

# **High-Frequency Trading**

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Commissioned by



## **Executive Summary**

High-frequency trading (HFT) has recently drawn massive public attention fuelled by the U.S. May 6, 2010 flash crash and the tremendous increases in trading volumes of HFT strategies. Indisputably, HFT is an important factor in markets that are driven by sophisticated technology on all layers of the trading value chain. However, discussions on this topic often lack sufficient and precise information. A remarkable gap between the results of academic research on HFT and its perceived impact on markets in the public, media and regulatory discussions can be observed.

The research at hand aims to provide up-to-date background information on HFT. This includes definitions, drivers, strategies, academic research and current regulatory discussions. It analyzes HFT and thus contributes to the ongoing discussions by evaluating certain proposed regulatory measures, trying to offer new perspectives and deliver solution proposals. Our main results are:

**HFT is a technical means to implement established trading strategies.** HFT is not a trading strategy as such but applies the latest technological advances in market access, market data access and order routing to maximize the returns of established trading strategies. Therefore, the assessment and the regulatory discussion about HFT should focus on underlying strategies rather than on HFT as such.

**HFT is a natural evolution of the securities markets instead of a completely new phenomenon.** There is a clear evolutionary process in the adoption of new technologies triggered by competition, innovation and regulation. Like all other technologies, algorithmic trading (AT) and HFT enable sophisticated market participants to achieve legitimate rewards on their investments – especially in technology – and compensation for their market, counterparty and operational risk exposures.

**A lot of problems related to HFT are rooted in the U.S. market structure.** The flash crash and the discussions on flash orders relate to the U.S. equity markets and the NMS. In Europe, where a more flexible best execution regime is implemented and a share-by-share volatility safeguard regime has been in place for two decades, no market quality problems related to HFT have been documented so far. Therefore, a European approach to the subject matter is required and Europe should be cautious in addressing and fixing a problem that exists in a different market structure thereby creating risks for market efficiency and market quality.

**The majority of HFT based strategies contributes to market liquidity (market making strategies) or to price discovery and market efficiency (arbitrage strategies).** Preventing these strategies by inadequate regulation or by impairing underlying business models through excessive burdens may trigger counterproductive and unforeseen effects to market quality. However, any abusive strategies against market integrity must be effectively combated by supervisory authorities.

**Academic literature mostly shows positive effects of HFT based strategies on market quality.** The majority of papers, focusing on HFT, do not find evidence for negative effects of HFT on market quality. On the contrary, the majority argues that HFT generally contributes to market quality and price formation and finds positive effects on liquidity and short term volatility. Only one paper critically points out that under certain circumstances HFT might increase an adverse selection problem and in case of the flash crash one study documents that HFT exacerbated volatility. As empirical research is restricted by a lack of accessible and reliable data, further research is highly desirable.

**In contrast to internalization or dark pool trading, HFT market making strategies face relevant adverse selection costs as they are providing liquidity on lit markets without knowing their counterparties.** In internalization systems or dark venues in the OTC space, banks and brokers know the identity of their counterparty and are able to “cream skim” uninformed order flow. In contrast, HFTs on lit markets are not informed on the toxicity of their counterparts and face the traditional adverse selection problems of market makers.

**Any assessment of HFT based strategies has to take a functional rather than an institutional approach.** HFT is applied by different groups of market players from investment banks to specialized boutiques. Any regulatory approach focusing on specialized players alone risks (i) to undermine a level playing field and (ii) exclude a relevant part of HFT strategies.

**The high penetration of HFT based strategies underscores the dependency of players in today's financial markets on reliable and thoroughly supervised technology.** Therefore, (i) entities running HFT strategies need to be able to log and record algorithms' input and output parameters for supervisory investigations and back-testing, (ii) markets have to be able to handle peak volumes and have to be capable of protecting themselves against technical failures in members' algorithms, (iii) regulators need a full picture of potential systemic risks triggered by HFT and require people with specific skills as well as regulatory tools to assess trading algorithms and their functionality.

**Any regulatory interventions in Europe should try to preserve the benefits of HFT while mitigating the risks as far as possible by assuring that** (i) a diversity of trading strategies prevails and that artificial systemic risks are prevented, (ii) economic rationale rather than obligations drive the willingness of traders to act as liquidity providers, (iii) co-location and proximity services are implemented on a level playing field, (iv) instead of market making obligations or minimum quote lifetimes, the focus is on the alignment of volatility safeguards among European trading venues that reflect the HFT reality and ensure that all investors are able to adequately react in times of market stress.

**The market relevance of HFT requires supervision but also transparency and open communication to assure confidence and trust in securities markets.** Given the public sensitivity to innovations in the financial sector after the crisis, it is the responsibility of entities applying HFT to proactively communicate on their internal safeguards and risk management mechanisms. HFT entities act in their own interest by contributing to an environment where objectivity rather than perception leads the debate: They have to draw attention to the fact that they are an evolution of securities markets, supply liquidity and contribute to price discovery for the benefit of markets.

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## 1 Introduction

For hundreds of years, exchanges were organized as physical venues where market participants met to exchange their trading interests. Traditionally, floor-based trading was supported by designated market intermediaries who arranged trades between different market participants. In the last decades, securities trading experienced significant changes and more and more stages in the trading process were automated by incorporating electronic systems. Nowadays, the securities trading landscape is characterized by fragmentation among trading venues and competition for order flow, different market access models and a significant market share of automated trading technologies like *algorithmic trading* (AT) and *high-frequency trading* (HFT).

*Algorithmic trading*<sup>1</sup> has altered the traditional relationship between investors and their market access intermediaries in agent trading. Computer algorithms which generate orders for trading individual instruments without any human intervention have been applied internally by sell side firms for years<sup>2</sup>. However, with the help of new market access models, the buy side has gained more control over the actual trading decision and order allocation processes and is enabled to develop and implement their own trading algorithms<sup>3</sup> or uses standard software solutions from independent software vendors (ISV). Nevertheless, the sell side still offers the majority of AT tools to their clients. Applying computer algorithms that generate orders automatically has reduced the overall trading costs for investors, as no expensive human traders are involved any longer. Consequently, AT has gained significant market shares in international financial markets in recent years.

The term *high-frequency trading* has emerged in the last five years and has gained some significant attention due to the flash crash in the U.S. on May 6, 2010. While AT is mostly associated with the execution of client orders, HFT relates to the implementation of proprietary trading strategies by technologically advanced market participants. HFT is often

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<sup>1</sup> The proliferation of AT is also documented in various descriptive surveys, e.g. Financial Insights (2005) and Financial Insights (2006) or EDHEC-Risk Advisory (2005). Directories are publicly available that list providers of AT and their algorithms (A-Team Group 2009).

<sup>2</sup> Although program trading notionally sounds alike, this is not related to applying computer algorithms to trading, but rather to buying or selling bundles of instruments.

<sup>3</sup> However, in order to apply their own algorithmic trading solutions, buy side institutions need sufficient trading expertise to integrate and parameterize their own algorithms into their trading desks. As Engdahl and Devarajan (2006) point out: “*With the exception of advanced quantitative trading houses, buy side trading desks are generally not equipped to build and deploy their own algorithms.*” The development of AT software is associated with considerable costs and most buy side institutions lack the technical expertise and/or the funds necessary for deploying their own AT solutions. Those investment firms buy customizable AT solutions either from brokers or independent software vendors (ISV).

seen as a subgroup of AT, however, both AT and HFT enable market participants to dramatically speed up the reception of market data, internal calculation procedures, order submission and reception of execution confirmations. Currently, regulators around the globe are discussing whether there is a need for regulatory intervention in HFT activities.

Figures concerning the market shares of HFT trading have been addressed in the responses to CESR's (CESR 2010a) Call for Evidence on Micro-structural Issues of the European Equity Markets (see Table 5 in the Appendix I). According to the trading platforms' responses, the HFT market shares in European equities trading range from 13% (Nasdaq OMX) to 40% (Chi-X). Based on studies originating from the securities industry and academic literature, market shares from 40% (Tradeworx 2010a) to 70% (Swinburne 2010) are reported for the U.S. and 19% (Jarrnecic and Snape 2010) to 40% (Swinburne 2010) can be found for Europe (see Table 6 in Appendix I). The Australian regulator ASIC reports that HFT activity in the Australian market as significantly lower, where a market share at around 10% can be observed (ASIC 2010a).

This paper is to provide background information on the proliferation of AT and HFT (due to the current discussions the main focus is set on HFT). It aims at supporting the public, policy makers and regulators in discussions around AT and HFT and in assessing potential regulatory steps on an informed basis. The remainder of this paper is structured as follows: Section 2 will provide some historical background and outlines drivers for AT and HFT as these technologies are linked to a multitude of recent developments and innovations in securities trading. In order to offer a clear foundation for further discussions, section 3 defines HFT and distinguishes it from other automated trading strategies, particularly from AT. In this context, common and distinct characteristics of AT and HFT strategies will be discussed. Trading strategies, that are based on HFT and AT as a technology, will be presented in the subsequent section 4. A review of academic literature on AT and HFT will be delivered in section 5. Regulatory discussions and initiatives on HFT in the U.S. and in Europe are presented in section 6 and eventually, the last section concludes with a series of policy implications for a potential regulatory handling of HFT.

## 2 Evolution of Electronic Trading

### 2.1 Historical Background and Electronification of Securities Trading

The electronification of securities trading commenced 40 years ago, when the National Association of Securities Dealers (NASD) started its computer-assisted market making system for automated quotation (AQ) in the U.S., forming what is nowadays known as NASDAQ (Black 1971a; Black 1971b). In Europe, the first computer-assisted equities exchanges launched their trading services in the 1980s, but not until the 1990s securities trading was organized in fully automated exchanges.

The majority of market models of those fully automated equities exchanges are implemented as electronic central limit order books (CLOB), which store market participants' trading interests visible to and executable for all other connected traders. According to Pagano and Roell (1996) and Jain (2005), the transparency induced by the introduction of CLOBs reduces information asymmetry, enhances liquidity and supports efficient price determination. While prices were determined manually in floor trading, orders are matched automatically according to price-time priority in electronic trading systems.<sup>4</sup> By applying uniform rules to all market participants, operational fairness and fair access to the respective trading venue shall be ensured (Harris 2003).

Thereby, the electronification of securities markets and the electronic connectivity of market participants went hand in hand, leading to decentralized market access. Physical trading floors were not required any longer and have mostly been replaced by electronic trading systems. Investors can submit their orders electronically to a market's backend from remote locations.

On the investors' side, human trading processes have been substituted by electronic systems, too. While systems generating automated quotes and stop-loss orders were the first technological artifacts that conquered the trading process, in recent years information technology (IT) has successively established and can nowadays be found on every stage of trading and post-trading processes. State-of-the-art technology has developed as a crucial competitive factor for market operators in recent decades and market participants themselves continued to further automate and optimize their trading processes along the entire value chain.

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<sup>4</sup> Although slight modifications exist, price-time priority has established as a de-facto standard in securities trading globally.

## 2.2 Drivers for Widespread Usage of Algorithmic/High-Frequency Trading

The emergence of AT and HFT in the past went hand in hand with other market structural developments in European securities trading. In the following, multiple drivers for the rise of AT and HFT are identified, i.e. new *market access models* and *fee structures*, a significant reduction of *latency* and an increase in *competition* for and *fragmentation* of order flow<sup>5</sup>.

In most markets, only registered members are granted direct access.<sup>6</sup> Hence, those members are the only ones allowed to conduct trading directly, leading to their primary role as market access intermediaries for other investors. Market members performing that function are referred to as brokers<sup>7</sup>. In the past, those access intermediaries transformed their clients' general investment decisions into orders that were allocated to appropriate market venues. As the cost awareness of the buy side has increased over the years, brokers have begun to provide different *market access models*, i.e. direct market access (DMA) and sponsored access (SA). When an investor makes use of DMA, his orders are no longer touched by the broker, but rather forwarded directly to the markets through the broker's infrastructure. One key characteristic of DMA presents the fact that the respective broker can conduct pre-trade risk checks.

Sponsored access (SA) represents a slightly different possibility for the buy side to access a marketplace. Here, an investment firm (that is not a member of the respective market) is enabled to route its orders to the market directly using a registered broker's member ID *without* using the latter's infrastructure (in contrast to DMA). Resulting from this setup, the sponsor can conduct pre-trade risk checks only if the option to conduct those checks is provided by the trading venue (filtered SA). In case of unfiltered (also referred to as naked) SA, the sponsor only receives a drop copy of each order to control his own risk exposure. A reduction in latency represents the main advantage of SA over DMA from a non-member firm's perspective and therefore is highly attractive for AT or HFT based trading strategies.

Another driver for the success of AT and HFT is the new trading *fee structures* found in Europe. Market operators try to attract order flow that is generated automatically (i) by applying special discounts for algorithmic orders within their fee schedules. MTFs

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<sup>5</sup> Obviously, this list of drivers is not exhaustive. Other drivers that could be listed additionally include, e.g., the growing number of proprietary trading firms founded by former investment bank staffers and other mathematically/technically oriented traders.

<sup>6</sup> Access is restricted to registered market members mainly due to post-trading issues, i.e. clearing and settlement. A pre-requisite for trading directly in a market is an approved relationship with the respective clearing house(s).

<sup>7</sup> As brokers basically offer their services to other market participants they are also referred to as the sell side. Respective clients purchasing those services are referred to as the buy side (Harris 2003).

implemented (ii) fee schedules with very aggressive levels to compete with incumbent exchanges. Furthermore, some MTFs like e.g. Chi-X, BATS or Turquoise started offering pricing schemes that are a novelty to European exchange fee schedules: (iii) asymmetric pricing (Jeffs 2009; Mehta 2008). With asymmetric pricing, market participants removing liquidity from the market (taker) are charged a higher fee while traders that submit liquidity to the market (maker) are charged a lower fee or are even provided with a rebate. Such an asymmetric fee structure is supposed to incentivize liquidity provision. Faced with the MTFs' aggressive pricing strategies, many European exchanges were urged to lower their fee levels as well, while others even adopted the asymmetric pricing regime. As will be further explained in section 4, market participants have specialized in making profits from those fee structures by applying trading algorithms.

Although *latency* has always been of importance in securities trading, its role is more intensely stressed by market participants with AT/HFT on the rise. In traditional trading involving human interaction on trading floors, a trader could also profit from trading faster than others. Traders often benefited from their physical abilities, e.g. when they could run faster across the trading floor or shout louder than their counterparts and thus drew a market maker's or specialist's attention to their trading intentions. With algorithms negotiating on prices nowadays, those physical advantages are no longer needed. Nevertheless, in markets trading at high speed, the capability to receive data and submit orders at lowest latency is essential. When the market situation at the arrival of an order differs significantly from the market situation, which led to that particular trading decision, there is a risk that the order is no longer appropriate in terms of size and/or limit (Harris 2003; Brown and Holden 2005; Liu 2009). Hence, an order bears the risk of being executed at an improper price or not being executed at all. To minimize that risk, reducing the delay of data communication with the market's backend is of utmost importance to AT/HFT based strategies concerning market data receipt, order submissions and execution confirmations. In order to reduce latency<sup>8</sup>, automated traders make use of co-location or proximity services that are provided by a multitude of market operators.<sup>9</sup> By co-locating their servers, market participants can place their trading machines directly adjacent to the market operator's infrastructure.

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<sup>8</sup> Actually, quantifying the economic value of low latency is hardly possible as measuring latency is difficult and the methodologies applied are inconsistent (Ende et al. 2011).

<sup>9</sup> Proximity services refer to facility space that is made available by specialized network providers to market participants for the purpose of locating their network and computing hardware closer to the matching engines specifically in order to optimize the location with respect to multiple venues and to maximize flexibility. Co-location services are provided by a market operator and refer to a setup where a market participant's hardware is located directly next to a market's matching engine.

Regulation in European securities trading has promoted the market penetration of AT/HFT as well: with the advent of MiFID (European Commission 2004), the European equity trading landscape became more complex. As intended by the regulator, *competition* among market venues has increased, and the available liquidity in a security is scattered among different market venues (Gomber et al. 2011b). This *fragmentation* of markets is a direct consequence of the harmonized level playing field for different types of trading venues intended by MiFID. In order to attract market share, new venues challenged the incumbent exchanges by lower trading fees and forced them to adapt their pricing schemes as well. These recently emerged MTFs steadily increased their market penetration. The lowered costs of trading (both explicit and implicit<sup>10</sup>) are beneficial for all market participants including issuers, as lower trading costs increase liquidity and thereby lower the cost of capital. However, Over the Counter (OTC)-trading<sup>11</sup> represents a high and stable market share around 40% (see Figure 1<sup>12</sup>).

