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# **TECHNOLOGY AND MARKET QUALITY: THE CASE OF HIGH FREQUENCY TRADING**

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## **Abstract**

*Technological innovations such as high frequency trading systems (HFT) and algorithmic trading systems have changed financial markets. We discuss technological and economic aspects of HFT and find that HFT have a major impact on all aspects of the internal market structure of exchanges. We use market quality measures on a unique dataset provided by NASDAQ in order to analyze the contribution of HFT to market quality. The empirical results are discussed in the context of external and internal factors of market quality. Our results indicate considerable differences in trading strategies: HFT engage in market making strategies and provide liquidity when it is expensive and demand liquidity when it is cheap. Their trades are more informed than non-HFT trades for stocks with a high market capitalization and therefore make prices more informative, but less informed across the entire sample.*

*Keywords: High Frequency Trading, Market Quality, Technological Innovation, IT Investment.*

# 1 Introduction

Technological innovation has always been a driving factor in the development of financial markets and improvements in market quality. The use of computers for the automation of the trading process has significantly altered the landscape of financial markets. Beside the automation of financial markets, the use of computer algorithms to support trading decisions or even to make independent trading decisions has become commonplace. Competition between investors has moved from trading floors to the server rooms of exchanges and alternative trading venues, where computers are dominating. The competitive edge has become an issue of speed and sophistication of algorithms. The speed of light has become a binding constraint for investors. Recent innovations, such as High Frequency Trading (HFT) and Algorithmic Trading (AT), have had immense technological and economic impact on investors and marketplaces. While AT is defined as “the use of computer algorithms to automatically make trading decisions, submit orders, and manage those orders after submission” (cf. Hendershott et al., 2011), HFT remains undefined, but it is considered as a subcategory of AT and includes more sophisticated and complex strategies that make use of the fast connection and processing speed of computers. Although HFT makes up more than 60% of the trading volume in the US (cf. Tabb et al., 2009), the effect of HFT on marketplaces, especially in terms of market quality, has remained widely unanalyzed. The recent incident on May 6, 2010, the so-called “Flash Crash”, has further drawn the attention of the critics and the SEC to HFT. (The “Flash Crash” on May 6, 2010 was a crash in the US stock market which resulted in a rapid 10% drop in the Dow Jones Industrial Average, with similarly rapid recovery within half an hour.) With this incident, the current market structure has revealed serious vulnerabilities to specific kinds of trading strategies that may be exacerbated by HFT.

In this paper, we discuss the role of HFT as a technological innovation in the context of regulatory factors as well as competitive and organizational factors and their contribution to market quality. In our case study, we apply extant market quality measures on a unique set of high frequency trade and quote data from NASDAQ, which include indicators for HFT and non-HFT for every trade and quote update (see section 3.1 for more details). The remainder of this paper is structured as follows. Sections 2 discusses technological and economic aspects of HFT with a focus on market quality, while Section 3 presents empirical results from the case study of NASDAQ and the analysis of market quality and HFT. Section 4 concludes with an outlook and further research questions.

## 2 Technological and Economic Aspects of HFT

The automation of the trading process within the last decade has led to a dominance of technology throughout the process. A prerequisite for this development is the technological advance made in the area of information and communication technology. The development of HFT systems has been enabled by more recent technological innovations. The technological and economic requirements and impacts of the automation of trading decisions are far-reaching and involve regulators, marketplaces,

	<b>Technological Aspects</b>	<b>Economic Aspects</b>	
<b>Regulators</b>	<b>Innovation</b> <ul style="list-style-type: none"> <li>- Trading strategies involving high speed and volume</li> <li>- Information and news processing</li> </ul>	<b>Investment</b> <ul style="list-style-type: none"> <li>- Investment costs and risks</li> <li>- Profitability</li> </ul>	<b>Investors</b>
	<b>Infrastructure</b> <ul style="list-style-type: none"> <li>- Investments into IT infrastructure</li> <li>- Latency reduction</li> <li>- System stability</li> <li>- Co-location services, datafeeds</li> </ul>	<b>Market Quality</b> <ul style="list-style-type: none"> <li>- Impact on different measures of market quality (market attractiveness)</li> <li>- Impact on external and internal influencing factors</li> </ul>	<b>Trading Venues</b>

Table 1. *Technological and economic aspects of the development of HFT*

and investors. Table 1 gives an overview of the most important technological and economic issues that the development of HFT involves. The aspects are grouped by interest groups, i.e. investors, trading venues, and regulators.

