price decline. The total trading volume generated by HFTs also increased dramatically around the time of the crash, given that as volatility increased, long-term traders withdrew from the market, and thus high-frequency traders had to buy and sell contracts from one another, generating a "hot-potato" effect. Kirilenko, Kyle, Samadi and Tuzun (2011) note that, after a five-second trading pause was automatically activated in the E-mini, opportunistic and longer term traders re-entered the market and rapidly accumulated long positions in the contracts, leading to a swift recovery in prices.

Even if the May 2010 flash crash was not primarily caused by HFT firms, high-speed trading likely augmented market volatility by enabling extremely rapid responses to the intense selling pressure on that day. Other more recent and narrower crashes, summarized in Table 1, also suggest a disruptive impact of very rapid, high-speed computerized trading under adverse or unusual conditions. The rapid clustering of several of these events over the past few months points to an increase in the fragility of automated markets in recent times.

Table 1

Timeline of market glitches 2010–2013

Date of event	Description of event
May 6, 2010 ("Flash crash")	The Dow Jones Industrial Average plummets nearly 1,000 points in less than 30 minutes before rebounding almost as quickly afterward, its largest intraday point loss in history. SEC (2010) explains that the stock market's decline on that day was caused by the rapidly executed sell order of \$4.1 billion of E-Mini S&P 500 Futures contracts on the CME, originated by a mutual-fund group and not by an HFT firm. This sale was reportedly conducted through an automated execution algorithm that considered only volume, not time or price, so that the sell orders were executed in just over 20 minutes.
Mar. 23, 2012	The third-largest U.S. stock exchange, BATS, halts trading in its own stock during its initial public offering (IPO), after a series of technical glitches in its system that disrupts the share prices of Apple and other companies. The system bug led to BATS' price plummeting from an opening level of \$15.25 to less than a 10th of a penny in a second and a half.
May 18, 2012	An unanticipated bug in NASDAQ's IPO system interacts with trading behavior to delay Facebook's highly anticipated IPO by 30 minutes. U.S. regulators in March 2013 approve a NASDAQ plan to reimburse customers as much as \$62 million for related losses.
Aug. 1, 2012	Market-maker firm Knight Capital Group Inc. loses \$460 million shortly after the open of trading at the NYSE, due to an error in newly installed trading software. The software malfunction led the firm's computers to rapidly buy and sell millions of shares in over 100 stocks for about 45 minutes after the markets opened. Knight was subsequently forced to seek rescue financing; it was eventually acquired by rival Getco LLC.
Apr. 23, 2013	A Twitter hoax wipes \$200 billion of value from U.S. stock markets in a flash. An alleged Associated Press tweet falsely reports that President Barack Obama had been injured in attacks on the White House, sending the Dow Jones Industrial Average, the NASDAQ and the S&P 500 all down by 1% immediately.
Apr. 25, 2013	A software glitch shuts down the Chicago Board Options Exchange for half the day, stalling all trading activity in its heavily traded stock-index options contracts.
Aug. 6, 2013	Trading outages affect both the BATS and Direct Edge exchanges, which together represent an average of approximately 20% of overall U.S. stock trading volume.
Aug. 20, 2013	Goldman Sachs Group Inc. sends erroneous orders into the U.S. stock-options market due to a technical error, disrupting prices.
Aug. 22, 2013	The data feed (SIP) providing prices for stocks and exchange-traded funds listed on the NASDAQ Stock Market fails after suffering connection problems with the NYSE Arca exchange, paralyzing the market for all NASDAQ-listed securities for three hours. (The main data feed for NASDAQ-listed stocks went down again briefly on September 4, 2013.) NASDAQ has since stated that it will manually shut off other exchanges' connections to SIP if they flood it with electronic messages in the future.
Sept. 9, 2013	A computer glitch at the Federal Reserve Bank of New York blocks Goldman Sachs' multibillion-dollar order of three-month U.S. Treasury bills, altering prices in the debt market.
Sept. 16, 2013	U.S. options trading briefly grinds to a halt due to a problem with a benchmark data feed (the Options Price Reporting Authority, or "OPRA"), supplying options prices to traders.