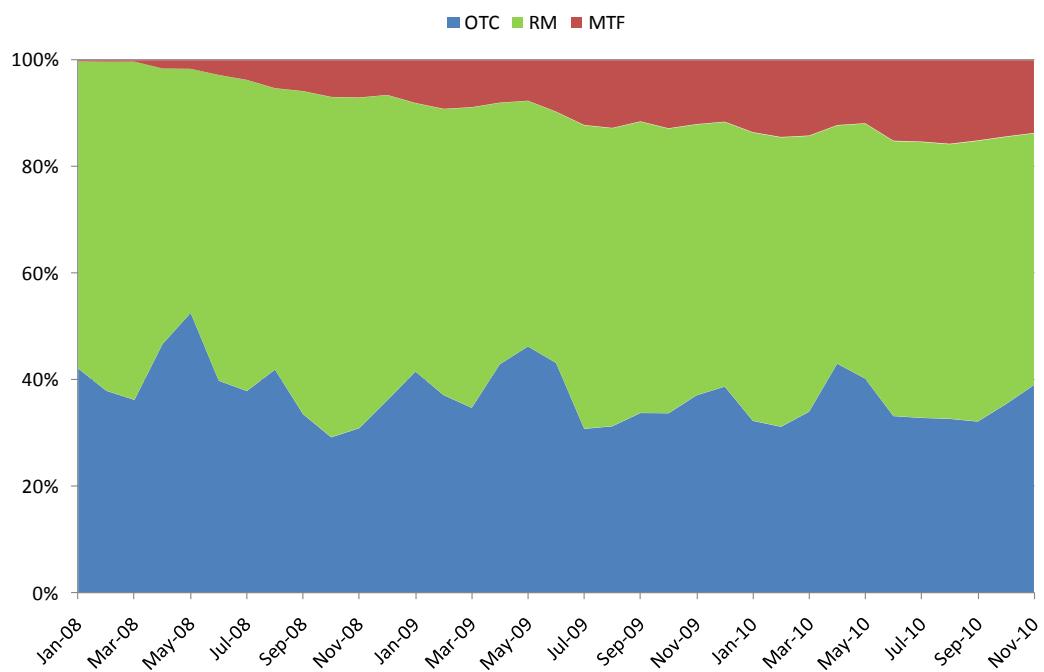


Figure 1: Distribution of trading among regulated markets, MTFs and OTC, based on Thomson Reuters (2008, 2009, 2010)

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Often market participants co-locate in multiple markets in order to achieve maximum execution performance both in proprietary and agent trading.

<sup>10</sup> See Gomber et al. (2011a) for a discussion of the MiFID effect on market liquidity

<sup>11</sup> For a discussion on the detailed structure of OTC trades in Europe, see Gomber et al. (2011b)

<sup>12</sup> Please note that the figures presented refer to European equities only. Figures for foreign equities traded in Europe are excluded.

Market participants are urged to compare potential prices offered as well as different fee regimes across a multitude of market venues, which imposes increased search costs for the best available price. In addition, dark pools and OTC trading, which are exempted from pre-trade transparency, distort the clear picture of available prices. Against this background, algorithms support market participants to benefit from competition between markets and help to overcome negative effects from fragmentation of order flow.

### 3 High-Frequency Trading Definitions and Related Concepts

#### 3.1 Why Algorithmic/High-Frequency Trading Need Clear Definitions

In order to assess HFT concerning its relevance and impact on markets, first, a clear definition and delineation of the term HFT itself is required. This section aims at giving an overview of available academic and regulatory definitions and at excerpting a common notion that incorporates most of the existing perceptions. The derived definitions serve as the working definitions for the following sections. We follow the notion that HFT is a subset of AT as it is supported by e.g. Brogaard 2010. Therefore, AT will be treated first in subsection 3.2.

Furthermore, subsection 3.3 lists related electronic trading concepts and technologies like market making, quantitative asset management and smart order routing in order to cover electronic trading concepts which share certain characteristics with AT/HFT.

#### 3.2 Delineating Algorithmic and High-Frequency Trading

##### 3.2.1 Algorithmic Trading

By now, the academic and general literature about AT is quite extensive. Thus, not surprisingly, the definitions of AT range from the very general “*Computerized trading controlled by algorithms*” (Prix et al. 2007) to the rather specific:

“*In algorithmic trading (AT), computers directly interface with trading platforms, placing orders without immediate human intervention. The computers observe market data and possibly other information at very high frequency, and, based on a built-in algorithm, send back trading instructions, often within milliseconds. A variety of algorithms are used: for example, some look for arbitrage opportunities, including small discrepancies in the exchange rates between three currencies; some seek optimal execution of large orders at the minimum cost; and some seek to implement longer-term trading strategies in search of profits.*” (Chaboud et al. 2009)

Appendices II and III list academic and regulatory definitions on AT and HFT. The variety of formulations shows that there is no general agreement on a single definition. Rather than adding another definition to the list, we will try to extract the main characteristics of these definitions that are non-contradictive in academic literature.

Throughout the literature, AT (and HFT as a subgroup) is viewed as a tool for professional traders that may observe market parameters or other information in real-time and automatically generates/carries out trading decisions without human intervention. It frequently applies DMA or SA technologies for order routing.

Accordingly, we define AT as trading that reveals most but not necessarily all of the following characteristics in Table 1. As HFT is a subset of AT, these characteristics are also valid for HFT, which will be described in more detail in the next paragraph.

<b>Common Characteristics of AT and HFT</b>
1) Pre-designed trading decisions
2) Used by professional traders
3) Observing market data in real-time
4) Automated order submission
5) Automated order management
6) Without human intervention
7) Use of direct market access

*Table 1: Common characteristics of AT and HFT*

However, there are characteristics specific to AT which are commonly not associated to HFT. Here, the focus is on the intelligent working of orders to minimize market impact relative to a pre-defined benchmark. In contrast to HFT, this (classical) part of AT may also relate to agent trading where customers hold securities over longer periods of time.

<b>Specific Characteristics of AT excluding HFT</b>
1) Agent trading
2) Minimize market impact (for large orders)
3) Goal is to achieve a particular benchmark
4) Holding periods possibly days/week/months
5) Working an order through time and across markets

*Table 2: Specific characteristics of AT excluding HFT*

### 3.2.2 High-frequency trading

HFT is a newer phenomenon in the AT landscape and much less literature and definitions can be found. In the same manner as for AT, studying the definitions of HFT in academic

literature was the basis for our working definition. Appendix III shows some typical definitions and descriptions for HFT in academic and regulatory documents.

Authors typically<sup>13</sup> specify that HFT strategies update their orders very quickly and have no over-night positions. The rapid submission of cancellations and deletions is necessary to realize small profits per trade. It is part of the business model to realize small profits in a large number of trades and hence, HFT focuses mainly on high liquid instruments. As a prerequisite, HFT needs to rely on high speed access to markets, i.e. low latencies or the usage of co-location/proximity services and individual data feeds. Table 3 shows basic features that are taken from the various definitions and are usually associated with HFT.

Specific Characteristics of HFT
1) Very high number of orders
2) Rapid order cancellation
3) Proprietary trading <sup>14</sup>
4) Profit from buying and selling (as middleman)
5) No significant position at end of day (flat position)
6) Very short holding periods
7) Extracting very low margins per trade
8) Low latency requirement <sup>15</sup>
9) Use of co-location/proximity services and individual data feeds <sup>16</sup>
10) Focus on high liquid instruments

Table 3: Specific characteristics of HFT

Thus, similarly to AT we define HFT as trading that reveals most but not necessarily all of the above characteristics of Table 3 (obviously in combination with the characteristics listed in Table 1).

Figure 2 sums up the characteristics of AT and HFT. In the lower left box, a list of typical properties is given that could be called “classical” algorithmic trading that is specific for AT but is not associated with HFT.

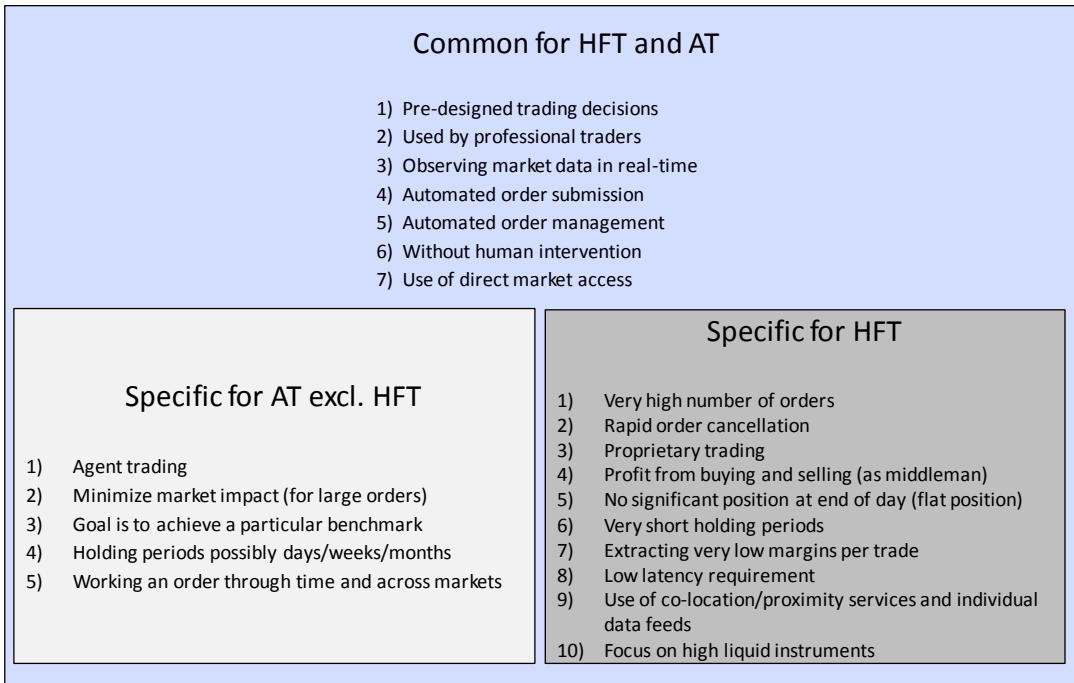
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<sup>13</sup> Not necessarily all characteristics need to be fulfilled for every strategy that is regarded a HFT strategy. For example Tradeworx states that “*some HFT strategies have no special speed requirements and do not even require collocation*” (Tradeworx 2010a).

<sup>14</sup> Proprietary traders utilize only their own capital for their trading activities (Harris 2003).

<sup>15</sup> To trade at high frequencies, HFTs rely on sophisticated high-speed connections to the relevant marketplaces.

<sup>16</sup> Co-location arrangements allow HFTs to place their trading engines close to the matching engines (servers) of a marketplace. This minimizes the time a signal needs to travel between the two engines (CFTC 2010). Individual data feeds can offer information faster than consolidated feeds, since it takes time to consolidate different feeds (SEC 2010a).



*Figure 2: Characteristics of AT and HFT - overview*

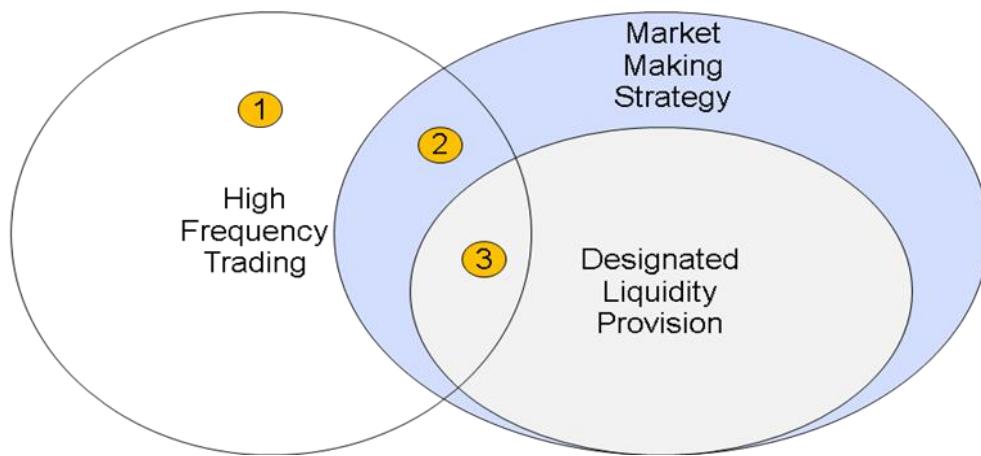
The following subsection depicts strategies and concepts that are connected to AT and HFT in order to clarify these concepts especially with regard to their relation to AT and HFT.

### 3.3 Related Concepts

#### 3.3.1 Market Making

The term market making refers to the strategy of quoting a simultaneous buy and sell limit order (quote) for a financial instrument in order to profit from the bid-ask spread. This can be either imposed by mandatory requirements set by market operators/regulators for entities covering that role (e.g. an official market maker such as the Designated Market Maker at the NYSE or Designated Sponsors at the Frankfurt Stock Exchange via the trading system XETRA), or voluntarily, i.e. without a determined obligation to quote. Several different terms are used to denote this kind of designated liquidity provision, e.g. market making with obligations, designated market making and registered market maker.

Market makers frequently employ “quote machines” which provide the respective electronic markets with their quotes. Quote machines are programs which generate, update and delete quotes according to a pre-set strategy. Due to the varying degree of sophistication among these programs, some of them employ techniques similar to HFTs, while others rely on the involvement of a human market maker. Since market making is a well known HFT strategy (Tradeworx 2010a), the following Figure 3 highlights the relationship between HFT and market making.



*Figure 3: Market making and HFT<sup>17</sup>*

The figure shows the interferences denoted by numbers from one to three that span the activities of HFT in market-making<sup>18</sup>:

- (1) represents all other HFT strategies apart from market-making (for details see section 4.2),
- (2) represents HFT that applies market making strategies without acting as a designated liquidity provider and
- (3) represents HFT that applies market making and is registered as a designated liquidity provider, e.g. GETCO is a Designated Market Maker at NYSE (Bunge and Peterson 2010).

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<sup>17</sup> Areas without numbers refer to the part of market making and designated liquidity provision that is not undertaken by HFT.

<sup>18</sup> As Figure 3 is not based on any numbers such as traded volume, the purpose is to illustrate the different possible combinations of market making and HFT and not to signify the proportions or dimensions of these combinations.

Fragmentation makes HFT market making strategies more relevant as it enables market participants to quote on less active venues based on reference quotes/limits available, e.g., on the most liquid market for that instrument.

Delineation of market making/quote machines to AT/HFT: quote machines originally supported market makers in fulfilling mandatory quotation obligations. Both mandatory and voluntary market making may apply HFT as a supporting technology.

### 3.3.2 Quantitative Portfolio Management (QPM)<sup>19</sup>

Quantitative portfolio managers use quantitative models to form investment portfolios. Chincarini and Kim define quantitative (equity) portfolio management in the following way:

*“The central, unifying element of quantitative equity portfolio management (QEPM) is the quantitative model that relates stock movements to other market data. Quantitative equity portfolio managers create such models to predict stock returns and volatility, and these predictions, in turn, form the basis for selecting stocks for the portfolio.”* (Chincarini and Kim 2006)<sup>20</sup>

In contrast to HFTs, QPMs frequently hold positions for extended periods of time, whereas HFTs tend to liquidate their positions rapidly and usually end trading days without a significant position (“flat”).

Compared to AT and HFT, QPM has a higher degree of human intervention. QPMs use algorithms to generate trading decisions based on statistical calculations and data analysis techniques. While QPMs automate the process of portfolio selection and the generation of trading signals, a human portfolio manager will usually validate the results of his quantitative model before transferring it to a (human or automated) trader for execution.

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<sup>19</sup> Also known as Quantitative Investing.