## 2.1 Technological aspects

The technological innovations that made HFT possible can be categorized into technological innovations in terms of the trading systems used by investors and the IT infrastructure of trading venues. The first category, the innovations of the trading systems of investors, includes the processing of diverse and considerable amounts of data sources, e.g. news information, historical transaction data. While popular AT algorithms are simple transaction cost minimizing algorithms, so-called “slice and dice” algorithms, which split large orders into smaller ones in order to minimize price impact and transaction costs (cf. Gomber and Gsell, 2006), HFT algorithms are often more complex. Research areas, such as the analysis of market and investor sentiment, semantic analysis, and text mining are only a few examples of the ongoing research being conducted to make texts or qualitative financial data interpretable for machines. The application of these technological advances would make HFT systems even more independent and perhaps more dangerous. The SEC broadly categorizes applied HFT strategies that might be harmful for financial markets into four groups: passive market making, arbitrage, structural, and directional strategies.

**Passive market making** makes use of liquidity rebates provided by marketplaces. While the classic structure is the payment of a fee for every transaction, there has been a shift to rebate pricing. This means that liquidity providers get a rebate, while liquidity takers pay a fee. Liquidity providers submit limit order to the book, while liquidity takers submit marketable orders, i.e. market orders or limit orders that can be executed directly against orders in the order book. What is questioned is the quality of liquidity provided since algorithms often cancel limit orders immediately after submission. This would result in a “flickering” of liquidity for a few milliseconds, but no liquidity that non-HFT can actually use. Since the rebates for liquidity provision are often only fractions of a basis point, passive market making strategies involve a high amount of trading volume and a fast connection to be profitable. Another point of discussion is the fairness against other long-term investors who cannot profit from this kind of rebate to the extent that HFT do. The question is whether marketplaces should adopt their business structure and also request certain requirements to grant this kind of rebate. HFT also have the possibility to make use of **arbitrage** opportunities that only exist for a few milliseconds, e.g. between different markets or between prices of underlying and derivative. A typical arbitrage strategy is pairs trading which makes use of statistical correlation of securities. It usually involves quantitative and heavily computational approaches, which can be better solved by computers than humans. The impact on market quality here is of a positive nature, since the detection of arbitrage improves price efficiency and market quality. **Structural** strategies include the exploitations of certain vulnerabilities of markets and participants and are often called predatory strategies. By using co-location and data feeds, HFT are able to pick off stale orders in the limit order book from traders that do not use HFT and they are able to compute an own or a faster NBBO by outrunning computers of marketplaces. These strategies usually do not contribute to market quality and are considered unfair by non-HFT. **Directional** strategies are for example speculative strategies that often contribute to price discovery. More problematic directional strategies are order anticipation strategies or momentum ignition strategies. While order anticipation strategies specifically harm the investor whose order is being anticipated, they do not improve market quality in any way and profit from non-HFT. Momentum ignition strategies are even more critical since they ignite a rapid price movement and hope for other traders to follow it while they take the other side of the market and profit from this movement. This is a kind of market manipulation and therefore harms market quality.

The second category, the IT infrastructure of trading venues, concerns the speed in which the trading data is transported to the server of the marketplace, as for example the geographic location of trader and broker servers, co-location services provided by marketplaces as well as connection speed, e.g. enabled by faster fiber-optic cables. IT investments have been enormous, like a recent high speed

connection between Chicago and New York, whose costs are estimated to around \$200,000 per mile (cf. Forbes 2010), and the construction of a high-speed connection between London and New York has also started (cf. WSJ 2010).

## 2.2 Economic aspects

The technological investments and advances made by financial markets have also been followed by investors. Economic issues mainly concentrate on the perspective of investors in terms of investment costs and profitability, while economic concerns for marketplaces are especially the influence on market quality and market risks. From the investors' perspective, HFT can be treated as a typical investment that bears costs, risks, and profits. While it is possible to estimate the costs of such an investment, the exact valuation can be considered as a typical investment problem. Solutions for this problem have been widely discussed. An important issue in IS literature is the evaluation of IT investments for companies. Hitt and Brynjolfsson (1996) extract three measures for the business value of IT, specifically productivity, consumer value, and business profitability. Since the productivity of trading companies would be difficult to measure, profitability is a more appropriate measure in this case. From recent discussions and reports, the investment in HFT systems has been high, but also highly profitable, as discussions and reports suggest. Estimates range from profits of more than \$21 billion per year by Tabb et al. (2009) to \$2.1 billion per year by Kearns et al. (2010), although the latter does not consider a significant amount of strategies, such as arbitrage or market making strategies. The relatively high profit due to speed advantages is one of the main points of critics.