(*Continued*)

Table 1 (*Continued*)

Timeline of market glitches 2010–2013

Date of event	Description of event
Sept. 18, 2013	Traders in Chicago exchange as much as $600 million in assets in the milliseconds before most other traders there could learn of the Fed's announcement to continue economic stimulus, seemingly faster than the speed of light.
Sept. 25, 2013	NYSE Euronext and NASDAQ OMX Group discuss a plan to address technology glitches, in which each company would run a backup for the other's benchmark stock pricing data.
Sept. 26, 2013	A technology problem at the smaller electronic stock exchange run by BATS Global Markets Inc. prompts the company to switch its operations to a backup facility in Chicago after halting trades earlier in the day.

6. The fairness of very high-speed trading

Some of the public anxiety over HFT arises because it appears to be making financial trading more of an insiders' game. The SEC (2010) concept release directly questions the fairness of the current market structure, HFT, and the use of a variety of HFT tools and strategies. Several tools and technologies used by HFT firms are, at least in principle, widely available to other investors, but others are not, creating market advantages for high-frequency traders. For example, co-location, the ability to access direct data feeds from exchanges, and sophisticated order execution algorithms are services that could be purchased by any investor. However, the cost-benefit tradeoff for investing in these tools and capabilities is likely to be much more favorable to organized, institutional, strongly capitalized high-frequency traders, given that the proportional increase in HFT profits from minute improvements in trading speed is potentially far greater across very large volumes of trades per day rather than for long-term, low-frequency investors. SEC (2010, p. 3610) directly asks questions about co-location, including "[D]oes co-location provide proprietary firms an unfair advantage because they generally will have greater resources and sophistication to take advantage of co-location services than other market participants, including long-term investors? . . . Is it fair for some market participants to pay to obtain better access to the markets than is available to those not in a position to pay for or otherwise obtain co-location services? Aside from physical proximity, are there other aspects of services offered by exchanges to co-location participants that may lead to unfair access concerns?"

Other aspects of the current market structure may also not be available to all participants. In response to the questions of fairness in SEC (2010), Narang (2010) and McInish, Upson and Wood (2014) point out that HFT firms are able to use Intermarket Sweep Orders (ISOs) to circumvent the Order Protection Rule and thus potentially jump ahead of other orders, although ISOs are mostly unavailable to investors unless they are broker-dealers. Narang (2010) also observes that the current rebate structure based on volume unfairly benefits HFT firms over non-HFT firms.

As another example of the insider advantages sometimes afforded to HFT traders, Patterson, Strasburg and Pleven (2013) report in *The Wall Street Journal* that the CME is aware that high-frequency traders are profiting from ordinary investors by exploiting a hidden loophole in the CME's computer systems. This loophole apparently enables high-speed traders with a direct connection to the CME's trading computers to know of their own trade executions about 10 ms prior to informing the rest of the market about the trade, allowing the firms to submit other orders and trade on this information before the rest of the market.

7. Regulatory implications of trading at very fast speeds

The SEC is currently investigating HFT after legislators, including Senators Charles Schumer of New York and Ted Kaufman of Delaware, question whether the practice is benefiting Wall Street at the expense of individual investors. One major area of focus is whether high-frequency market-makers should be subject to regulations that would require them to stay active in volatile markets, rather than deserting the markets en masse and damaging liquidity. This concern follows from the SEC's and the CFTC's findings in their 2010 joint report on the flash crash in SEC/CFTC (2010, p. 5) that "some market makers and other liquidity providers widened their quote spreads, others reduced offered liquidity, and a significant number withdrew completely from the markets."[25] Similar concerns are also arising overseas. A major study by the U.K. government (Foresight, 2012) in October 2012 was designed to explore how computer-generated trading in financial markets might evolve in the next ten years or so. The project recommended a number of priorities for regulatory action, including limiting possible future market disturbances by implementing accurate, high resolution, synchronized time stamps, and developing software for the automated forensic analysis of adverse or extreme market events. Recently, SEC Commissioner Michael Piwowar called for a comprehensive review of U.S. markets, similar to the Foresight project model, which among other things should examine the role of speed in the markets.[26]

Regulatory issues related to fast trading expand well past issues related to HFT. The SEC has taken further recent steps toward regulating high-speed trading in general. In July 2012, the SEC approved a rule to require all U.S. stock exchanges and other markets to establish a uniform system for tracking all orders and trades

[25] SEC/CFTC (2010) suggests a number of regulatory changes, including pre-trade risk safeguards and single-stock circuit breakers to dampen volatility, strict supervisory requirements on firms using algorithmic strategies to execute large and potentially disruptive orders, and a consolidated audit trail, only some of which have been implemented.