<sup>20</sup> An alternative definition of QPM is provided e.g. by Quoniam: “*Quantitative portfolio management means the analysis and evaluation of situations relevant for the capital market using statistical methods.*” Quoniam Asset Management GmbH (2010)

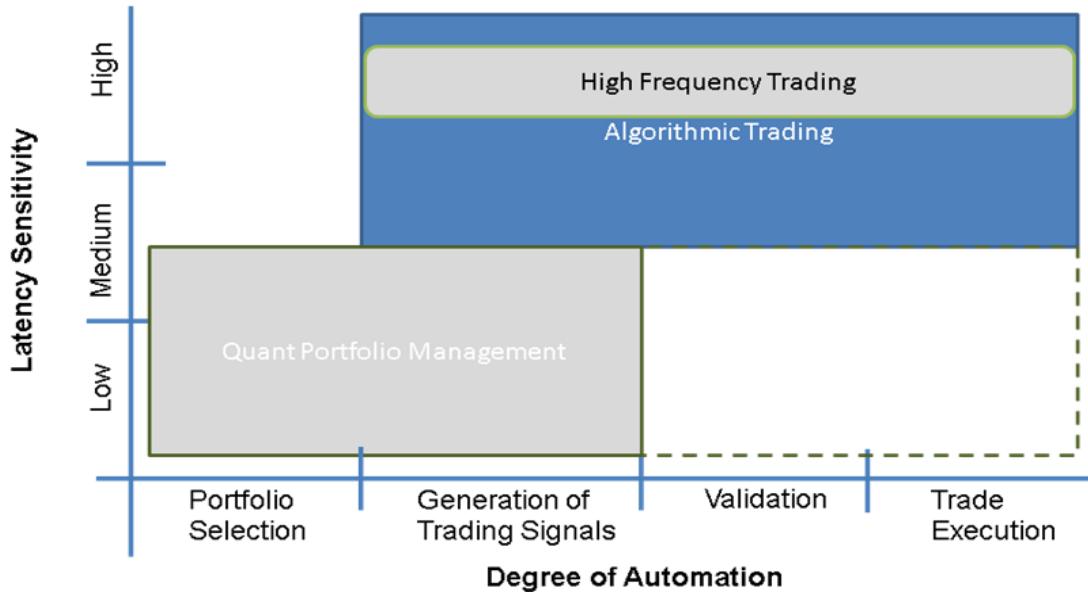


Figure 4: Quantitative portfolio management vs. algorithmic trading

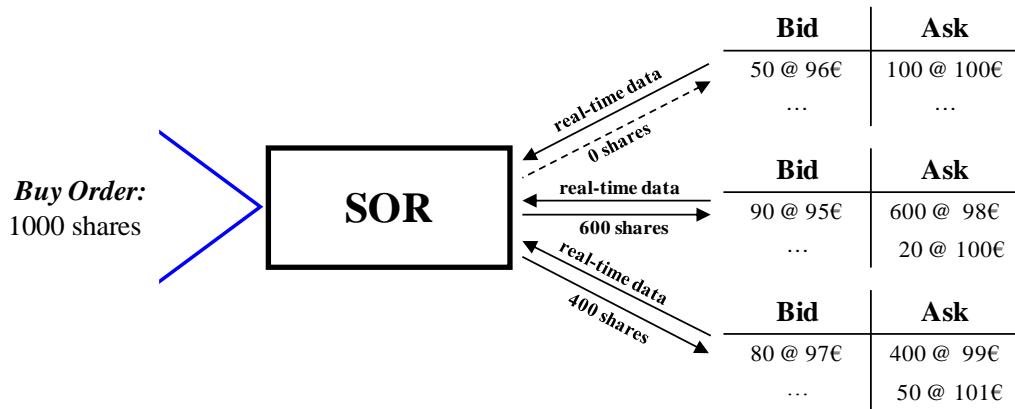
Figure 4 illustrates the relation between QPM and AT with respect to the dimensions degree of automation and latency sensitivity. Some QPMs use algorithms to a greater extent than others. The dashed line in Figure 4 indicates that they may use (third party) algorithms to execute their trades and investment decisions. Yet, long-term (portfolio selection) and short-term (generation of trading signals) asset allocation decisions are generally automated in QPM. This differentiates them from HFTs, which do not conduct portfolio selection, since they base their activities on specific market situations (like current order book statuses or arbitrage opportunities) instead of individual investment decisions. However, with increasing automation, the distinction between QPM and the broadly defined concept of AT/HFT can become blurred.

Delineation of QPM to AT/HFT: QPM primarily supports asset allocation decisions. In contrast to AT/HFT, QPM mostly does not cover the order execution part.

### 3.3.3 Smart Order Routing (SOR)

In fragmented markets, real-time investigation of different accessible order execution venues and of available order limits and quotes can improve execution results in agent and proprietary trading. Smart order routing (SOR) systems enable to access multiple liquidity pools to identify the best order routing destination and to optimize order execution (Ende 2010). They scan pre-defined markets in real-time to determine the best bid and offer limits or quotes for a specific order, thereby achieving the best price or other pre-defined

execution benchmarks. Figure 5 illustrates this process and shows how a given order can be distributed among multiple venues.



*Figure 5: Smart Order Routing - basic principle (Ende and Lutat 2010)*

The smart order router selects the appropriate execution venue on a dynamic basis, i.e. real-time market data feeds are used by a rule framework. Such provisions support a dynamic allocation of the order to the execution venue offering the best conditions at the time of order entry including or excluding explicit transaction costs and/or other factors (e.g. the current technical latency of the venue). In order to achieve the best result in order execution on a real-time basis, i.e. price and explicit execution costs, two steps are required: first, at order arrival a routing system of an investment firm has to screen the respective execution venues for their order book situations, i.e. the execution price dimension. Second, the system has to incorporate a model that enables to calculate the total execution price of trades in different markets including applicable trading, clearing and settlement fees or even taxes, i.e. the explicit costs dimension (Domowitz 2002).

Delineation of SOR to AT/HFT: SOR targets to optimize execution particularly in fragmented markets. SOR primarily applies real-time order book data from fragmented markets without a need for timing or slicing algorithms or additional mathematical models that are typically used in AT/HFT based trading strategies.

## 4 Algorithmic and High-Frequency Trading Strategies

### 4.1 Algorithmic Trading Strategies

#### 4.1.1 The Scope of Algorithmic Trading Strategies

HFT is mostly defined as a subset of AT strategies. However, not all algorithmic strategies are necessarily high frequent. Most non-HFT algorithmic strategies aim at minimizing the market impact of (large) orders. They slice the order into several smaller child orders and spread these child orders out across time (and/or venues) according to a pre-set benchmark. The following subsections describe some of the more common non-HFT algorithmic strategies.<sup>21</sup>

The classification into four generations is based on Almgren (2009) and includes information from Johnson (2010). First generation algorithms focus solely on benchmarks that are based on market generated data (e.g. VWAP) and are independent from the actual order and the order book situation at order arrival, while the second generation tries to define the benchmark based on the individual order and to handle the trade-off between market impact and timing risk. Third generation algorithms are furthermore able to adapt to their own performance during executions. A fourth generation – that is not included in the Almgren (2009) classification – consists of so called newsreader algorithms.

#### 4.1.2 First Generation Execution Algorithms

##### Participation Rate Algorithms

Participation rate algorithms are relatively simple. They are geared to participate in the market up to a predefined volume. Such an algorithm could for example try to participate by trading 5% of the volume in the target instrument(s) until it has built or liquidated a target position. Since these algorithms target traded volume, they reflect the current market volume in their orders. Variants of these algorithms add execution periods during which orders are submitted to the market or maximum volumes or prices.<sup>22</sup> Furthermore, randomized participation rates are used to make the algorithm harder to detect for other market participants.

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<sup>21</sup> Some market participants may employ variants of these strategies or conduct strategies similar to the ones mentioned in the HFT subsection, but without being as latency sensitive as HFTs.

<sup>22</sup> If the algorithm has only a pre-set execution period, it may not be able to execute the whole target position during this period if traded volume is not sufficiently high.

## Time Weighted Average Price (TWAP) Algorithms

TWAP algorithms divide a large order into slices that are sent to the market in equally distributed time intervals. Before the execution begins, the size of the slices as well as the execution period is defined. For example, the algorithm could be set to buy 12,000 shares within one hour in blocks of 2,000 shares, resulting in 6 orders for 2,000 shares which are sent to the market every 10 minutes. TWAP algorithms can vary their order sizes and time intervals to prevent detection by other market participants.

## Volume Weighted Average Price (VWAP) Algorithms

VWAP algorithms try to match or beat the volume weighted average price (their benchmark) over a specified period of time. VWAP can be calculated applying the following formula for n trades, each with an execution price  $p_n$  and size  $v_n$  (Johnson 2010):

$$VWAP = \frac{\text{Overall Turnover}}{\text{Total Volume}} = \frac{\sum_n v_n p_n}{\sum_n v_n}$$

Since trades are being weighted according to their size, large trades have a greater impact on the VWAP than small ones. VWAP algorithms are based on historical volume profiles of the respective equity in the relevant market to estimate the intraday/target period volume patterns.

See Figure 6 for a graphical depiction of key first generation algorithms and their respective benchmarks.

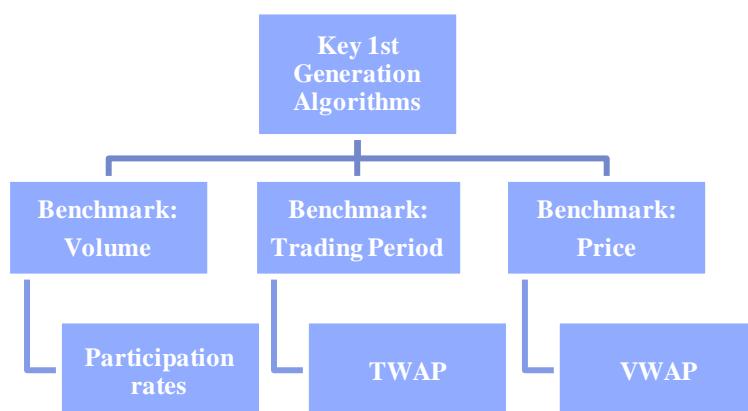


Figure 6: The first generation of execution algorithms

#### 4.1.3 Second Generation Execution Algorithms

The most prominent second generation algorithms try to minimize implementation shortfall. The current price/midpoint at the time of arrival of an order serves as a benchmark, which shall be met or outperformed (order based benchmark). Implementation shortfall algorithms<sup>23</sup> try to minimize the market impact of a large order taking into account potential negative price movements during the execution process (timing risk). To hedge against an adverse price trend, these algorithms predetermine an execution plan based on historical data, and split an order into as many as necessary but as few as possible sub orders.

In contrast to TWAP or VWAP, these orders will be scattered over a period which is just long enough to dampen the market impact of the overall order (Johnson 2010). Figure 7 shows the trade-off between minimizing market impact and timing risk.

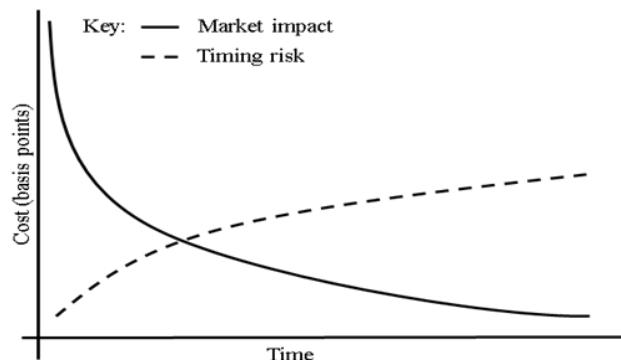


Figure 7: Market impact vs. timing risk. Based on: Johnson (2010)

#### 4.1.4 Third Generation Execution Algorithms

Adaptive algorithms form the third generation in Almgren's classification (Almgren 2009). These algorithms follow a more sophisticated approach than implementation shortfall algorithms. Instead of determining a pre-set schedule, these algorithms re-evaluate and adapt their execution schedule during the execution period, making them adaptive to changing market conditions and reflecting gains/losses in the execution period by a more/less aggressive execution schedule.

#### 4.1.5 Newsreader Algorithms

Investors have been relying on news to make their investment decisions ever since the first stock market opened its gates. Since then, traders who possess valuable information have been using it to generate profits. However, there is a limit to the quantity of data a human

<sup>23</sup> Deutsche Bank's Implementation Shortfall algorithm is one of many examples for this kind of Algorithmic Execution Strategy (Deutsche Bank 2009).

trader can analyze, and maybe even more important, the human nature of an investor/trader limits the speed with which he/she can read incoming news. This has led to the development of newsreader algorithms.

These automated newsreaders employ statistical methods as well as text-mining techniques to discern the likely impact of news announcements on the market. Newsreader algorithms rely on high-speed market data. Exchanges and news agencies have developed low latency news feeds, which provide algorithmic traders with electronically processable news.

## 4.2 High-Frequency Trading Strategies

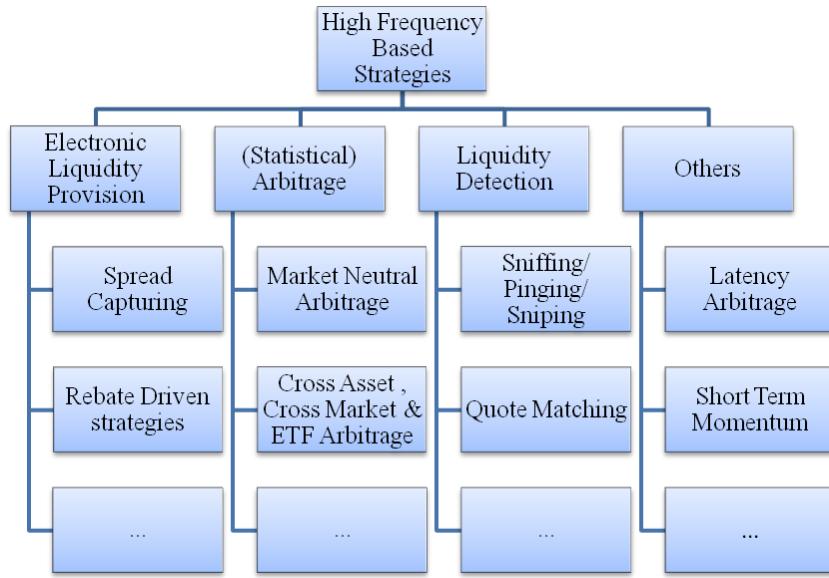
While consolidated information on the major players in HFT is still scarce, the community of market participants leveraging HFT technologies to implement their trading strategies is highly diverse. Its members range from broker-dealer operated proprietary trading firms and broker-dealer market making operations to specialized HFT boutiques to quantitative hedge funds leveraging HFT technology in order to increase the profits from their investment and trading strategies (see Easthope and Lee 2009). There is (i) a multitude of different institutions with different business models that use HFT and (ii) there are many hybrid forms, e.g. broker-dealers which run their proprietary trading books applying HFT techniques. Therefore, in the assessment of HFT it is very important to take a functional rather than an institutional perspective. In order to achieve a level playing field, all institutions that apply HFT based trading strategies have to be taken into consideration independent of whether HFT is their core or an add-on technology to implement trading strategies.

### 4.2.1 *The Scope of HFT Strategies*

While the universe of HFT strategies is too diverse and opaque to name them all, some of these strategies are well known and not necessarily new to the markets. The notion of HFT often relates to traditional trading strategies that use the possibilities provided by state-of-the-art IT. HFT is a means to employ specific trading strategies rather than a trading strategy in itself. Therefore, instead of trying to assess HFT as such, it is necessary to have a close look at the individual strategies that use HFT technologies (see Figure 8). The following subsections shed light on some of the best known and probably most prominent HFT based strategies.<sup>24</sup>

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<sup>24</sup> The classification of HFT strategies into liquidity provision, statistical arbitrage, and liquidity detection is based on (ASIC 2010a).

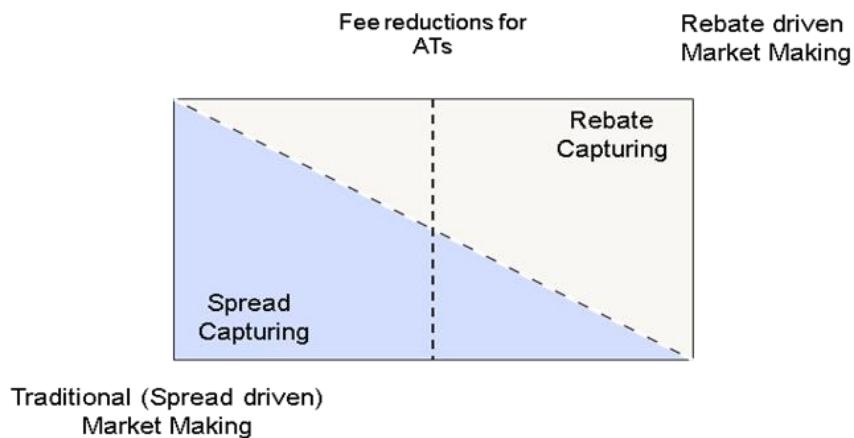


*Figure 8: Common high frequency based trading strategies*

#### 4.2.2 Electronic Liquidity Provision

One of the most common HFT strategies is to act as a liquidity provider. While many HFTs provide the market with liquidity like registered market makers, they frequently do not face formal obligations to quote in the markets in which they are active.

HFT liquidity providers have two basic sources of revenues: (i) They provide markets with liquidity and earn the spread between bid and ask limits and (ii) trading venues incentivize these liquidity providers by granting rebates or reduced transaction fees in order to increase market quality and attractiveness. Figure 9 depicts these different revenue sources for HFT electronic liquidity provision strategies.



*Figure 9: Revenue sources for high-frequency based liquidity provision strategies*

## **Spread Capturing**

A HFT strategy, which closely resembles its traditional counterpart, i.e. market making, is spread capturing. These liquidity providers profit from the spread between bid and ask prices by continuously buying and selling securities (ASIC 2010a). With each trade, these liquidity providers reap the spread between the (higher) price at which market participants can buy securities and the (lower) one at which they can sell securities.