The economic importance of AT and HFT has rapidly grown within the last years. Today, AT make up more than 50% of all trades in Germany and its impact in Germany and the US has been analyzed in several academic papers (cf. Hendershott and Riordan, 2009, Hendershott et al., 2011, and Chaboud et al., 2009). With more than 60% of the trading volume involving HFT on US markets, concerns have been raised towards market risks and impacts on market quality. While proponents argue that the increased use of AT and HFT made financial markets more efficient and liquid, the public opinion of practitioners and regulatory authorities is dominated by scepticism and aversion. Despite the prominence of this topic in the news and public discussions, academic literature on AT and HFT is still relatively sparse. This might be due to the lack of available data and the relatively short timeframe of influence.

Although the public discussion emphasizes the negative aspects of HFT, academics have yet to find negative influences of AT or HFT on market quality. Hendershott et al. (2011) mainly concentrate their analyses on the improvement of liquidity and indeed find a positive impact of algorithmic trading on liquidity. They do not find an increase of volatility caused by AT, on the contrary they find that an increased activity of AT leads to more efficient prices for large stocks. Chaboud et al. (2009) analyze the effects of AT in foreign exchange market on volatility. Despite an apparent correlation of high frequency trading strategies, a higher activity of high frequency trading is not associated with higher volatility. Hendershott and Riordan (2009) analyze the impact on price efficiency and information. Their findings indicate that ATs provide more efficient quotes, which is in line with the results of Chaboud et al. (2009) on volatility. Brogaard (2010) and Hasbrouck and Saar (2010) both find positive effects of HFT on market quality. While the former uses a dataset of one week with a specific classification of HFT, the latter uses "strategic runs" as a proxy for HFT.

The question on the impact of market quality has also been asked by regulatory authorities, such as the Securities and Exchange Commission (SEC). In their call for comments from January 2010, the SEC addresses different aspects of HFT with their main concern and interest in the impact of HFT on market quality. Next to their investigations on these issues, they have made first attempts to regulate specific "unfair practices" such as flash trading. This strategy is enabled by marketplaces that "flash" orders that currently cannot be filled by the marketplace to subscribers of this service for just a few milliseconds and gives them the opportunity to take the other side of the order. This trade opportunity is only available to HFT who get valuable trading information less than one second in advance and can

process this kind of information within this short timeframe. Since this practice creates a two-tiered market in the opinion of the SEC, they proposed a ban for flash orders (cf. SEC, 2009).

## 2.3 HFT and market quality

Market quality is a direct measure for the attractiveness of a market for investors and therefore important. Clemons and Weber (1990) define market attractiveness as the combination of several measures measured as liquidity, depth, efficiency, information, and fairness. These measures have to be analyzed in the context of the role technology is playing, the competitive impact as well as the organizational situation. These factors are also applied by Levecq and Weber (2002), who analyze market design choices in the context of these external factors regulation, competition and IT. Zhang et al. (2011) provide an overview of the most prevalent measures of market quality and embed them in a framework of external factors, i.e. technology, regulation, and competition, and the internal market structure of trading venues. The internal market structure, which is also analyzed by Levecq and Weber (2002), can be categorized in the spirit of Holtmann et al. (2003) into business structure, IT system, and market microstructure. In our discussion, we consider the influence of HFT as part of the external factor technology and concentrate on its impact on the internal structure of trading venues.

The technological developments in the last years linked computers as well as users globally and more closely together. Due to the sophistication and the advances made in computing power and network systems, financial market innovations, such as HFT, have gained more importance. This development has been strengthened by the market entries of alternative trading systems, such as multilateral trading facilities (MTFs) in Europe. Due to the resulting market fragmentation, the automation of trading systems became more crucial in order to keep track of several markets at the same time and also to benefit from arbitrage opportunities between those markets. The increased competition between trading venues has also led to the adaption of the internal market structure, e.g. by offering special services as co-location and special data feeds as discussed in section 2.1. Different types of traders have specific requirements towards the internal market structure of financial markets, specifically the business structure, the IT system of the market, as well as the market microstructure. Hence, if the goal of trading venues is to attract more trading volume by meeting the demand of HFT, they also have to adapt their internal market structure.