[26] Piwowar (2013): "Furthermore, in a review of equity market structure we should not spend our time at the outset thinking about market structure concepts in the abstract—who is or who is not a so-called high-frequency trader, how fast is too fast, or how many trading venues are too many. Rather, we should ask what incentives underlie the current market structure. What drives the supposed 'need-for-speed?' Why are traders directing flow to so-called 'dark pools' rather than 'lit' markets?"

(a consolidated audit trail). The SEC also levied its first civil enforcement penalty against an exchange (the NYSE) in September 2012, regarding "compliance failures" that allowed certain customers to receive stock prices and other data milliseconds, or even up to multiple seconds, before the broader public. Protess (2012) reports that the SEC subsequently forced the NYSE to adopt a series of internal controls and pay a $5 million fine. In March 2013, the SEC proposed a new set of rules, Regulation Systems Compliance and Integrity (Regulation SCI), that would establish new, enforceable standards for the maintenance and testing of trading systems used by exchanges and brokers. Those rules, which have yet to be approved by the agency, would replace existing, voluntary guidelines around trading technology. In October 2013, Stevenson (2013) reports that the SEC fined Knight Capital $12 million to settle charges that it failed to implement adequate safeguards in August 2012 to prevent the flood of erroneous stock orders that rendered the brokerage firm nearly bankrupt. The fine marked the first time the SEC has used the so-called "market access" rule, which requires brokers and dealers with direct access to U.S. exchanges to adopt controls to respond to unexpected market failures, against a trading firm.

Furthermore, in July 2013, U.S. and U.K. regulators (as well as the CME) imposed penalties and a trading ban on the HFT firm, Panther Energy Trading LLC, for manipulating the prices of futures contracts which trade on the CME via a practice known as "spoofing." It is alleged that Panther placed orders to buy futures contracts, with the intention of giving other traders the impression that the price of a contract was heading higher. Panther would then sell contracts at that higher price before quickly canceling its buy orders. The CFTC stated that this was the first case to be brought using new rules against spoofing contained in the Dodd-Frank financial reform legislation, as reported by Jones and McCrank (2013).

Some critics of the current market structure are calling for even stricter reforms. One change that has been contemplated among regulators (and implemented to some extent already in Europe, with Italy leading the charge as Stafford [2013] reports) is a financial transaction tax, which would force firms to pay a small levy on each trade. At the right level, this could pare back HFT without undermining other types of trading, including other forms of very rapid, high-speed trading. Opponents of such a tax claim that it could damage market efficiency and even make it more expensive for companies to raise capital (see Jones, 2013a). Other market participants have suggested levying an order-cancellation or excess-message traffic tax (such as the charges NASDAQ is currently imposing for excessive limit order submissions that are more than 0.2% outside of the national best bid and offer [NBBO]). European equity markets have similar fees in place.[27]

Given that the use of computers, co-location, and other high-speed trading factors allow for the very rapid submission and cancellation of trades (for evidence

[27] For example, the NYSE Euronext imposes a surcharge of EUR 0.10 on each order above the 100:1 order-to-trade ratio (see Jones, 2013a).

on cancelled orders, see Van Ness, Van Ness and Watson, 2013), proposals have also recently been put forward for enforcing minimum order exposure times, which were mentioned in the SEC's 2010 concept release on equity market structure, and are currently being tested on the NASDAQ OMX and PHLX exchanges.

In an effort to curb future errant trading or technology malfunctions, FINRA sent letters to 10 U.S. high-speed trading firms in July 2013, requesting further information about their trading programs, the steps they have in place to test their algorithms before trading with them, and the risk controls or other measures they have implemented to deal with unexpected trading problems and potential market disruptions (Patterson, 2013). According to McCrank (2013), NASDAQ also recently announced a partnership with the HFT firm Tradeworx to launch a facility in early 2014 that will enable firms to test their algorithms using historical market data to simulate trading on all major U.S. stock exchanges. Finally, the CFTC published a concept release on HFT in September 2013 that invited industry input on a series of measures to limit future disruptions inherent to automated environments (Commodity Futures Trading Commission, 2013). As reported by Miedema (2013), some of these measures include maximum order sizes and limits on the number of orders companies can send out.