## **Rebate Driven Strategies**

Other liquidity provision strategies are built around particular incentive schemes of some markets. In order to attract liquidity providers and react to increasing competition among markets, some trading venues have adopted asymmetric pricing: members removing liquidity from the market (taker; aggressive trading) are charged a higher fee while traders who submit liquidity to the market (maker; passive trading) are charged a lower fee or are even provided a rebate. An asymmetric fee structure is supposed to incentivize liquidity provision<sup>25</sup>. A market operator's rationale for applying maker-taker pricing is given by the following: traders supplying liquidity on both sides (buy and sell) of the order book earn their profits from the market spread. Fee reductions or even rebates for makers shall stimulate a market's liquidity by firstly attracting more traders to post passive order flow in form of limit orders. Secondly, those traders submitting limit orders shall be incentivized and enabled to quote more aggressively, thus narrowing the spread<sup>26</sup>. The respective loss of profits from doing so is supposed to be compensated by a rebate. If this holds true, those markets appear favorable over their rivals and market orders are attracted enhancing the probability for the makers to have their orders executed (Lutat 2010).<sup>27</sup>

Based on Chi-X's quarterly trading statistics in 2009 and the associated (maker-) rebate for visible execution of 0.2 basis points (bps), we estimate the total rebate paid to makers on Chi-X in 2009 to amount to €17.4 million (see Table 4).

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<sup>25</sup> See e.g. Gomber and Lutat (2007)

<sup>26</sup> In some cases, these rebates are used to subsidize the quotation of very tight spreads, making rebates the dominant source of profits for these traders (Iati et al. 2009).

<sup>27</sup> Some markets have adopted an inverse model of maker-taker pricing where liquidity takers receive a rebate, while the providers of liquidity are charged a fee, see for example: CBSX (2010).

Turnover on Chi-X (from Trading Statistics)	
Q1 2009	148.919.627.926
Q2 2009	209.530.354.507
Q3 2009	233.862.287.802
Q4 2009	277.448.834.535
Total turnover 2009	869.761.104.770
Rebate for passive execution	0.2 bps
Rebates on Chi-X	17.395.222,10

Table 4: Turnover and rebates on Chi-X<sup>28</sup>

These figures are small when compared to e.g. Nasdaq, where the maker rebates paid in 2009 were close to \$1.4 billion (Nasdaq OMX 2010). The magnitude of the difference between the rebates on those two marketplaces can be attributed to turnover on the respective venues and respective fee schedules<sup>29</sup>. In a recent report, Gomber et al. (2011a) state that the 2010 mean relative spread in a sample of EURO STOXX shares amounts to 8.31 bps, making spread capturing a much larger potential source of revenues than rebates.

#### 4.2.3 (Statistical) Arbitrage

Opportunities to conduct arbitrage strategies frequently exist only for very brief periods (fractions of a second). Since computers are able to scan the markets for such short-lived possibilities, arbitrage has become a major strategy applied by HFTs. These HFTs conduct arbitrage in the same way as their traditional counterparts; they leverage state of the art technology to profit from small and short-lived discrepancies between securities. The following types of arbitrage are not limited to HFT, but are conducted by non-automated market participants as well. Since arbitrageurs react on existing inefficiencies, they are mainly takers of liquidity.

#### Market Neutral Arbitrage

This form of statistical arbitrage aims to be “market neutral”. Arbitrageurs try to hold instruments while simultaneously shorting other instruments. Since the instruments are closely correlated, gains and losses due to movements of the general market will (mostly) offset each other. However, in order to gain from this strategy, arbitrageurs sell an instrument which they deem to have a relatively lower intrinsic value, while simultaneously buying an instrument, which reacts very similar (ideally identical) to changes in the market environment and which they deem to have a relatively higher intrinsic value. If the

<sup>28</sup> Sources: Chi-X® Europe Trading Statistics – Q1, Q2, Q3, Q4 2009

<sup>29</sup> Maker-rebates on Chi-X are paid on a volume basis, while those for stocks on Nasdaq are paid on a per-share basis.

respective valuation of these instruments “normalizes” into the expected direction, the arbitrageur liquidates its market neutral position. Gains from this strategy result from the difference between the individual valuation of the assets at the time the position is opened and their “normalized” prices at the time the position is liquidated. Since this strategy offers protection against market movements, it is highly attractive for HFTs and traditional arbitrageurs alike. (Aldridge 2010)

### **Cross Asset, Cross Market & Exchange Traded Fund (ETF) Arbitrage**

An established arbitrage strategy is to trade instruments across markets or to trade related instruments and to profit from pricing inefficiencies across markets: if an asset shows differing prices across marketplaces, arbitrageurs generate profits by selling the asset on the market where it is valued higher and simultaneously buying it on another market where it is valued lower.<sup>30</sup> Cross market arbitrage strategies have profited from the increased market fragmentation in Europe as described in section two. A higher number of markets increases the probability that an instrument has different prices across these markets. Similarly, arbitrageurs can profit from inefficiencies across assets: if, e.g. an option is priced too high relative to its underlying; arbitrageurs can earn profits by selling the option and simultaneously buying the underlying. In a similar way, ETF arbitrageurs trade ETFs against their underlying and profit from respective pricing inefficiencies. Since such inefficiencies exist only shortly on modern securities markets, HFTs leverage their speed advantage to trade against them (see Aldridge 2010 for more information).

#### *4.2.4 Liquidity Detection*

Another category of HFT strategies is liquidity detection. These HFTs try to discern the patterns other market participants leave in the markets and adjust their actions accordingly. Liquidity detectors focus their attention on large orders and employ various strategies to detect sliced orders<sup>31</sup>, hidden orders, orders being submitted by execution algorithms or to gain further information about electronic limit order books (ASIC 2010a). Liquidity detectors gathering information about algorithmic traders are frequently referred to as

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<sup>30</sup> To earn profits the difference between the ask price and the bid price needs to exceed twice the transaction fees.

<sup>31</sup> AFM (2010) describes related strategies in the following way: “*Order anticipation strategies: a trader looks for the existence of large (for example) buyers, in the objective of buying before these orders, in order to benefit from their impact.*”

“sniffing out” other algorithms. Other detectors “ping” or “snipe” in order books or dark pools to retrieve information from them (see e.g. ASIC 2010a).<sup>32</sup>

Another possible way to use HFT technology would be a high speed version of the “quote matching” strategy described by Harris (2003). Using this strategy, a trader who has detected a large order within the order book places his own order ahead of the large order. If he has detected for example a large buy order, he places his own buy order at a slightly higher limit. Should prices now move upwards, he profits from the rise. However, should prices fall, the large order resting in the book serves as an option/hedge against which the trader can sell his own shares, thereby limiting his possible losses as long as the large limit order rests within the book.

#### 4.2.5 *Other High-Frequency Trading Strategies*

##### **Latency Arbitrage**

Some market participants accuse HFTs of conducting a form of arbitrage which is purely based on their faster access to market data. This modern form of arbitrage, where HFTs are said to be able to see (and interpret) new market information before many market participants even receive it, is frequently referred to as latency arbitrage. These latency arbitrageurs leverage direct data feeds and co-located infrastructure to minimize their reaction times. Especially in the U.S., where many market participants rely on the “national best bid and offer” (NBBO)<sup>33</sup>, latency arbitrageurs are said to be able to profit from their speed advantage in comparison to the NBBO (see e.g. Gaffen 2009).<sup>34</sup> Since actions of these

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<sup>32</sup> In case of the U.S. and its consolidated tape system, such algorithms are frequently referred to as “sniffing the tape”.

<sup>33</sup> The NBBO is determined as the nationwide best available bid or ask price for a security using consolidated data from U.S. marketplaces (see section 6.1 for more information on the NBBO).

<sup>34</sup> Among the most prominent critics of this form of arbitrage is Themis Trading, who have provided their critical view on several aspects of HFT in a number of white papers. They describe these arbitrageurs as market participants, who are able to know that an order will move the NBBO into a certain direction, before this fact is reflected by the NBBO (because it takes time to discern the NBBO). Based on this knowledge, they trade against any existing liquidity at the (stale) price which is still being displayed and offer these securities to the trader who initially caused the move in the NBBO. To profit from this, the arbitrageurs will offer the securities at a higher price, in case of an incoming buy order, or respectively at a lower price in case of an incoming sell order (Arnuk and Saluzzi 2009).

This argumentation is directly contradicted by Tradeworx, who explains that it is not possible to trade ahead of existing orders based on latency alone. The fact, that the NBBO may not instantaneously reflect an order has nothing to do with its priority in the order book, but rather with the latency of the systems which discern it. Therefore, even if a HFT would know that an order is going to move the NBBO into a certain direction, there will be no liquidity left to trade against, since the respective orders are already in the book, but are not reflected by the NBBO (Narang 2010).

However, Tradeworx explains that U.S. broker/dealer HFTs can leverage direct data feeds and profit from the latency of the NBBO system by using a special type of order, the “intermarket

market participants are said to impair the prices at which other traders (e.g. buy side execution algorithms) are able to trade, they are often called “predatory”.

While it is not possible for the authors to assess the actual effect of latency arbitrage on securities markets or the magnitude at which this strategy is conducted, it seems that the discussion described above is currently limited to the U.S. and its NBBO. Therefore, at least those forms which are built around this distinctive feature of the U.S. market system are not applicable in European markets, where no (statutory) NBBO exists.<sup>35</sup>

### **Short-Term Momentum Strategies**

Market participants leveraging HFT technologies to conduct short-term momentum strategies are a modern equivalent to classical day traders. In contrast to many other HFT based strategies they are neither focused on providing the market with liquidity, nor are they targeting market inefficiencies. They usually trade aggressively (taking liquidity) and aim at earning profits from market movements/trends. Their trading decisions can be based on events influencing securities markets and/or the movements of the markets themselves. Momentum based trading strategies are not new and have been implemented by traditional traders for a long time.<sup>36</sup>

#### *4.2.6 Summary of Algorithmic and High-Frequency Trading Strategies*

HFT is not a trading strategy as such but describes the usage of sophisticated technology that implements traditional trading strategies. The individual trading strategies need to be assessed rather than HFT as such. It is diametric to market efficiency if regulation would prohibit or even limit HFT strategies that contribute to market liquidity and to the efficiency of the price formation process. Electronic liquidity provision strategies based on HFT rely

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sweep order (ISO)”. NYSE defines this order type as: “*A limit order designated for automatic execution in a specific market center even when another market center is publishing a better quotation. When sending an intermarket sweep order, the sender fulfills Reg NMS order-protection obligations and NYSE Rules by concurrently sending orders to market centers with better prices. These orders are not subject to auto-routing and must be marked with a trade indicator of ‘F’.*” (NYSE 2006)

ISOs allow these market participants to send orders directly to marketplaces while they appear to be locked due to the latency of the respective consolidated data feeds. Tradeworx explains that this may lead to a violation of time priority, since ISOs may directly be executed, while “normal” orders are not directly executed because they would appear to “lock the market” (a “locked market” describes a situation, where bid and ask price for a given security are equal, i.e. there is no spread. Rule 611 Reg NMS prohibits these situations). Tradeworx asks the U.S. regulators to lift the current ban on “locked markets” (Narang 2010).

<sup>35</sup> For more information on the European and U.S. market systems see section 6.1

<sup>36</sup> One needs to distinguish them from the similarly named “momentum ignition” strategies, where market participants deliberately try to induce market movements in order to profit from them. Such strategies are potentially abusive and are currently under investigation by regulatory bodies (see e.g. SEC 2010a).

on lowest latency thereby enabling them to minimize risk in quotation and to quote tight spreads. As arbitrageurs, they exploit extremely short-lived price inefficiencies. Both strategies have become more relevant due to the increased fragmentation triggered by MiFID in Europe<sup>37</sup>. However, it has to be assured that any strategies that have a negative impact on market integrity and that enable for market abuse are thoroughly investigated. This is especially important if HFT as a technology eases the implementation of these strategies, makes them more profitable or creates an uneven and unfair playing field among market participants. Since market abuse is not limited to a particular subset of traders, all market participants should be investigated when applying such strategies.

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<sup>37</sup> Although it is hardly possible to isolate the different effects like increase in AT/HFT and the effect of fragmentation/competition, the fact that market quality in terms of available market liquidity in Europe has increased between pre-MIFID and post-MiFID periods in spite of the financial crisis in Europe (Gomber et al. 2011b) signals that the usage of these strategies tends to be positive for European market quality.

## 5 Systematic Analysis of Academic Literature

HFT is attracting more and more attention not only among practitioners but also in the academic community. However, research that examines HFT explicitly is still rare. Especially the flash crash brought HFT to the attention of regulators, the public and academic literature. Thus, research papers presented here are often very new and are partly working papers still waiting to be published.

The most prominent questions regarding HFT can be summed up to: “Is high-frequency trading beneficial or harmful to the economy?” Research papers in this context focus mainly on market quality parameters, such as liquidity, volatility or informativeness of prices. Other issues treated in academic research with respect to HFT are profitability of HFT and fairness (especially fair access). The following subsection will present recent studies on market quality, which are extraordinary in quality or focus on specific aspects. The two subsections thereafter cover fairness and market penetration respectively. Also, the overall tendency of research papers with respect to market quality will be summarized in the last subsection.

### 5.1 Market Quality

The first theoretical model to address the impact of HFT on market quality can be found in Cvitanic and Kirilenko (2010). They model an electronic market populated by low-frequency traders (humans) and then add a high frequency trader (machine). It is important to note that the high frequency trader is modeled as an uninformed trader, following the classical notion that a market maker does not possess any superior information. In the model, the only advantage of the machine is the speed at which it can submit and cancel orders. Cvitanic and Kirilenko (2010) find that the presence of the high frequency trader is likely to change the average transaction price and the distribution of transaction prices as a whole. Particularly, they show that the transaction prices are more concentrated around the mean (i.e. have lower volatility) and they find an improvement of forecastability of transaction prices. Secondly, according to their model, trading volume and intertrade duration, i.e. the time span between two trades, should increase in direct proportion to the share of humans that change the speed of their orders in the presence of the machine. This implicates an increase in market liquidity measures based on trading volume and intertrade duration.

Most academic literature, especially empirical studies, confirms these results. Jarnecic and Snape (2010) use data from the LSE that consolidates high frequency participants. Due to

their data set, they have access to member categorization that allows them to examine the activity of a group of high-frequency participants directly. Each member is classified into one of six categories. The six categories are high-frequency participants, traditional market makers, three types of institutional members (i.e. small, large and investment banks) and retail brokers. The results of this paper suggest that HFTs are more likely to smooth out liquidity over time and are unlikely to exacerbate volatility.

A somewhat different understanding concerning the information asymmetry between HFT and other traders can be found in the paper “Middleman in Limit Order Markets” by Jovanovic and Menkveld (2010). It consists of two parts, a theoretical model and an empirical analysis. In this paper, the term middleman refers to high frequency traders who simply profit from buying and selling securities. In contrast to classical models, e.g. Glosten and Milgrom (1985), Kyle (1985), Foucault et al. (2003), middlemen are not uninformed. The empirical part consists of an event study: the start of trading Dutch index stocks at Chi-X, on April 16, 2007. The first 77 trading days of 2007 and 2008 are compared to study a “treatment effect” since the advent of middlemen by exploiting the introduction of an HFT-friendly trading venue (in this case: Chi-X) as an instrument. Indeed, the authors find evidence that middlemen are better informed about recent news than the average investor, i.e., their reaction times are faster and their trading decisions are in the right direction. Concerning the main question of the contribution of HFT to welfare, the results are mixed. In the theoretical model, a pre-existing adverse selection problem can be solved by middlemen, but on the contrary, middlemen can also create or exacerbate an existing adverse selection problem. This can then lead to either more trading and more narrow spreads (increasing welfare up to 30%) but can also cause a rise of bid-ask spreads and a decline of the number of trades in the latter case.

The comparison of these insights with the results of Cvitanic and Kirilenko (2010) shows how different assumptions in theoretical models (e.g. if high frequency traders are regarded as uninformed or not) may influence the outcome of the analysis. The somewhat critical results of Jovanovic and Menkveld (2010) are rather scarce in the available literature on HFT. The majority of papers that examine the effects of HFT or AT are empirical studies and find positive results for market quality parameters such as increasing liquidity and lower short term volatility. Examples of those are: Jarnebic and Snape (2010), Brogaard (2010), Hasbrouck and Saar (2010) and Groth (2011).

Brogaard (2010) states in his paper:

*"I find that HFTs' supply of liquidity is mixed. They are frequently at the inside bid and offer, yet the depth of liquidity they provide on the order book is much less than that provided by non-HFTs. In addition, HFTs are strategic with their liquidity provisions and tend to avoid trading with informed traders. Finally, I find evidence that suggests HFT dampens intraday volatility. Overall, the results in this paper suggest that HFTs' activities are not detrimental to non-HFTs and that HFT tends to improve market quality."*

As these examples show, most scientific papers<sup>38</sup> do not find any evidence that automated trading has a negative effect on market quality. Studies that examined the effect of AT, such as Hendershott et al. (2011) and Groth (2011), rather found positive effects on market quality. Hendershott et al. (2011) in their empirical study on NYSE stocks state that:

*"For large stocks in particular, algorithmic trading narrows spreads by reducing adverse selection and increasing the amount of information in quotes as compared to trades. These indicate that algorithmic trading does causally improve liquidity and enhances the informativeness of quotes and prices."*

Taking a closer look at volatility, Groth (2011) "...provide[s] strong evidence that algorithmic trading does not exceedingly increase volatility".