**Business structure** concerns the target group of customers or investors the market wants to attract by offering specific services and products. An example for a typical business structure issue would be the choice of a classic or a rebate fee structure. The latter is made use of by aforementioned HFT market making strategies. This decision is closely linked to the decision of the market which groups of clients to attract and how to balance trading volume and fees per transaction. For example, NASDAQ applies a rebate structure, while NYSE has kept a classic fee structure until 2009. Additionally, NASDAQ followed Direct Edge in offering flash orders, while NYSE has been a critic of flash trading from the beginning. These examples clearly show the different business structure of both exchanges, with NASDAQ targeting traders that rely on speed and NYSE targeting block traders for whom filling of their order is more relevant. The **IT system** of the market consists of the trading system and the technical infrastructure. As discussed in section 2.1, trading venues undertake enormous investments to provide ultra-low latency systems which can handle this huge amount of order flow. While the reaction time of human traders takes at least 200ms (Hasbrouck and Saar, 2010) or even several seconds for more complex decisions, only computers can profit from this kind of speed improvement. A similar example is presented by Hendershott et al. (2011), who analyze the introduction of an automated quoting system at NYSE called Autoquote. While this update did not provide any improvement for human traders, it did for AT, which the authors also demonstrated in their paper. Finally, the **market microstructure** determines the functioning of the market by providing explicit trading rules. Previous literature has shown that IT has an enormous impact on market design choices. Levecq and Weber (2002) further show the diversity of market structure choices that can be accounted to the impact of technology. They concentrated on crucial points of market microstructure, specifically market structure, types of order, order execution priority rules, price discovery rules, time stamping,

and transparency. In terms of transparency, Granados et al. (2006) provide a theoretical framework to structure the impact of technology on market transparency, with the combination of competitive forces and institutional forces. Former development resulted in an increase of transparency, e.g. by the introduction of NYSE’s OpenBook in 2002. OpenBook made it possible for non-floor traders to observe depth in the limit order book at all levels and for all securities. Recent trends point more towards platforms that are less transparent and ensure more anonymity for traders than on exchanges, like ECNs and dark pools. A direct effect of the higher activity of HFT on market microstructure is the adaption of circuit breakers in order to prevent market failure. Circuit breakers stop market activity in case of very high price volatility, but they haven’t been triggered during the “Flash Crash” on May 6<sup>th</sup>, 2010. As lessons learned from this incident a circuit breaker program as well as new procedures for the breaking of erroneous trades have been introduced to prevent such incidents in future (cf. SEC, 2010).

### 3 Case Study: High Frequency Trading and Market Quality

#### 3.1 Data and institutional details

The dataset contains trade and quote data from NASDAQ. Our data sample consists of trade and quote data of three weeks between 2008 and 2010, specifically September 15-19, 2008, October 05-09, 2009, and February 22-26, 2010. It is a unique dataset for the analysis of high frequency traders. The dataset indicates 26 HFT firms as HFT, while the non-HFT group includes the remaining trading firms. While the non-HFT group includes more than 1000 trading firms on NASDAQ, our results for trading activity are limited to the interpretation of these two groups. The trade data contains identifiers that characterize the liquidity demander and provider of the trade as HFT and non-HFT. The specific trade types are HH, HN, NH, and NN, with HH for example involving HFT as liquidity demander as well as liquidity supplier. The quote data contains best bid and ask prices and sizes quoted by HFT as well as non-HFT. Trade and quote data is on a millisecond basis. The original stock sample of 120 stocks is the result of a random pick to ensure an unbiased sample. We delete stocks with less than 10 transactions per day and with less than one trade per day that involves HFT within the sample period.

			Stock IDs
Mcap 1	No. of stocks	39	AA AAPL ADBE AGN AMAT AMGN AMZN AXP BHI BIIB BRCM CB CELG CMCSA COST CSCO DELL DIS DOW EBAY ESRX GE GENZ GILD GLW GOOG GPS HON HPQ INTC ISRG KMB KR MMM MOS PFE PG PNC SWN
	Mean	50,885	
	Std. Dev.	51,660	
	Min	11,178	
	Max	202,890	
Mcap 2	No. of stocks	39	AINV AMED ARCC AYI BRE BXS CBT CETV CKH CNQR COO CPWR CR CRI CSE CSL CTSH ERIE EWBC FCN FL FMER FULT GAS ISIL JKHY LANC LECO LPNT LSTR MANT MELI NSR NUS PNY PTP ROC SF SFG
	Mean	1,878	
	Std. Dev.	314	
	Min	1,138	
	Max	2,397	
Mcap 3	No. of stocks	39	ABD ANGO APOG AZZ BAS BW BZ CBEB CBZ CCO CDR CPSI CRVL CTRN DCOM DK EBF FFIC FPO FRED IMGN IPAR KNOL MAKO MDCO MFB MIG MOD MRTN MXWL NC NXTM PBH PPD RIGL ROCK ROG RVI SJW
	Mean	445	
	Std. Dev.	92	
	Min	309	
	Max	775	
Total	No. of stocks	117	
	Mean	18,154.89	
	Std. Dev.	38,195.84	
	Min	309.10	
	Max	202,890.21	