Interestingly, industry leaders and regulators in several other countries around the globe have adopted stricter limits on HFT than in the United States, to protect against the disruptions in the American markets.[28] For example, Jones (2013b) states that the European Union recently reached a tentative deal to rein in high-speed trading, including requirements for exchanges and trading venues to synchronize their clocks to make it easier to spot potential abuses and more rigorous testing of high-frequency algorithms. The broadest changes so far have come out of Canada, where a quarter of all stock trading is done by HFT firms (many of which are U.S.-based firms). In spring 2012, Canadian regulators began charging firms for all the orders they cancel, not just those they execute. Popper (2012b) reports that in October 2012, new rules were also approved in Canada to curtail the growth of dark pools, by only allowing them to take orders if they offer a significantly better price than on the public exchanges. Finally, the Royal Bank of Canada (R.B.C) implemented a new trading program that slows down customers' orders so that they reach all exchanges at exactly the same moment. Popper (2013) reports that this program helps to evade HFT traders who can, in the time that it takes for an R.B.C trade to travel between exchanges, spot the trade, cancel its order on one exchange and raise the price on another to take advantage of the R.B.C client.

Other regulatory issues that remain unexplored include the obligations of brokers with regard to best execution and routing requirements. Ding, Hanna, and Hendershott

[28] One reason why the United States has been slower to adopt regulation against HFT than other countries is that many of the largest U.S. market participants, including the big banks, have built high-speed trading desks and dark pools, and as a result have a vested interest in protecting them against new regulations.

(2014) note that the "official" NBBO can be well behind a "synthetic" NBBO that can be created using proprietary data feeds. As a result, Ding, Hanna, and Hendershott (2014) state that, although fleeting, "[p]rice dislocations between the NBBOs occur several times a second in very active stocks and typically last one to two milliseconds," so that the NBBO feed does not necessarily indicate where the best price is. Given that these proprietary data feeds are expensive, but available, to brokers, it is not clear whether in today's high-speed markets brokers can or should solely rely on the official NBBO for routing customer orders in association with their best execution obligations.

8. Conclusions

As SEC (2010, p. 3606) notes, "By any measure, HFT is a dominant component of the current market structure and is likely to affect nearly all aspects of its performance." Computerized, high-speed order submission, cancellation, and trading has been riding a wave of technological momentum and innovation over the past decade which is an extension of many past improvements in trading technology and speed. While high-speed trading may have reached a recent peak in terms of volume and profit-making in the U.S. equity markets, due to competition, costs, and reaching the technological limits of speed, there is evidence to suggest that high-speed trading is expanding internationally into nonequity markets. In parallel, such rapid trading, particularly HFT, is generating an increasing level of controversy. While early evidence suggests that under "normal conditions" high-frequency traders appear to provide liquidity and enhanced market efficiency by acting as market-makers or statistical arbitrageurs across markets, more recent evidence and theoretical work has called into question the benefits of high-speed trading. In particular, errant or poorly designed HFT programs without necessary risk controls can lead to occasional shocks or disruptive events that affect markets and, perhaps as importantly, the general public's perception of them. In addition, the implementation of certain HFT strategies raises concerns about their fairness, given the availability of certain tools or exchange rights to high-frequency traders that are not widely available to other types of investors. Moreover, the lack of ability to isolate HFT and other high-speed traders from other types of trading renders it difficult to measure the direct impact on the market of computerized, rapid trading.

As a result of the controversies about HFT and other less transparent corners of the markets, the SEC and CFTC are conducting ongoing investigations of the impacts of these strategies, as well as proposing further regulatory oversight and solutions to address their potentially adverse side effects. Many of the recent aberrant events in the market are still not fully understood as to their causes or best potential cures. Furthermore, the United States and the rest of the world do not yet appear to be in synch on concerns and plans for how or whether to regulate this type of trading. Overall, very fast, rapid, high-speed computerized trading is likely to remain a major area of interest for financial researchers, as well as a concern for market regulators for several years to come.

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