Out of eight research papers dealing with HFT, only Menkveld suggests that HFT might have negative effects on market quality under special circumstances and Kirilenko et al. (2010) find evidence that HFT increased short-term volatility in their study on the flash crash.<sup>39</sup> The clear majority of the studies find evidence that HFT increases market quality.

The interested reader who wants to study the papers in more detail will find a list of available research papers on HFT and AT in Appendix IV, which includes a short description of the research question, the applied methodology and the results of the papers.

## 5.2 Fairness and Co-location

As mentioned before, the discussion about HFT is closely related to the issue of fairness. This is due to the fact that high frequency traders need low latency access, which gives them a speed advantage compared to other traders. This private advantage of preferred access is

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<sup>38</sup> It should be noted that all empirical papers mentioned here both concerning AT or HFT are based on data of lit markets. Concerning automated trading in the OTC space (e.g. in internalization or crossing systems), empirical papers are not existent due to a lack of data.

<sup>39</sup> See section 6.2.5 for more information on the flash crash

neither new nor introduced by the occurrence of HFT. Hasbrouck and Saar (2010) admit that co-located traders have a significant timing advantage and that floor traders had a timing advantage over off-floor traders in the same manner.

They also state that the economic advantage for the trader is hard to quantify. It is small when thinking only about volatility, but it can be relevant under certain circumstances:

*“What is the real economic cost of a delay? It depends on both the risk borne over the delay duration and the effects on participants’ strategies. (...) If the daily volatility is unconditionally distributed evenly over the 6.5 hour trading day, then the volatility over 10 ms is a negligible 0.2 basis points.*

*The importance of delay for strategic interactions, however, might be much greater. Suppose that the daily volatility is generated by a single randomly-timed announcement that causes the value to change (equiprobably) by  $\pm 3\%$ . This 3% can be captured by a first-mover who observes the announcement and takes a long or short position against others yet unaware, irrespective of whether his absolute time advantage is one minute or one microsecond.”*

Usually, HFT gain their speed advantage by a proximity or co-location service<sup>40</sup>. Although this kind of preferred access is controversial, Hasbrouck and Saar (2010) correctly state that the problem of fairness is more complex. The authors point out that, on the one hand, the SEC forbids firms to release fundamental information to a subset of investors but, on the other hand, it allows market centers to sell data feeds directly to certain subscribers, thus creating a tiered system of investors.

More concrete suggestions on co-location are given by Jovanovic and Menkveld (2010) in their comment:

*“Our evidence on the welfare contribution of middlemen is mixed. On the one hand, middlemen’s participation lowers bid-ask spreads but, on the other, it also lowers volume. The net effect is uncertain. Our theoretical analysis and the mixed evidence on welfare suggest that there is room for optimal market design...the speed privilege that HFTs can buy into, co-location, might require a differentiated order-fee schedule. Passive orders submitted through this pipe might optimally be rewarded more whereas aggressive orders might have to be charged more. The reason is that passive orders come with the positive externality of liquidity supply to others*

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<sup>40</sup> “The HFT firms use sophisticated trading tools such as high-powered analytics and computing co-location services to reduce latency.” (Brogard 2010).

*whereas aggressive orders have a negative externality of creating adverse selection for non-co-located participants.”*

This quote typically shows how interwoven the topic of HFT is with other aspects of trading such as a pricing scheme.

Ende et al. (2011) find that the latency effects are negligible for retail investors individually as their trading frequency is low and costs arising from latency disadvantages are small. In line with Hasbrouck and Saar (2010), they argue that for all others the amount as to which they are negatively affected by being slower than others is highly dependent on the strategy applied.

Overall, it can be stated that research papers address fairness issues only theoretically but hardly list the exact terms for co-location, i.e. possible number of accesses, number of participants, pricing schemes etc. This might indicate that there is a lack of transparency, which prevents comparison of access conditions between marketplaces. However, researchers agree that speed advantage is both recognizable and may well yield a competitive advantage.

### **5.3 Market Penetration and Profitability**

In Brogaard's (2010) unique data set from Nasdaq where a group of HFTs is identifiable, HFT was involved in 68% of the dollar trade volume. He estimates HFT's gross return to be approximately \$2.8 billion annually and obtaining a Sharpe ratio of 4.5.

Lower numbers regarding the participation of HFT from the LSE are reported by Jarnebic and Snape (2010). In their sample “*high frequency participants [participate] in between 20% and 32% of total trades and 19% and 28% of total volume, depending on the size of the stock. When computed as the absolute number of trades in which high frequency participants are involved on either side of the trade (i.e. not double counting trades and volume), this percentage rises to between 40% and 64%.*”

A study by Kearns et al. (2010) aims at giving an upper bound on the profitability of HFT. Though the study has its weaknesses, e.g. it only covers aggressive (marketable) order placement, the results seem to be in line with the estimation by Brogaard (2010). For an omniscient trader, i.e. a trader who knows the development of prices in advance, they estimate a possible profit of \$3.4 billion in 2008. This is regarded as an upper bound for HFT and the authors argue that this is a huge overestimation, mainly because they do not consider trading fees, adverse price movement or other profit reducing factors.

A slightly lower estimation of \$2 billion annually is coming from a high-frequent trader Tradeworx (2010a) in its comment to the “SEC Concept Release on Equity Market Structure”. Their calculation is based on a market share of 40%.

As HFT generates a significant part of trading volumes, it has drawn the attention of both regulatory authorities and the public. The debate in academic research however, deviates from ongoing discussions in regulatory documents and in media. The size of HFT and its market penetration surely represents an important reason to conduct further research, especially to clarify whether and to what extend systemic risk is implied. But increasing market shares as such should not be the basis to justify regulatory intervention.

#### **5.4 Summary of Academic Literature Review**

Most academic studies on HFT examine the effects on market quality. The majority of these papers is empirical and concludes that there is no evidence for negative effects. Concerning the most important parameters, liquidity and volatility, most studies discover positive effects of HFT.

Quite a few studies note that a missing obligation to deliver quotes might cause the risk of a sudden liquidity withdrawal, but empirical evidence for this is not given in any research paper. The results of Kirilenko et al. (2011) make it doubtful that obligations are helpful in times of market stress, as the described “hot potato” effect (rapid decline or increase of prices in a series of trades between HFTs) could still occur. Thus, the recommendation of the authors is different: *“However, as markets change, appropriate safeguards must be implemented to keep pace with trading practices enabled by advances in technology.”*

With regard to fairness, to the best knowledge of the authors, no academic study could be found that provides evidence that HFT is applying unfair or illegal strategies. The debate about co-location is rather about fair access than about assumed negative effects of faster trading. In this respect, it must not be seen as a resemblance of a specific problem of HFT. It has been and will be the task of regulators, venues and traders to agree on rules in order to ensure a level playing field providing non-discriminatory access to co-location and proximity services<sup>41</sup>.

The importance of HFT for today’s electronic markets is undisputed in academic research. Especially in the U.S., HFT can be assumed to roughly have a share of half to two thirds of

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<sup>41</sup> In the European context, FESE (the Federation of European Securities Exchanges) has pointed out, that: *“Most RMs and MTFs which offer co-location services already provide a transparent and non discriminatory service which is available to any member wishing to use it and have the commercial business case to do so.”* (FESE 2011)

all trading volume at major marketplaces. Thus, it is not pretentious to state that HFT has become a highly relevant source of market liquidity.

## **6 Status of High-Frequency Trading Regulation and Regulatory Discussion**

HFT has become a highly relevant and intensively discussed issue for market participants, market operators and regulatory bodies on both sides of the Atlantic. With HFT being a relatively new phenomenon in securities markets, regulators strive to collect information in order to decide on potentially new provisions which might become necessary if HFT proves to present a risk to capital market quality or integrity.

This subsection provides insights on ongoing discussions and initiatives related to HFT and its accompanying technological innovations (e.g. proximity services and market access models). Basic differences between U.S. and European market systems will be clarified first, followed by a presentation of current regulatory discussions. A summary and discussion of the regulatory status as well as proposals for tackling the major issues will close the section.

### **6.1 Differences between the U.S. and the European Market System**

Two key features differentiate the U.S. market system from the European set-up:

- The U.S. Regulation National Market System (Reg NMS) codified the national best bid best offer (NBBO).<sup>42</sup> To calculate the NBBO, marketplaces are obliged to distribute their best bid and best offer for securities they are listing to a securities information processor (SIP). The processor aggregates the quotes coming from marketplaces and ascertains the nationwide best bid and offer in a given security as the NBBO. This system has been implemented to enable market participants to trade on the best available prices in the U.S.
- To guarantee that trades are always executed at the best available price, rule 611 Reg NMS implemented the trade-through rule<sup>43</sup>, which bars marketplaces from trading at prices that are worse for their customers than the NBBO (SEC 2005). If a marketplace is not able to match an incoming order at the NBBO or a better price, it is forced to route the order to the trading venue that is currently offering the best price (which requires inter-linkage of all markets) or cancel the order instead of routing it away.<sup>44</sup>

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<sup>42</sup>The NBBO is defined as the U.S. wide best available ask price for customers who want to buy securities and the best bid price for those who want to sell securities.

<sup>43</sup>Also known as “order protection rule”.

<sup>44</sup>Marketplaces are only forced to route orders away if the better price is offered on a *fast market*. Since floor based markets cannot match the execution speed of electronic markets and are

The necessity to execute incoming orders at the NBBO or better prices changed the landscape of the U.S. market system. Since the relevant price is now the most important factor when determining where a given trade is executed, new marketplaces displaying aggressive quotes can attract orders from other exchanges.

In Europe, MiFID introduced a principles-based best execution regime compared to the rules-based U.S. approach. Instead of establishing a pan-European best price like the NBBO, MiFID requires investment firms to: “*[...] take all reasonable steps to obtain, when executing orders, the best possible result for their clients taking into account price, costs, speed, likelihood of execution and settlement, size, nature or any other consideration relevant to the execution of the order.*” (European Commission 2004). The second key difference is the fact that best execution is an obligation relating to investment firms in Europe while it is “outsourced” to the market venues in the U.S. However, the actual implementation of best execution is not codified in Europe. Therefore, there are two basic ways for financial institutions to implement this obligation. The first one would be to implement best execution as a process, i.e. to establish an order execution system which routes orders to execution venues that have proven to provide best execution results on a consistent basis. The second way would be to determine the best execution venue on an order by order basis. This approach – that goes beyond the minimum regulatory requirements of MiFID – relies on access to real-time market data to determine where to route and execute an incoming order to provide customers with the best possible execution results on a trade by trade basis (Gomber et al. 2009). However, SOR comes at a cost and is not yet available to all market participants.

Both, MiFID and Reg NMS made it easier for new marketplaces to compete with established exchanges. This had the intended effect of improving fee and service competition among trading venues.

## **6.2 Regulatory Initiatives Concerning High-Frequency Trading in the U.S.**

In the following, regulatory initiatives in the U.S. are described: first, general HFT related topics, which are currently under the scrutiny of the U.S. regulatory bodies, will be discussed and thereafter the flash crash and regulatory topics directly resulting from this incident will be presented.

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therefore unlikely to qualify as fast markets, they implemented electronic trading systems to prevent a loss of order flow (Gomber et al. 2009).

### 6.2.1 Naked/Unfiltered Sponsored Access

Market members in the U.S. have offered their customers a special kind of sponsored access.<sup>45</sup> This so-called naked or unfiltered (sponsored) access offers traders the opportunity to route orders to markets using the market participant identifier (MPID) of their sponsoring broker. In contrast to other forms of sponsored access, naked access arrangements allow traders to access markets without associated pre-trade risk checks. Naked access arrangements without associated pre-trade risk checks can help to reduce latency (SEC 2010b). Therefore, naked access is of specific relevance for HFTs that are not direct members of the respective market. Risk checks are only possible using drop-copies of submitted orders. However, erroneous orders may have been executed before the sponsoring participant is able to react to them.

Many market participants acknowledge that these arrangements could expose financial markets to undue risks.<sup>46</sup> In the wake of these concerns, the SEC issued a de facto ban on naked access in November 2010 by obligating brokers “[...]to put in place risk management controls and supervisory procedures to help prevent erroneous orders, ensure compliance with regulatory requirements, and enforce pre-set credit or capital thresholds.” (SEC 2010c)

Such a step to implement mandatory risk checks in the order routing system clearly helps to mitigate systemic risk in U.S. markets.

Corresponding risk management processes have to be under direct and exclusive control of the respective broker. Banning naked access arrangements has been met with widespread acceptance from U.S. market participants. Objections were voiced in cases where brokers offer market access to other brokers. Therefore, an exception from the rule permits brokers to allocate risk management and supervisory processes to a sponsored customer if the customer is (i) a registered broker-dealer and (ii) if the customer can implement such processes more effectively (SEC 2010b).

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<sup>45</sup> See section 2.2 for more information on sponsored access.

<sup>46</sup> See for example Marques (2010)

Pre-trade risk checks are especially important in an AT/HFT context, where traders are able to issue a very high number of orders in a short period of time. In an exemplary calculation, the SEC shows that a malfunctioning algorithm could place more than 120,000 orders within a two minute interval. Assuming that each order covers 300 shares and that the average price per share amounts to \$20, such an algorithm could theoretically build a position worth \$720 million within this time frame (SEC 2010b).

### 6.2.2 Flash Orders

Based on an exception from the trade through rule which forces U.S. marketplaces to route incoming orders to other marketplaces if they are not able to match them at the NBBO, some marketplaces have implemented “flash orders”.<sup>47</sup> A flash order is a special kind of order, which market participants can choose as order type (see Figure 10 for a depiction of the basic mechanism of flash orders). If the flash order cannot be executed against available liquidity at the marketplace where it is issued, it is “flashed” within this market instead of directly being routed away. For the duration of the flash (usually measured in milliseconds) a marketable order is displayed within the marketplace at the national best bid or offer. If a market participant steps up and executes against a flashed order, it is not routed to the marketplace currently offering the best execution price.

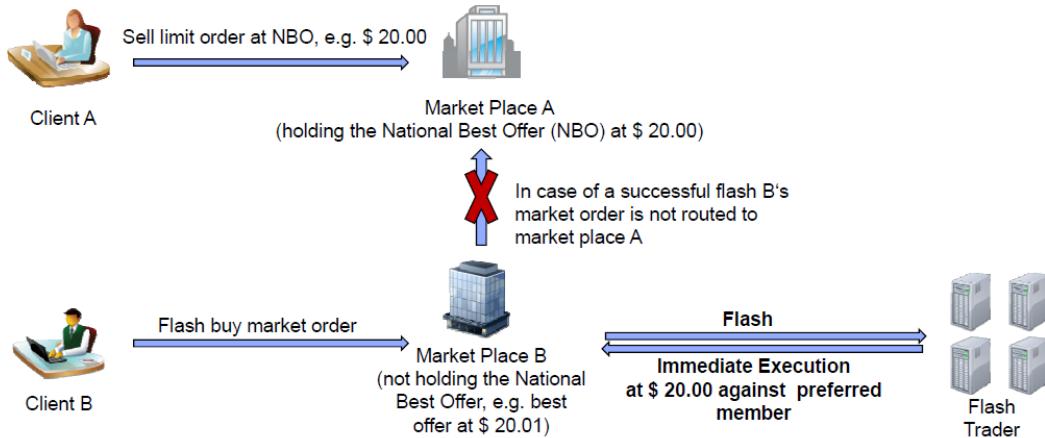


Figure 10: Principle of flash order trading

Flash orders effectively convert marketable orders into a limit order at the NBBO. Since these flashes last only fractions of a second, only HFTs or similar low latency market participants are able to react to them. This fact spawned a variety of complaints about the fairness of this type of order. However, market participants are still at odds on the effects these orders have on markets. Some state that flash orders have the potential to create a two tiered market, impair the price discovery process, or undermine reliability of the U.S. consolidated tape (see e.g. Kaufman 2009 or Leibowitz 2009), supporting the fairness concerns mentioned above. Moreover, the usage of flash orders may disincentivize liquidity provision by limit orders since limit orders are less likely to be executed against orders being routed from another market if the remote market uses flash orders. As depicted in

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<sup>47</sup> The usage of these orders is known as “flash trading”. Despite the similar name, flash trading and the flash crash are different phenomena within the U.S. securities markets.

Figure 10, such a situation occurs for client A, whose order is not executed. These concerns lead to a proposed ban on flash orders (SEC 2009).