Table 2. Final sample constituents and their market capitalization

Our final data sample consists of 117 Russell 3000 stocks. Table 2 presents sample constituents and their statistics. The values of market capitalization (Mcap) are in \$ million. The sample contains large companies with a high market capitalization, e.g. General Electric Company and Apple Inc., as well as smaller companies with a low market capitalization, e.g. Acco Brands Corp. and Maxwell Technologies Inc. The sample is ranked by their average market capitalization (Mcap) over the entire sample. It is further categorized into three market capitalization groups: Mcap 1 (39 stocks with the highest Mcap), Mcap 2 (39 stocks with medium Mcap), and Mcap 3 (39 stocks with low Mcap). NASDAQ itself is the world's largest exchange company and has over 20% of the market share in listed US equity. It is a fully electronic market, with trading hours from 9:30 a.m. to 16:00 p.m. There are call auctions, called "crosses", throughout the day: an opening cross at 9:30 a.m., a closing cross at 4:00 p.m., as well as three intraday crosses. In our study, we focus only on continuous trading periods and delete the first and last fifteen minutes of the trading period in order to avoid data errors from opening and closing procedures.

### 3.2 Market quality measurement

There is vast literature that analyzes different aspects of market quality. In market quality literature, the term market quality usually involves aspects of market activity, liquidity, and information. Bessembinder (1999) uses mostly descriptive measures of trading activity and quote frequency, specifically measures like number of trades per day, daily trading volume, average trade size, and number of quote updates. He further analyzes spread measures as a measure for transaction cost, specifically quoted, effective, and realized spreads.

Quoted spread is an ex-ante measure of liquidity which can be calculated directly from order book data. However, it only measures the transaction costs of small trades on the upper level of the order book. Quoted spread can also be calculated as trade-time quoted spread (*Quoted Spread Trade*), i.e. the prevailing quoted spread at the time when a trade occurred. Let  $Ask_{i,t}$  denote the ask price for a stock  $i$  at time  $t$ ,  $Bid_{i,t}$  the respective bid price, and  $Mid_{i,t}$  the midpoint. The quoted spread is then calculated as follows:

$$Quoted\ Spread_{i,t} = (Ask_{i,t} - Bid_{i,t}) / (2 * Mid_{i,t})$$

The effective spread is an ex-post measure. It represents the actual transaction costs paid when an incoming market order is executed against a limit order. Let  $Price_{i,t}$  denote the execution price and  $D_{i,t}$  the trade direction, with -1 for a market sell and +1 for a market buy order, then the effective spread is calculated as follows:

$$Effective\ Spread_{i,t} = D_{i,t} * ((Price_{i,t} - Mid_{i,t}) / Mid_{i,t})$$

The effective spread can be decomposed into the realized spread, i.e. liquidity suppliers' revenue, and the price impact after time  $x$ . Time intervals  $x$  of 5 and 15 minutes are most common.

Realized Spread equals losses of the market marker to better informed traders and is defined as follows:

$$Realized\ Spread_{i,t} = D_{i,t} * ((Price_{i,t} - Mid_{i,t+x}) / Mid_{i,t})$$

While spread measures account for the width of liquidity, depth is another dimension of liquidity. It measures the quoted volume of limit orders in the order book at a given price (cf. Barclay et al., 2003). Let  $Vol.Bid_{i,t}$  and  $Vol.Ask_{i,t}$  denote the volume at the best bid and ask, respectively. Depth at the best bid and ask can then be measured as:

$$Depth_{i,t} = (Vol.Bid_{i,t} + Vol.Ask_{i,t}) / 2$$

Finally, Barclay et al. (2003) and Hendershott et al. (2011) also use information measures, such as price impact and Hasbrouck information measures (Hasbrouck, 1991), in order to measure market quality. The measurement of information and price efficiency is still a challenge in most electronic markets. Since we have continuous price discovery on financial markets, we are able to measure the