Some respondents to the SEC proposal attribute to flash orders various positive effects in options markets, including an increase in available liquidity and the possibility for price improvements (see e.g. Brodsky 2010). To assess the specific role of these orders in options markets and to gather further information, the SEC has issued a second call for comments on flash orders (SEC 2010d).

#### 6.2.3 *Co-location/Proximity Hosting Services*

In June 2010, the Commodity Futures Trading Commission (CFTC) proposed a rule which is intended to assure equal and fair access to co-location/proximity hosting services. The CFTC argues that these services offer a significant competitive advantage for high frequency traders and therefore have to be equitably accessible. To ensure fair and open access for all traders, the regulator proposes that marketplaces and third parties listing significant price discovery contracts (SPDCs) should implement uniform fees for co-location and associated services.<sup>48</sup> In this context, it states that any kind of privileged pricing for specific market participants or classes of participants would not be regarded as equitable pricing. Furthermore, the CFTC wants to increase the “latency transparency” and therefore proposes to make the disclosure of latency information mandatory. Markets would for example have to disclose their longest, shortest and average latencies. This latency information would have to be updated regularly. Moreover, the regulator’s intention is to secure that sufficient co-location space is available and to ensure that shortages in co-location space can not impair fair access (CFTC 2010).

While the proposed steps would help to improve fairness of access to, and transparency of co-location services, some respondents to this proposal rose organizational concerns about its implementation (see e.g. Knuff 2010).

#### 6.2.4 *Large Trader Reporting System*

In a step to increase regulatory ability to analyze the activity of important traders, the SEC proposed the implementation of a “large trader reporting system”. This system is designed to “[...] identify large traders and collect trading data on their activity at a time when, for example, many such traders employ rapid algorithmic systems that quote and trade in huge volumes.” (SEC 2010e)

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<sup>48</sup> “SPDCs [Significant Price Discovery Contracts] are contracts that are linked to existing exchange-traded contracts; are traded on an electronic exchange; and perform a "significant price discovery function".”(Bracewell and Giuliani, 2009).

Market participants would have to identify themselves as large traders according to the proposal if they meet at least one of the following criteria:

- a) They trade at least two million shares or shares equivalent to \$20 million during one day.
- b) They trade at least twenty million shares or shares equivalent to \$200 million during one month.

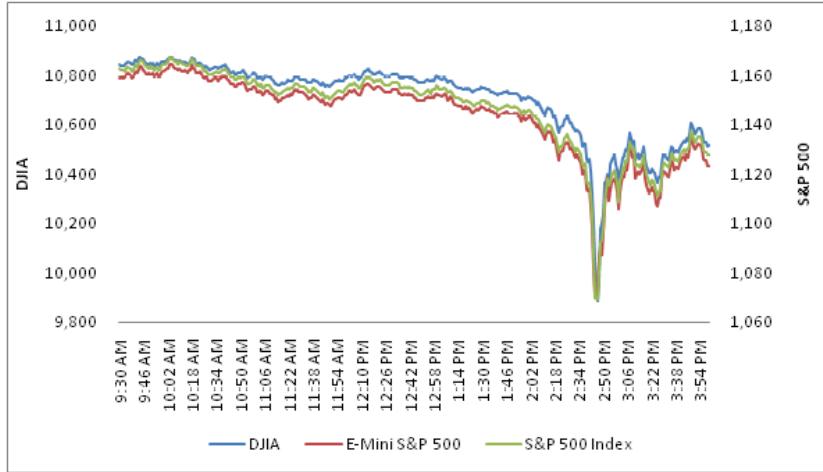
Large traders would receive a large trader identification number (LTID) which they will have to provide to their respective broker-dealers. Using these identification numbers, the SEC's capability to identify and monitor important market participants would be improved. The respective broker-dealers will have to store all relevant data including the LTID based on the already existing *Electronic Blue Sheet System*. They will have to provide this data to the regulator upon request on the morning following a transaction. Moreover, brokers will have to monitor whether their customers comply with this rule (SEC 2010f).

This proposal to increase regulatory ability to monitor the behavior of market participants (including HFTs) is supplemented by the proposed “*consolidated audit trail system*” (see below).

#### 6.2.5 *The Flash Crash and Resulting Regulation*

In their combined report, (CFTC & SEC 2010a) describe potential reasons for the extreme market movements on May 6, 2010 which have become known as the “*flash crash*”. While a detailed description of the flash crash is beyond the scope of this paper, some key points relevant for HFT regulation are described below.

During less than half an hour on May 6, 2010, the Dow Jones Industrial Index (DJIA) and other indices experienced a sharp drop followed by an immediate recovery of a significant part of these losses (see Figure 11).



*Figure 11: Selected equity indices and equity index futures, May 6, 2010  
(CFTC & SEC 2010b)*

At the end of the day, the DJIA closed with a loss of 3.20 percent. In the aftermath of this crash, which hit other securities like exchange traded funds and futures as well, market participants were fast to accuse high frequency traders for it. However, while it seems that their behavior may have contributed to the crash, they are not responsible for it (Kirilenko et al. 2010). Rather, specific characteristics within the U.S. market structure and their interdependencies were the main drivers of the crash.

“*Existing market-wide circuit breakers*” (CFTC & SEC 2010a), which would have halted trading on U.S. markets were not triggered during these events, while individual safety measures to slow down trading and/or aggregate available liquidity at specific markets were triggered. However, these measures were not coordinated among the markets. Following the events of May 6, 2010, four regulatory initiatives were triggered:

#### *i. Circuit Breaker*

U.S. regulators have introduced a pilot program which implements automated circuit breakers for individual securities. They halt trading in certain important securities as soon as their respective price changes by 10% or more within five minutes. These circuit breakers are nationwide and halt trading in individually affected securities on all U.S. markets for a period of five minutes (SEC 2010g)

#### *ii. Erroneous Trades*

Another issue during the crash arose from unclear regulation concerning the annulment of erroneous trades. In order to provide U.S. markets with a clearer definition of when and

under which conditions trades may be broken in the future, the SEC proposed more precise rules for clearly erroneous trades (SEC 2010h). This shall lead to more confidence in executions when trading in volatile situations.

*iii. Stub Quotes*

Some of the worst executions during the crash were a direct result of market makers quoting far away from the current price (i.e. at \$0.01 or \$100.000). Such quotes are called *stub quotes*. Market makers use them to comply with existing quotation obligations; however, they do not have any intention for these quotes to be executed. Yet, the sudden loss of liquidity due to registered and non-registered market makers withdrawing their quotes during the flash crash lead to their execution. As a result, the SEC has declared a ban on stub quotes, forcing market makers in exchange-listed equities to quote within pre-defined bands around the current NBBO (SEC 2010i).

*iv. Consolidated audit trail system*

The consolidated audit trail system is a second and more complex move to increase the monitoring abilities of U.S. regulators beyond the large trader reporting system. Aimed at giving regulators the ability to monitor for abuse and analyze atypical events across the fragmented U.S. markets, this system is proposed to be built around one new central database. This database would enable regulators to access detailed information about orders “*from receipt or origination, through the modification, cancellation, routing and execution of an order.*” (SEC 2010j)

Much of this information would have to be reported in near real time and would need to include “*the ultimate customer who generated the order*” (SEC 2010j), enabling regulators to conduct investigations faster and more efficiently.

To sum up, the aforementioned bans on stub quotes as well as the introduction of a policy to break clearly erroneous trades combined with the improvement of the circuit breaker system pose major steps towards a more resilient market system in the U.S. However, its complex interdependencies still pose potential unintended effects that are less likely to occur in the more decentralized European set-up.

### **6.3 Regulatory Initiatives Concerning High-Frequency Trading in Europe**

Driven primarily by the U.S. incidents (flash crash) and its increasing market share, HFT strategies have also come under the scrutiny of the European Commission and other regulatory bodies within the European Union. Against this background, initiatives and

documents which will supposedly influence regulatory provisions in the future are presented in the following. These include CESR's *Technical Advice to the European Commission* published in April 2010, the *Report on regulation of trading in financial instruments – ‘dark pools’ etc.* adopted by the European Parliament in November 2010 and the EU Commission's *Public-Consultation: Review of the Markets in Financial Instruments Directive (MiFID)* published in December 2010.

### 6.3.1 CESR Technical Advice to the European Commission<sup>49</sup>

Conceptually similar to the SEC's Concept Release on Equity Market Structure (SEC 2010a), CESR issued an open questionnaire to market participants on micro-structural issues in the European equity markets in April 2010 (CESR 2010a). For the MiFID review, CESR acknowledged that several technology-driven developments had intensified and revealed its intention to assess those developments and their “*potential effects on overall equity market structure and the efficiency of those markets in the EU*” (CESR 2010a).

Participants were addressed to respond on HFT and related topics. CESR (CESR 2010b) acknowledges that “*The majority of respondents argued that HFT firms had played a role in supplying the markets with liquidity. This had helped to reduced bid-offer spreads and had reduced demand and supply imbalances, thereby helping to limit volatility.*”

Yet, other respondents raised concerns that HFT activity might impose certain risks (CESR 2010b) like “*increased bandwidth usage; order entry/deletion and rogue algorithms; increased market abuse with detection becoming more difficult in a fragmented and highly automated environment; sudden liquidity withdrawal; and potential de-correlation of prices from market fundamentals if trading strategies focused solely on short term profits.*”

Conclusions drawn by CESR (CESR 2010b) based on its call for evidence are reflected in their action plan. These include (i) a necessity for further research on HFT to better understand “*strategies and the risks that they [HFTs] pose to the orderly functioning of markets*” (ii) “*development of specific guidelines on the application of appropriate systems and controls for investment firms and trading platforms in a highly automated trading environment*” (iii) “*the MiFID Article 2(1)(d) exemption for non-market making firms that trade only on a proprietary basis.*”

Furthermore, CESR covers other related micro-structural topics, i.e. sponsored access, co-location services, fee structures and tick size regimes. For co-location, sponsored access and

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<sup>49</sup> Full title: CESR Technical Advice to the European Commission in the Context of the MiFID Review and Responses to the European Commission Request for Additional Information (CESR 2010b)

fee structures, CESR states that the European regulator should be given the authority to develop “*binding technical standards in precisely defined areas as regards RMs/MTFs organisational requirements*”. (CESR 2010b)

Regarding sponsored access, CESR recommends to identify risks from naked access and to analyze pre- and post-trade checks. With respect to co-location, CESR demands more transparency on an objective basis.

### 6.3.2 Report on Regulation of Trading in Financial Instruments

In this report (European Parliament 2010) also known as the “Swinburne Report”, the Committee on Economic and Monetary Affairs explores regulation of trading in financial instruments including many issues related to HFT. In the following, key propositions from that report related to the topics of the paper at hand will be presented.

Referring to the flash crash, the Committee on Economic and Monetary Affairs suggests the implementation of three important measures for European markets:

- robust infrastructure of all trading platforms (ability to cope with order barrage),
- demonstration of the ability of all trading platforms to re-create order books after unusual market activity,
- ESMA supervision and definition by implementing acts of pan-European volatility interrupts and circuit breakers.

Apart from these measures, the Committee discusses several other market micro-structural issues: it urges to conduct more investigation on costs and benefits of HFT. Especially, it focuses on whether HFT provides real liquidity to markets and proposes to examine whether there is potential for market abuse by manipulation. Specifically, the practice of ‘layering’ and ‘quote stuffing’ shall be defined as market abuse.<sup>50</sup> Flash orders should be prohibited in Europe.

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<sup>50</sup> AFM (2010) defines (spoofing and) layering in the following way:

“*Spoofing: introducing an order (for example a buy order) to the order book, which is not meant to be executed, whose size and ranking in the order book results in a change in the spread to another (in this example: higher) level.*

*Layering: a form of spoofing in which a trader on one side of the order book (for example the buy side) inserts a large quantity of orders with different price limits. This is designed to create the impression of increasing pressure on one side of the order book. The actual intention of this trader however is to trade opposite transactions to the orders originally inserted (in this example: to sell). The buy orders in question are then cancelled before they are executed.*“

High Frequency trader using quote stuffing are said to “[...] flood the marketplace with bogus orders to distract rival trading firms”(Rampton et al. 2011)

Further investigations are also demanded on whether there is a need to regulate HFT entities and to undertake regular reviews of their algorithms (especially with regard to their behavior under stress). Simultaneously, the report asks for an examination on market monitoring, i.e. to what extend HFT causes new challenges on the detection of market abuse for regulators.

Concerning co-location and market access, the Committee requests practices that guarantee non-discriminatory access for all participants as well as a prohibition of naked access and appropriate risk management measures for all kinds of market access. Moreover, proprietary ATs which hitherto are unregulated by MiFID should be forced to carry out their trading activities solely through a regulated intermediary. Since it believes that many HFTs operate as unregulated proprietary traders, it considers "*the expansion of MiFID reporting rules to cover these entities being required as a matter of urgency*" (European Parliament 2010). Furthermore, regarding the recipients of maker rebates the Commission proposes that ESMA should conduct research into this issue, and consider the necessity to make recipients subject to formal market maker obligations.

#### 6.3.3 *Review of the Markets in Financial Instruments Directive (MiFID)*

In its consultation on the MiFID Review (European Commission 2010), the European Commission states that European securities market regulation requires an update due to the emergence of alternative trading functionalities, rapid technological developments, and that the growing spotlight on OTC trading makes it necessary to amend MiFID. The Commission also includes a discussion on automated trading, specifically HFT in the consultation paper. Especially, it asks for input concerning the following potential MiFID amendments:

- a broader definition of AT and the consideration of HFT as a subgroup of AT,
- assuring that all persons involved in HFT over a minimum threshold would be authorized as investment firms, including proprietary HFTs falling under the Article 2.1(d) MiFID exemption, i.e. from licensing requirements for persons dealing on own account,
- amendments to Articles 13, 14 and 39 of MiFID, i.e.
  - requirements for authorized firms involved in automated trading relating to risk controls against trading system errors, notification of competent authorities concerning design, purpose and functioning of algorithms as well as risk controls for sponsored access and
  - requirements for operators of trading venues concerning risk controls and risk mitigations by circuit breakers and stress tests as well as concerning

equal and fair access to co-location services (on a non-discriminatory basis).

Furthermore, the European Commission considers introducing two amendments to Articles 14 and 39 MiFID that may well be perceived as highly controversial as they directly affect the business model of many HFTs by requiring operators of regulated markets<sup>51</sup>:

- (i) to ensure that a high frequency trader has to provide continuous liquidity (by quotation) similar to market makers if it executes significant numbers of trades in financial instruments on the market and
- (ii) to ensure that “*orders would rest on an order book for a minimum period before being cancelled. Alternatively they would be required to ensure that the ratio of orders to transactions executed by any given participant would not exceed a specified level.*”

Specifically these two proposals will be discussed in detail in the following section 6.3.4.

#### 6.3.4 *Summary of Regulatory Status and Discussion*

In order to sum up as well as to assess the current discussions and to provide solution proposals, this subsection will first discuss the *scope of the current regulatory discussions* and will thereafter specifically focus on the most intensively discussed issues: *systemic risk, market making obligations, safeguards and minimum order lifetimes*.

##### *Scope of regulatory discussions*

Specifically after the flash crash, a lot of regulatory changes relating to HFT have been introduced in the U.S. In contrast, Europe is currently in initial discussions whether and how to regulate HFT strategies. This is not surprising, as many problems associated with HFT are rooted in the U.S. market structure – they are not directly transferable to Europe. Particularly the trade through rule leads to complex interdependencies in the U.S. market and is very different from European trading and best execution requirements.

There are two striking observations concerning the current regulatory discussions listed above: (i) the need to regulate HFT seems to be taken as given and (ii) these discussions only relate to the role of HFT in regulated venues, while the existence of automated strategies in the dark/OTC trading mechanisms is hardly touched:

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<sup>51</sup> Furthermore, the Commission discusses implementing measures for further specifying minimum tick sizes. However, as European regulated markets and MTFs have already agreed on a harmonization of tick sizes, this issue appears to be less controversial in the discussion about HFT regulation.

- (i) Against the background of the flash crash and as there is little doubt about the market relevance of HFT strategies, regulators around the world are actively discussing *how* to regulate HFT. A perceived need to actively do “something” in regulating these automated trading strategies can be observed. There seems to be an underlying assumption that the question *whether* there is a need regulate these trading strategies explicitly or if existing regulation, e.g. concerning market abuse, is sufficient or whether the issues concerning HFT can be handled by the industry itself via transparency, communication or voluntary self-commitments seems to be already answered pro regulation. This is specifically striking as there is a lack of data and still no agreed terminology and clear differentiation covering the various roles, strategies and actors<sup>52</sup>.
- (ii) OTC markets in Europe show a high and stable market share of around 40% (see section 2). As Gomber et al. (2011 b) have shown, the majority of trades in European OTC markets is rather small and these trades would not trigger market impact if executed on lit order books of the most liquid markets for the respective securities<sup>53</sup>. Furthermore, there is an increasing market share of broker crossing systems in the OTC space that are positioned to enable the buy side to execute large orders in dark venues without pre-trade transparency. These crossing systems are highly automated systems which enable customers to apply AT strategies to execute their large parent orders via slicing and dicing strategies into smaller orders. To maximize execution likelihood of these orders the crossing networks also include streaming retail order flow and proprietary positions of the respective investment bank providing the crossing system. Here, the proprietary desks of the crossing system providers often act as market makers applying strategies that are largely

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<sup>52</sup> Most recently published regulatory documents include another new definition (see e.g. European Commission (2010) or the list of regulatory definitions in Appendix II).