information content of trades and quotes by the price development after their submission. For example, the 5 minute price impact after a buy order is positive if the midpoint after 5 minutes after execution is higher than the midpoint at the time of execution, i.e. can interpreted as the short-term profit of a trade. In order to approximate the information content of a trade, the price impact can be used, calculated as the price adjustment after a trade:

$$Price\ Impact_{i,t} = D_{i,t} * ((Mid_{i,t+x} - Mid_{i,t}) / Mid_{i,t})$$

Price impact only serves as an indication for information content, since it only considers the specific price 5 and 15 minutes after a trade. This time interval might be too long for very actively traded stocks, for which a shorter time interval can be assumed to impound new information in the prices, while 5 or 15 minutes might be too short for trades that are only traded several times a day. More robust measures are information measures described in Hasbrouck (1991). The information measures are based on a pre-defined number of quote revisions after a trade and trades after a quote revision, defined as the number of lags. They therefore take the actual trade activity of the specific stock into account instead of a fixed time interval. As in Hasbrouck (1991), we use a vector autoregressive model (VAR) with 10 lags:

$$r_t = \gamma_{0,r} + \sum_{i=0}^{10} \alpha_{t-i} x_{t-i} + \sum_{i=0}^{10} \beta_{t-i} r_{t-i} + u^r$$

$$x_t = \gamma_{0,x} + \sum_{i=0}^{10} \delta_{t-i} x_{t-i} + \sum_{i=0}^{10} \eta_{t-i} r_{t-i} + u^x$$

with  $r_t$  as the time series of quote revisions and  $x_t$  the time series of trade direction.  $\gamma$ ,  $\alpha$ ,  $\beta$ ,  $\delta$ , and  $\eta$  are the coefficients of the respective VAR models, and  $u^r$  and  $u^x$  are the error terms. We can see that the quote revision  $r_t$  is decomposed into ten preceding trades  $x_{t-10}, \dots, x_t$ , ten preceding quote revisions  $r_{t-10}, \dots, r_t$ , as well as the mean  $\gamma$  and the error term  $u^r$ . The cumulative impulse response function is the result of the inversion of the VAR-model to a vector moving average (VMA) representation and the addition of the coefficients of the VMA model  $\sum_{t=0}^{10} a$ . The cumulative impulse response function can be interpreted as the information impact of 10 preceding trades on the current quote.

### 3.3 Results and interpretation

The descriptives give insight about the contribution of HFT on market quality. We evaluate the contribution of HFT to market quality as compared to non-HFT, grouped by the three categories market activity, liquidity, and information. To test for significance of the differences between HFT and non-HFT measures, we apply robust Thompson clustered standard errors (cf. Thompson, 2011).

In Table 3, we analyze the contribution of HFT to market activity. We differ between measures of trading activity and quoting activity.  $H\_Dem$  and  $N\_Dem$  indicate that the trade initiator is a HFT and non-HFT respectively, while  $H\_Supp$  and  $N\_Supp$  indicate whether the passive order was from a HFT or a non-HFT. The difference between  $H\_Dem$  and  $N\_Dem$  as well as  $H\_Supp$  and  $N\_Supp$  is shown in the column *Diff* with the t-statistic in parentheses. *Turnover* is the average daily trading volume in \$ million, *Trade Count* the average number of trades per day, *Trade Size* the average number of shares per trade, and *Quote Frequency* the total number of price and volume updates per day. *Quote Frequency* is grouped by the initiator of the quote update, i.e. HFT ( $H\_init$ ) or non-HFT ( $N\_init$ ). \*\*\*, \*\*, and \* denote significance at the 1%, 5%, and 10% level respectively. We can see that HFT initiate a smaller portion of the trades, in terms of turnover and trade count, and that they use smaller initiating orders. Non-HFT make up around 55% of the total turnover in the sample period and they also initiate 54% of the trades. Although this result is counterintuitive, we already mentioned the limitations relating to the data in section 3.1. The comparison of the group HFT consisting of 26 HFT firms and the remaining firms demonstrates that turnover and trade count *per firm* is actually higher for HFT.