<sup>53</sup> The analysis of individual OTC trade size data between January 2008 and April 2010 both for high liquids (EURO STOXX 50 constituents) and a sample of less liquid securities by Gomber et al. (2011 b) shows that most OTC transactions are neither above Standard Market Size (SMS) nor would they face market impact if concluded on open, public order books. In the full observation period, nearly every second OTC trade in high liquids is below SMS and nearly six out of ten OTC trades in less liquids are below SMS. The share of OTC trades that are smaller than SMS increased from 40% in 2008 to 54% in 2010 in high liquids and from 53% in 2008 to 61% in 2010 in less liquids. A new measure to identify trades that would face no market impact on the reference market (ANOMIS) was introduced. For the high (less) liquids more than seven (six) out of ten OTC trades would face no market impact if concluded on the transparent public reference market. The share of OTC trades that would face no market impact increased from 68% in 2008 to 80% in 2010 for high liquids and from 58% in 2008 to 66% in 2010 for less liquids. Furthermore, the analysis shows that - although the average turnover of OTC trades is significantly higher than the trades on the primary markets - the median turnover, i.e. the turnover value below which 50% of all observations can be found is quite similar with around eight thousand Euro in the OTC market and around six thousand Euro on the primary markets for high liquids.

comparable to HFT market making on lit markets. However, in these OTC venues, be it internalization systems or dark venues, banks and brokers know the identity of their counterparty and are able to “cream skim” uninformed order flow and thereby to protect themselves against adverse selection. In contrast, HFT market-making strategies on lit markets face relevant adverse selection costs as they are providing liquidity on the market without knowing their counterparties. They have to manage, minimize and compensate their losses from trading against informed order flow and are not informed on the toxicity of their counterparts. Given the relevance, market shares and structure of OTC trades in respect of trading sizes, highly automated trading strategies in the OTC space should not be completely neglected in regulatory discussions.

### *Systemic Risk*

An argument that is commonly raised when discussing potential issues emanating from the propagation of HFT is potential systemic risk arising from their activity. Such risks can be the result of malfunctioning/rogue algorithms, which “bombard” a marketplace with orders until the marketplace’s infrastructure is no longer able to cope with the amount of orders. A malfunctioning algorithm may also have the potential to drive the price of a security (far) into an unintended and undesired direction. Alike other technical problems the solution should be of a technical nature. In case of HFT, marketplaces and sell side infrastructure have to be compatible to each other. Therefore, both parties have to put in place the appropriate infrastructure (including risk checks) to prevent severe damage stemming from rogue algorithms. Naturally, this means that practices such as naked access are not in line with this perception of market reliability. Given the results of the sections above, it is essential that all actors along the securities trading value chain actively contribute to prevent potential systemic risk stemming from the increased usage of new technology driven strategies as far as possible. This refers to firms operating HFT, market operators, clearing & settlement institutions as well as to regulators and supervisory authorities: On the side of entities running HFT strategies, this requires the logging and recording of all the algorithms’ input and output parameters for internal back testing as well as for supervisory investigations. Furthermore, they have to be able to prove that they apply sophisticated risk management tools and operational safeguards and have to be able to demonstrate that they are in full control of their algorithms at any time. Market operators as well as clearing & settlement organizations have to be able to handle peak volumes and have to be capable of protecting themselves against technical failures in members’ algorithms. Furthermore, their technical membership rules should assure that a human trader responsible for the algorithm

is permanently available during trading hours to be able to immediately react in case market operators or clearing intuitions detect unusual behavior. Last but not least, regulators need to be enabled for near-time reactions and rapid investigations in case of market stress. Detailed information on the extent of HFT activities to assure a full picture of potential systemic risks triggered by HFT needs to be available. Regulators and supervisory authorities require people with specific skills and regulatory tools to assess trading algorithms and their functionality.

#### *Market making obligations*

The most controversial discussions refer to uncontrollable algorithms and concerns about extreme market movements based on liquidity withdrawal by HFTs in market stress. Since a sudden loss of liquidity contributes to extreme market movements (by thinning out the order book), regulators in Europe as well as in the U.S. are currently considering whether HFTs should face quotation obligations comparable to those for registered market makers and/or are prevented from entering and deleting orders at high speed.

For example, Senator Kaufman demands in his letter to the SEC (Kaufman 2010) that “*the SEC should impose some liquidity provision obligations on high frequency traders*”. On the other side of the Atlantic, the European Commission consults on

- the effectiveness of market making obligations for HFTs: “*Market operators would be required to ensure that if a high frequency trader executes significant numbers of trades in financial instruments on the market then it would continue providing liquidity in that financial instrument on an ongoing basis subject to similar conditions that apply to market makers*” and on
- the appropriateness of minimum order lifetimes or – alternatively – a maximum ratio of orders to transactions. (European Commission 2010).

At first sight, demanding obligations for HFTs to quote seems to be an appropriate measure to tackle the problem of a sudden liquidity withdrawal. However, whether any rule can force market makers to buy in the face of overwhelming selling pressure is highly doubtful (Connell et al. 2010). In such a situation they might rather take the risk of receiving fines for not fulfilling their obligations. This objection is expressed by many<sup>54</sup> HFTs and also by market operators: “[...] obligations have never worked historically since market making firms are not willing to catch a falling knife by its

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<sup>54</sup> See e.g. (Connell 2010)

*point. The consequences of not fulfilling obligations are always small relative to putting the firm out of business.”* (Katz 2011)

In their combined report on the flash crash the CFTC and the SEC (CFTC & SEC 2010b) describe the behavior of market participants during the flash crash: a “hot potato” effect emanated during which HFTs rapidly sold securities among each other in a very short period of time. This procedure of events is also described in more detail by (Kirilenko et al. 2010). Later on, registered market makers as well as HFTs without market-making obligations stopped providing liquidity as the U.S. markets continued to display unusual behavior and extreme volatility. Moreover, instead of providing liquidity both registered and non-registered types of market makers started to actively take liquidity from the markets (potentially to hedge open positions) exacerbating volatility/price movements. Market makers stated that they had encountered technical problems, i.e. unusual latencies, leading to a complete stop of their liquidity provision activities.<sup>55</sup>

Most markets enable their market makers to pull out their quotes if they encounter data or internal system problems; however, waving the “technical” white flag in times of extreme market stress is an obvious last exit for market makers to prevent significant losses. In this respect, the flash crash and the numerous executions at stub quote level due to missing market maker quotes support arguments that market-making obligations will be likely to fail in extreme market situations anyway and that the issue is similar both for registered or non-registered market makers<sup>56</sup>, i.e. HFT market-making obligations will drive many liquidity providers out of the markets as taking risk is contrary to most HFT business models and would create significant regulatory costs for them.

#### *The alternative to market-making obligations – appropriate safeguards*

If market-making obligations will not prevent market stress and executions at extreme prices, what could do the job better? Coordinated halt – calm down – coordinated restart.

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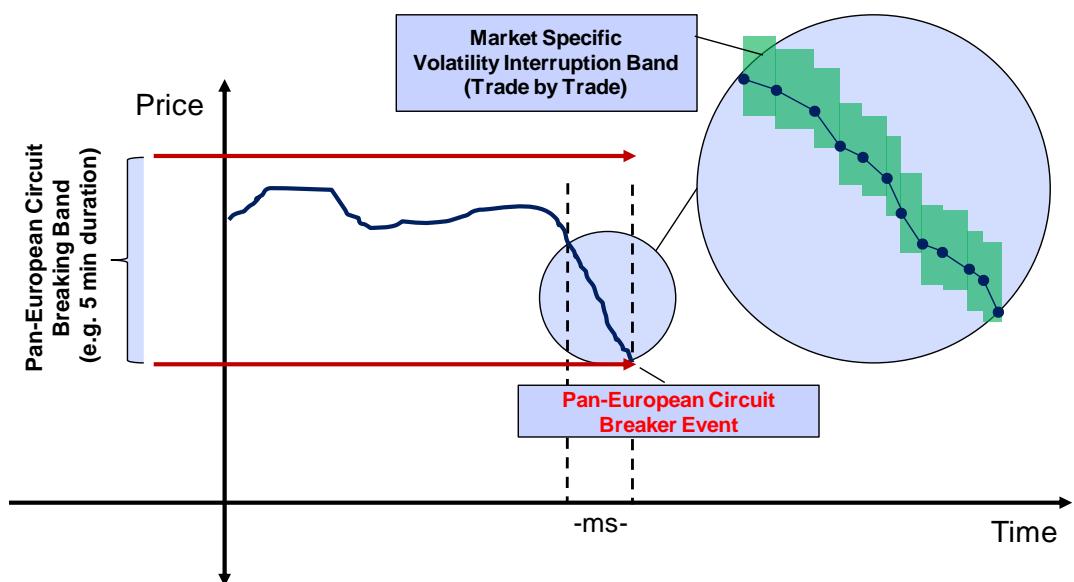
<sup>55</sup> A detailed description of these events can be found in either (CFTC & SEC 2010a) or (Kirilenko et al. 2010)

<sup>56</sup> However, market operators should react to the possibility of immediate withdrawal of liquidity by incorporating the existence of “fleeting” liquidity into their assessment of quoting obligations. One approach would be the evaluation of non-HFT liquidity for specifying designated liquidity provider obligations, i.e. the question whether a specific instrument needs registered liquidity providers (that are driven by respective incentives) and the extent of their obligations should be assessed based on the available non-HFT liquidity in the market: if non-HFT liquidity in itself is not sufficient to assure liquid trading, this security should be supported by designated liquidity providers. Respective data should be available to all market operators.

Market stress itself is not a new problem for trading venues. Safeguards such as volatility interruptions in Europe and circuit breakers in the U.S. are already in place. Nevertheless, they have to be adapted to the new environment by:

- (1) considering high speed trading and new technologies explicitly in their design,
- (2) combining best practices concerning trading interruptions worldwide, and
- (3) reflecting the reality of fragmentation by intermarket coordination.

Regulators and market operators have to assure that (1) the design of safeguards develops and goes along with the advances of HFT technologies. There are two clear advantages of the European volatility interruptions: firstly, they are security specific and, secondly, they trigger auctions to calm down and restart independently whether prices rise<sup>57</sup> or fall extremely from one price to the (potential) next price, thereby assuring price continuity. In most markets, volatility interruptions are triggered on a trade-by-trade basis that primarily serves to prevent erroneous order submission (“fat finger trade”). In an HFT environment with many small but high frequent executions, a lot of small and steady price changes might be within the respective volatility bands without triggering volatility interruptions. Nevertheless, cumulatively the price changes might be significant and occur within milliseconds – a situation shown in Figure 12.



*Figure 12: Proposal: Pan-European inter and intra-market safeguard mechanism*

<sup>57</sup> During the flash crash some stocks (e.g. Sotheby's) rose to the maximum technically possible value. Thus, reflecting both price increase and price drops in trading interruptions is important for the prevention of events like the flash crash.

Therefore, an additional threshold needs to be in place that limits short term volatility and brings control back from machines to humans. Introducing a second security-specific “circuit breaker band” that controls for price movements over a specified time horizon (e.g. five minutes<sup>58</sup>), would trigger call auctions<sup>59</sup> if price movements drive the (potential) price out of this range (see Figure 12). This approach (2) combines the advantages of the European volatility interruptions and the new security-based U.S. circuit breakers.

As fragmented markets and competition are a reality in Europe, concepts for the (3) coordination of safeguards between markets need to be developed. This concept should try to cope with the trade-off between effective inter-market trading halts on the one hand and autonomy/independence of trading venues in a competitive environment on the other hand. In the concept proposed above, this would be achievable by triggering the trade-by-trade interruptions (e.g. due to isolated fat-finger events on one market) only for the respective individual market, while circuit breakers would trigger a coordinated halt (in this security) for all European regulated markets, MTFs and also OTC trading. Thereby, fast upward or downward spirals resulting from an overflow of e.g. massive amounts of sell orders from venue to venue can be prevented. The circuit breaker should be triggered by the most liquid market<sup>60</sup> (e.g. based on the MiFID specifications for the respective most liquid market per security). Thereby, unnecessary interruptions at other venues triggered by circuit breakers at less active markets are prevented.

#### *Minimum lifetime for orders and maximum order to trade ratios*

While minimum quotation lifetimes and/or maximum order to trade ratios seem to be a possible solution to prevent immediate liquidity withdrawal, system spamming or the creation of confusing market statuses for other participants, they would result in considerable drawbacks:

- (i) Both measures impede the ability of market participants to react to market exogenous events if minimum periods have to expire before orders can be adjusted or due to reaching the maximum level in the order to trade ratio.

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<sup>58</sup> This differentiates the concept from existing trading halt combinations like the Deutsche Börse AG (Deutsche Börse 2011) dynamic and static volatility interruptions where the static interruptions refer to the last auction price instead of a time window like the U.S. circuit breakers.

<sup>59</sup> In contrast to trading halts, call auctions immediately provide price indications and aggregate available liquidity over reasonable time horizons so that human traders can agree on efficient prices.

<sup>60</sup> In this concept, it must be assured that the role of the reference market for the European circuit breaker is transferred to another market in case the original reference market faces technical problems.

- (ii) Minimum lifetimes in case of important news would force market participants to keep their orders in the market providing a free option for others to trade against.
- (iii) Minimum lifetimes would provide an incentive to develop high-speed trading strategies to exploit the fact that orders are “trapped” for an ex-ante known time window.
- (iv) Order to trade ratios would create massive problems for specific securities or strategies, e.g. if participants provide liquidity in a foreign stock where the quotes not only depend on security-related information but also on exchange rates that are adapting at high-frequency in FX markets.
- (v) Order to trade ratios would incentive traders to optimize the ratio by deliberately triggering e.g. one share trades to increase the denominator (number of trades).

The list of arguments above supports the assumption that both approaches would tend to decrease market efficiency. Impeding the ability of liquidity providers to react quickly on exogenous events negatively affects their ability to manage risk from standing orders and would decrease the liquidity those traders are willing to provide.

## **7 Conclusions**

**HFT is a technical means to implement established trading strategies.** HFT is not a trading strategy as such but it applies latest technological advances in market access, market data access and order routing to maximize the returns of established and well known trading strategies. Therefore, the assessment and the regulatory discussion about HFT should focus on underlying strategies rather than on HFT as such.

**HFT is a natural evolution of the securities markets instead of a completely new phenomenon.** Since the advent of electronic markets, market participants tried to minimize trading costs and to maximize their profits from electronic executions. While “HFT” is a relatively new term, the underlying concept is not new at all. From the first quote machines to direct market access tools to smart order routing systems, there is a clear evolutionary process in market participants’ adoption of new technologies in changing market environments, triggered by competition, innovation and regulation. Like all other technologies, HFT enables sophisticated market participants to achieve legitimate rewards on their investments – especially in technology – and compensation for their market, counterparty and operational risk exposures.

**A lot of problems related to HFT are rooted in the U.S. market structure.** Both the flash crash on May 6, 2010 and the discussions about flash orders relate to the U.S. equity market structure and the NMS. Some market observers argued that HFT is the key problem of the flash crash and around flash orders. However, the U.S. trade-through rule and a circuit breaker regime that neither targeted at individual equities nor sufficiently aligned among U.S. trading venues are relevant causes for both problems. In Europe, where a more flexible best execution regime without re-routing obligations has been implemented by MiFID and a share-by-share volatility safeguard regime has been in existence for two decades, no market quality problems related to HFT have been documented so far. Therefore, a European approach to the subject matter is required and Europe should be cautious in addressing and fixing a problem that exists in a different market structure, hence potentially creating risks for European market efficiency and market quality.

**The majority of HFT strategies contributes to market liquidity (market-making strategies) or to price discovery and market efficiency (arbitrage strategies).** Preventing these strategies by inadequate regulation or by impairing underlying business models through excessive burdens may trigger counterproductive and unforeseen effects to market efficiency and quality. Any arguments that try to associate or equate HFT based strategies with market abuse miss the point; there is no ground for treating entities that are applying HFT differently from other market participants in this respect. However, any approach that uses the new possibilities of sophisticated IT to run abusive strategies against market integrity or in order to deliberately exercise disruptive or confusing effects on other market participants must be effectively combated by supervisory authorities.