	Entire sample	H_Dem	N_Dem	Diff (t-statistic)	H_Supp	N_Supp	Diff (t-statistic)
Trading Activity							
Turnover [Mio.]	59.825	27.015	32.841	-5.826** (-2.066)	26.154	33.716	-7.562** (-2.007)
Trade Count	8,336	3,814	4,526	-712*** (-2.333)	4,356	3,987	369 (0.814)
Trade Size	128	119	134	-15*** (-7.289)	115	138	-23*** (-9.376)
Quoting Activity							
Quote Frequency	84,787	H_init	62,461		N_init	22,436	

Table 3. Results for total trading activity and quoting activity

Therefore these results on trading activity provide an additional reference point to interpret the following results. As expected from the previous discussions of trade characteristics and definition of HFT, trades initiated by HFT involve a smaller trade size measured in number of shares. The right part of the table presents results for trading activity grouped by the passive side of a trade. Although HFT provide less liquidity in terms of turnover, they provide liquidity more often than non-HFT, as shown in the results for trade count. The smaller turnover can be related to the smaller trade size, from which we can infer that HFT trade smaller order sizes when they demand and supply liquidity. The quoting activity is measured by the number of price and volume updates per day. We can see that the number of quote updates initiated by HFT is threefold the number of quote updates initiated by non-HFT. From the results for trading activity and quoting activity, we can infer a significant amount of market making strategies since HFT supply a similar amount of liquidity in terms of trade count, but provide less liquidity in terms of turnover. This is accompanied by a smaller trade size and a high quoting activity.

In order to analyze how HFT influence the total liquidity provision and liquidity demand of the market, we differentiate between quote- and trade-based measures in Table 4. Quote-based measures are grouped by  $H\_Two$  ( $N\_Two$ ), which denotes the case when HFT (non-HFT) provide liquidity on both sides of the spread, i.e. supply liquidity at the best bid and ask price. For trade-based measures,  $H\_Dem$  and  $N\_Dem$  indicate that the trade initiator is a HFT and non-HFT respectively, while  $H\_Supp$  and  $N\_Supp$  indicate whether the passive order was from a HFT or a non-HFT.  $Diff$  is the difference

	Quote-based Measures						
	Entire sample	H_Two	N_Two	Diff	t-statistic		
Quoted Spread	13.721	13.954	11.894	2.060***	(3.687)		
Depth	38,004	40,194	41,760	-1,566***	(-3.883)		
	Trade-based Measures						
	Entire sample	H_Dem	N_Dem	Diff (t-statistic)	H_Supp	N_Supp	Diff (t-statistic)
Quoted Spread Trade	8.762	8.175	8.999	-0.824*** (-4.188)	9.901	8.498	1.403*** (2.445)
Effective Spread	6.847	5.774	7.165	-1.391*** (-4.786)	8.070	6.625	1.445*** (4.638)
Realized Spread 5	-0.665	-1.764	-0.273	-1.492*** (-4.975)	0.728	-0.871	1.599 (1.197)
Realized Spread 15	-0.769	-1.610	-0.448	-1.162*** (-2.767)	0.968	-1.014	1.982 (1.019)
Depth Trade	36,804	36,343	37,331	-988* (-1.521)	36,045	37,645	-1,601*** (-5.146)

Table 4. Results for total liquidity provision and liquidity demand

between  $H\_Dem$  and  $N\_Dem$ , as well as  $H\_Supp$  and  $N\_Supp$  respectively. \*\*\*, \*\*, and \* denote significance at the 1%, 5%, and 10% level respectively. The quoted spread in case HFTs provide liquidity on both sides of the market is significantly higher compared to the case when non-HFT are on both sides of the market, while the depth is significantly lower when HFT are best on both sides of the market. This means that HFT provide liquidity when the market is less liquid, meaning that liquidity is rather expensive since quoted spreads are higher and depth is lower. The trade-based measures are determinants when HFT initiate trades and when they provide liquidity. The spread measures are all significantly lower when HFT initiate a trade, which means that they trade more aggressively when liquidity is cheap. As for the liquidity supply of HFT, we get a confirmation on our observation that HFT supply liquidity when it is expensive. They provide liquidity in case of significantly higher quoted spread at trade and effective spreads as well as lower depth.

Table 5 presents results for price impact grouped by  $H\_Two$  and  $N\_Two$ ,  $H\_Dem$  and  $N\_Dem$ , as well as  $H\_Supp$  and  $N\_Supp$ . *Diff* is the difference between  $H\_Two$  and  $N\_Two$ ,  $H\_Dem$  and  $N\_Dem$ , as well as  $H\_Supp$  and  $N\_Supp$ . \*\*\*, \*\*, and \* denote significance at the 1%, 5%, and 10% level respectively. The results for price impact are inconclusive, since we find no significant differences of H-initiated and N-initiated as well as H-supplied and N-supplied trades respectively. For more robust results, we compute impulse response functions as developed by Hasbrouck (1991) to compare the differences in information impact between HFT and non-HFT for the three different groups of market capitalization. Results are shown in Table 6, categorized into HFT and non-HFT and grouped by the three Mcap groups. \*\*\*, \*\*, and \* denote significance at the 1%, 5%, and 10% level respectively. The overall information impact is significantly lower for the entire sample. This is also the case for Mcap3 stocks while Mcap2 stocks yield inconclusive results. On the other side, information impact is significantly higher for HFT than for non-HFT for Mcap1 stocks. We might infer that HFT bring information into the market only for high market capitalization stocks, although we cannot distinguish whether the information impact results from the speed advantage due to information processing algorithms, connection speed, or whether HFT use order anticipation methods.

	Entire sample	H_Dem	N_Dem	Diff (t-statistic)	H_Supp	N_Supp	Diff (t-statistic)
Pimpact 5	7.563	7.414	7.527	-0.114 (-0.202)	7.511	7.528	-0.018 (-0.033)
Pimpact 15	7.666	7.260	7.703	-0.443 (-0.797)	7.271	7.672	-0.401 (-0.213)

Table 5. Results for price impact

	H	N	Diff	t-statistic
Mcap1	1.070	0.873	0.197	4.075***
Mcap2	1.397	1.445	-0.049	-0.654
Mcap3	1.765	3.234	-1.469	-5.280***
Entire sample	1.410	1.851	-0.441	-3.491***

Table 6. Results for Hasbrouck impulse response functions

## 4 Conclusion

The aim of this paper is to discuss the technological and economic aspects of the technological innovation HFT with an emphasis on the contribution of HFT on market quality shown on an exemplary case study of the NASDAQ stock market. The contribution is measured by the application of the most prevalent market quality measures. Our first discussion concerning the technological aspects involved gives insight into the complexity of this topic. While HFT is currently undergoing

more regulatory inspections, it is still a major driver for technological and economic advances in electronic trading. This is especially shown by the developments of internal market structure, specifically IT system, business structure, and market microstructure. HFT challenges marketplaces to improve and invest in their IT system in order to meet the needs of computer traders. Additionally, these marketplaces also adapt their business structure in order to attract HFT and adjust their market microstructure to make this kind of trading possible and safe. The adaptations of the internal market structure as well the increased trading activity of HFT had different effects on market quality, which we analyze in our case study. Our empirical results indicate the contribution of HFT and non-HFT to different extents on different measures of market quality. Non-HFT make up a higher portion of turnover and trades, partly due to the smaller trade size applied by HFT and to the limitations discussed in section 3.1. In general, a significant amount of HFT engages in market making strategies. They provide liquidity when it is expensive and demand liquidity when it is cheap, which is also in line with the results of Hendershott and Riordan (2009). In terms of information, price impact does not show significant differences of HFT and non-HFT trades. The results on impulse response functions give more conclusive insight. They show that HF trades are also more informed than non-HFT trades for Mcap 1 stocks, though they are less informed overall. Nevertheless, there is still work to be done in order to provide results using more robust measures for information impact. In conclusion, our results support the existing results in academic literature that found predominantly positive effects of HFT. With our unique dataset, we were able to show that a majority of HFT apply market making strategies and that only 26 HFT firms make up more than 40% of the total trading volume in our data sample. This result shows the importance of HFT and adds to the concern whether such a large amount of trading volume coming from a small group of traders could pose systemic risk to financial markets.

For future research, other strategies have to be analyzed and the verified strategies should be analyzed in more detail. Next to the discussion on market quality, regulatory discussions also involve the fairness for long-term investors as well as the risk involved with the growing importance of HFT. The Flash Crash on May 6<sup>th</sup>, 2010 was a striking demonstration of systemic risks that are incorporated in financial markets. Opponents claim stricter regulation of HFT as a group regarding their market making activities from which trading venues profit, but on which they also rely heavily. Although a majority of U.S. retail advisor believed in an “overreliance on computer systems and high-frequency systems” that caused the Flash Crash (Kirilenko et al., 2011), academic literature haven’t found any negative effects of HFT and moreover supports evidence on positive effects. As for the growing literature on HFT that researches into the volatility and risk effects of HFT, more research has to be done in this field in order to draw conclusions and to make well reasoned suggestions to regulatory authorities.

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