**Academic literature mostly shows positive effects of AT-/HFT based strategies on market quality.** Six out of eight recently published or publicly accessible papers, focusing on HFT, do not find evidence for negative effects of HFT on market quality. On the contrary, the majority argues that HFT generally contributes to market quality and price formation. In this regard, most studies find positive effects on liquidity and short term volatility. Only one paper, in its theoretical part, critically points out that under certain circumstances HFT might increase an adverse selection problem. The issue of HFT behavior under market stress has not been in the focus of many analyses so far, but in case of the flash crash one study documents that HFT exacerbated volatility. It should be noted that empirical research is restricted by a lack of easily accessible and reliable data on HFT activities and market sizing. As of today, it is nearly impossible for researchers (and regulators) to identify exactly on an order-by-order basis whether the respective action can be allocated to HFT operations. Here, further research – ideally in cooperation with HFT entities – is highly desirable.

**In contrast to internalization or dark pool trading, HFT market making strategies face relevant adverse selection costs as they provide liquidity on lit markets without knowing their counterparties.** HFT market makers face the traditional problems of market makers concerning adverse selection costs and have to manage, minimize and compensate their losses of trading against informed order flow. In contrast to internalization systems or dark venues in the OTC space, where banks and brokers in their role as market access intermediaries know the identity of their counterparty and are able to “cream skim” uninformed order flow, HFTs are not informed on the toxicity of their counterparts. Therefore, HFT market makers provide an important function for market quality in supervised and regulated trading venues. Highly automated trading strategies carried out in the OTC space create potential issues for fairness and price discovery.

**Any assessment of HFT based strategies has to take a functional rather than an institutional approach.** HFT is applied by different groups of sophisticated market players from top-tier investment banks to specialized proprietary trading boutiques. Any regulatory approach focusing on specialized players alone risks(i) to undermine a level playing field and (ii) exclude a relevant part of HFT based strategies. In order to manage systemic risk adequately, supervisory authorities have to consider all market participants using automated trading techniques. In this context, it has to be taken into account that the separation of investment banks' proprietary trading operations increases the share of entities that would not be subject to registration as an investment firm, due to the current MiFID Article 2.1 (d) exemptions.

**The high penetration of HFT based strategies underscores the dependency of players in today's financial markets on reliable and thoroughly supervised technology.** Therefore: (i) *entities running HFT* based strategies need to establish sophisticated risk management tools and operational safeguards and have to be able to demonstrate that they are in full control of their algorithms at any time, e.g. by logging and recording algorithms input and output parameters for supervisory investigations and back testing. (ii) *Market operators* as well as clearing & settlement organizations have to be able to handle peak volumes and have to be capable of protecting themselves against technical failures in members' algorithms, e.g. by requiring that a human trader responsible for the algorithm is always available during trading hours. (iii) *Regulators* need a full picture of potential systemic risks triggered by HFT, require people with specific skills and regulatory tools to assess trading algorithms and their functionality, e.g. to be enabled for near-time reactions and rapid investigations in case of market stress.

**Any regulatory interventions in Europe should try to preserve the benefits of HFT while mitigating the risks as far as possible.** The fragmentation of liquidity triggered by MiFID has led to a structural break and prepared the ground for HFT strategies that were not profitable in the pre-MiFID environment. However, these changes have reduced both explicit and implicit trading costs and improved market quality in European lit equity markets. Regulatory interventions should attempt to improve overall market quality, resilience as well as robustness in the given, technology-driven environment **by assuring that ...**

- (i) ... a diversity of trading strategies prevails and that artificial systemic risks are prevented. Based on a clear functional approach in the assessment of HFT, any undue regulatory burdens for smaller players should be avoided. Furthermore, it

is key to prevent any systemic risks by an “equalization” of algorithms that is triggered by a need for HFTs to create largely similar algorithms in order to be compliant with regulatory requirements. It is vital for our financial markets that multiple players of different size, with diverse business models and with different strategies are able to compete.

- (ii) ... **economic rationale rather than obligations drive the willingness of traders to act as liquidity providers.** HFT quoting obligations are in sharp contrast to the business model of HFTs that relies on minimizing risk, keeping positions for shortest periods and staying mostly flat. Therefore, a quoting obligation and the resulting shut-down of HFT strategies would likely reduce market liquidity instead of improving it. The history of financial markets shows that in times of extreme market stress even designated liquidity providers prioritize sanctions for not fulfilling their obligations over bankruptcy. The key challenge both for regulators and market operators is the design of the right economic incentives rather than imposing obligations/fines that drive liquidity providers temporarily or completely out of markets. The incentives should be based on the respective contribution to market liquidity of market makers independent of whether they are designated or voluntary liquidity providers.
- (iii)... **co-location and proximity services are implemented on a level playing field.** In contrast to floor trading (where physical presence and physical strength influences access to deals) or to remote access (where the distance to the location of an electronic trading venue’s backend influences the round trip latencies in order execution), HFT, set up in a fair and non-discriminatory co-location environment (especially concerning pricing), assures equality in the access to market data feeds and to the main matching engine. This fairness also has to relate to the provision of co-location or proximity services as such: all market participants have to demonstrate that their providers are able to warrant the physical and operational integrity of their engines independent of the nature of the hosting entity, i.e. Regulated Market, MTF or Network Services Provider.
- (iv)... **volatility safeguards are aligned among European trading venues, reflect the HFT reality and ensure that all investors are able to react in times of market stress.** Although the flash crash is a U.S. phenomenon, market operators in Europe have to rethink their safeguards in a fragmented high-speed environment. Extreme market movements should trigger aligned pan-European circuit breakers that enable even retail investors to react and to consider how to

position themselves with new orders during a general market halt. This study provides some ideas how this can be put into operation.

**The market relevance of HFT requires supervision but also transparency and open communication to assure confidence and trust in securities markets.** With a market share of HFT undoubtedly above one third of trading volume in major markets, it is necessary to enable regulators to assess the robustness and reliability of HFT systems and risk management operations. Given the public sensitivity to innovations in the financial sector after the crisis, it is furthermore the responsibility of entities applying HFT to proactively communicate on their internal safeguards and risk management mechanisms. One has to accept that HFTs cannot publicly release their intellectual property rights and the core of their business models, i.e. the mechanisms of their algorithms and operations. But the observable unwillingness by lot of entities to interact with the public, the media or with other market participants as well as an appearance and behavior shrouded in mystery is not a means to generate trust – especially in the aftermath of the flash crash on May 6, 2010. HFT entities act in their own interest by contributing to an environment where objectivity rather than perception dominates the center of the debate: they have to actively draw attention to the fact that they are an evolution of modern securities markets, supply substantial liquidity and contribute to price discovery for the benefit of all market participants.

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## Appendix I – High-Frequency Trading Market Sizing

Estimated share of HFT in the European market	Market party responding	Comments from market parties responding
<i>Trading platforms</i>		
-	BATS	Says it does not use a specific HFT classification
20% (equities)	Borsa Italiana (LSE)	
30% (futures)	Borsa Italiana (LSE)	
40%	Chi- X	
35- 40%	Deutsche Bank	
33%	LSE	
13%	Nasdaq OMX	Share of the Nordic markets
23%	NYSE Euronext	Was 5% in Q1 2007
-	SIX Swiss	Says it does not use a specific HFT classification
21%	Turquoise (LSE)	
<i>HFT parties</i>		
45%	Flow Traders	
>40%	IMC	Derived from figures stated in the market, think it is too high
30- 40%	Optiver	Derived from Rosenblatt Securities
<i>Consultants</i>		
25%	AITE Group	Expects 30% at end 2010 and 45% in 2012
30-40% (futures)	Rosenblatt Securities	
35% (equities)	Rosenblatt Securities	
<i>Other</i>		
50- 80%	European Banking Federation	Concerns all forms of algorithmic trading

*Table 5:HFT Market share based on responses to CESR Call for Evidence on Micro-structural Issues of the European Equity Markets.*

*Source:AFM (2010)*

<b>Origin</b>	<b>Date of publication</b>	<b>US</b>	<b>Europe</b>	<b>Australia</b>
TABB Group	Sep-09	61%		
Celent	Dec-09	42% of US trade volume	Rapidly growing	
Rosenblatt Securities	Sep-09	66%	~35% and growing fast	
Broogard	Nov-10	68% of Nasdaq trade volume		
Jarnecic and Snape	Jun-10		20% and 32% of LSE total trades and 19% and 28% of total volume	
Tradeworx	Apr-10	40%		
ASX	Feb-10			10% of ASX trade volume
Swinburne	Nov-10	70%	40%	
TABB Group	Jan-11		35% of overall UK market and 77% of turnover in continuous markets	

*Table 6: HFT Market shares from industry and academic studies*

## Appendix II – Academic and Regulatory Definitions of Algorithmic Trading

Academic Definitions Algorithmic Trading			
Authors	Title	Year	Def. Algorithmic Trading
Jarnecic, Elvis; Snape, Mark	An analysis of trades by high frequency participants on the London Stock Exchange	2010	Algorithmic trading is the use of computer algorithms to execute human generated, pre-designated trading decisions and is designed specifically to minimize price impact.
Hendershott, Terrence; Riordan, Ryan	Algorithmic Trading and Information	2009	The speed and quality of access to such markets encourages the use of algorithmic trading (AT denotes algorithmic traders as well), commonly defined as the use of computer algorithms to automatically make trading decisions, submit orders, and manage those orders after submission.
Prix, Johannes; Loistl, Otto; Huettl, Michael	Algorithmic Trading Patterns in Xetra Orders	2007	Computerized trading controlled by algorithms.
Chaboud, Alain; Benjamin, Chiquoine; Hjalmarsson, Erik; Vega, Clara	Rise of the Machines: Algorithmic Trading in the Foreign Exchange Market	2009	[...] algorithmic trading, where computer algorithms directly manage the trading process at high frequency [...] ; [...] In algorithmic trading (AT), computers directly interface with trading platforms, placing orders without immediate human intervention. The computers observe market data and possibly other information at very high frequency, and, based on a built-in algorithm, send back trading instructions, often within milliseconds. A variety of algorithms are used: for example, some look for arbitrage opportunities, including small discrepancies in the exchange rates between three currencies; some seek optimal execution of large orders at the minimum cost; and some seek to implement longer-term trading strategies in search of profits. Among the most recent developments in algorithmic trading, some algorithms now automatically read and interpret economic data releases, generating trading orders before economists have begun to read the first line.
Domowitz, Ian; Yegerman, Henry	The Cost of Algorithmic Trading: A First Look at Comparative Performance	2006	Like Grossman [2005], we generally define algorithmic trading as the automated, computer-based execution of equity orders via direct market-access channels, usually with the goal of meeting a particular benchmark.
Hendershott, Terrence; Jones, Charles M.; Menkveld, Albert J.	Does Algorithmic Trading Improve Liquidity?	2009	Many market participants now employ AT, commonly defined as the use of computer algorithms to automatically make certain trading decisions, submit orders, and manage those orders after submission.
Brownlees, Christian T.; Cipolliniy, Fabrizio; Gallo, Giampiero M.	Intra-daily Volume Modeling and Prediction for Algorithmic Trading	2010	The last few years have witnessed a widespread development of automated order execution systems, typically known in the financial industry as algorithmic (or algo) trading. Such algorithms aim at enhancing order execution by strategically submitting orders: computer-based pattern recognition allows for instantaneous information processing and for subsequent action taken with limited (if any) human judgment and intervention.
Foucault, Thierry; Kadan, Ohad; Kandel, Eugene	Liquidity Cycles and Make/Take Fees in Electronic Markets	2009	The automation of monitoring and orders submission.
Gsell, Markus; Gomber, Peter	Catching up with technology – The impact of regulatory changes on ECNs/MTFs and the trading venue landscape in Europe	2006	Algorithmic Trading emulates a broker's core competence of slicing a big order into a multiplicity of smaller orders and of timing these orders to minimize market impact via electronic means.

Regulatory Definitions Algorithmic Trading		
Regulator	Document	Def. Algorithmic Trading
CESR (2010a) Committee of European Securities Regulators	CALL FOR EVIDENCE Micro-structural issues of the European equity markets	Algorithmic trading or black-box trading, [is] based on the use of computer programs for entering orders with the computer algorithm deciding on individual parameters of the order such as the timing, price, or quantity of the order.
ASIC (2010b) Australian Securities & Investment Commission	CONSULTATION PAPER 145. Australian equity market structure: Proposals.	[A]utomated electronic trading activity whose parameters are set by predetermined rules.
ASIC (2010a) Australian Securities & Investment Commission	REPORT 215: Australian equity market structure	We have characterized it in this report as electronic trading whose parameters are determined by strict adherence to a predetermined set of rules aimed at delivering specific execution outcomes. These parameters may include any one or more of volume, price, instrument, market, type, timing and news.
AFM (2010) Authority For the Financial Markets	High frequency trading: The application of advanced trading technology in the European marketplace	HFT can be regarded as a sub-category of algorithm trading, which has undergone enormous expansion since the late 1980s. Algorithm trading is the collective term for all strategies whereby orders are given according to a pre-programmed set of rules (algorithms).
European Commission (2010)	Public consultation: Review of the Markets in Financial Instruments Directive (MiFID)	Automated trading also known as algorithmic trading can be defined as the use of computer programs to enter trading orders where the computer algorithm decides on aspects of execution of the order such as the timing, quantity and price of the order. This form of trading is used by an increasingly wide range of market users (including for example funds and brokers).

## Appendix III - Academic and Regulatory Definitions of High-Frequency Trading

Academic Definitions High-Frequency Trading			
Authors	Title	Year	Definition of High-Frequency Trading
Jovanovic, Boyan; Menkeld, Albert J.	Middlemen in Limit Order Markets	2010	Electronic limit order markets enable agents to automate trading decisions. Computer algorithms are used to either minimize transaction cost when trading into position ('working' an order through time and across markets or to simply profit from buying and selling securities as a middleman). This latter type is the focus of our study and is often referred to as high-frequency trading (HFT).
Jarnebic, Elvis; Snape, Mark	An analysis of trades by high frequency participants on the London Stock Exchange	2010	HFT is the use of high-speed computer algorithms to automatically generate and execute trading decisions for the specific purpose of making returns on proprietary capital.
Cvitani, Jaksa; Kirilenko, Andrei	High Frequency Traders and Asset Prices	2010	HFT typically refers to trading activity that employs extremely fast automated programs for generating, routing, canceling, and executing orders in electronic markets. HF traders submit and cancel a massive number of orders and execute a large number of trades, trade in and out of positions very quickly, and finish each trading day without a significant open position.
Brogaard, Jonathan A.	High Frequency Trading and its Impact on Market Quality	2010	HFT is a type of investment strategy whereby stocks are rapidly bought and sold by a computer algorithm and held for a very short period [...] HFT is a subset of algorithmic trading (AT). AT is defined as "the use of computer algorithms to automatically make trading decisions, submit orders, and manage those orders after submission" (Hendershott and Riordan, 2009). AT and HFT are similar in that they both use automatic computer generated decision making technology. However, they differ in that ATs may have holding periods that are minutes, days, weeks, or longer, whereas HFTs hold their position for a very short time and try to close the trading day in a neutral position. Thus, HFT is a subset of AT, but not all AT is HFT.
Kirilenko, Andrei; Samadi, Mehrdad; Kyle, Albert S.; Tuzun, Tugkan	The Flash Crash: The Impact of High Frequency Trading on an Electronic Market	2010	We define Intermediaries as those traders who follow a strategy of buying and selling a large number of contracts to stay around a relatively low target level of inventory. Specifically, we designate a trading account as an Intermediary if its trading activity satisfies the following two criteria. First, the account's net holdings fluctuate within 1.5% of its end of day level. Second, the account's end of day net position is no more than 5% of its daily trading volume. Together, these two criteria select accounts whose trading strategy is to participate in a large number of transactions, but to rarely accumulate a significant net position. We define high frequency traders as a subset of intermediaries, who individually participate in a very large number of transactions. Specifically, we order Intermediaries by the number of transactions they participated in during a day (daily trading frequency), and then designate accounts that rank in the top 3% as high frequency traders. Once we designate a trading account as a HFT, we remove this account from the Intermediary category to prevent double counting.

Regulatory Definitions High-Frequency Trading		
Regulator	Document	Def. High-Frequency Trading
SEC (2010a) The Securities and Exchange Commission	Concept Release on Equity Market Structure	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. These traders could be organized in a variety of ways, including as a proprietary trading firm (which may or may not be a registered broker-dealer and member of FINRA), as the proprietary trading desk of a multi-service broker-dealer, or as a hedge fund (all of which are referred to hereinafter collectively as a “proprietary firm”). 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 timeframes 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).
CESR (2010a) Committee of European Securities Regulators	CALL FOR EVIDENCE Micro-structural issues of the European equity markets	HFT is a form of automated trading and is generally understood as implying speed. Using very sophisticated computers and IT programs, HF traders execute trades in matters of milliseconds on electronic order books and hold new equity positions possibly down to a “sub-second”. HFT generally involves getting in and out of positions throughout the day with a „flat“ position at the end of the day. HF traders use their own capital and do not act on behalf of clients. HF traders follow different strategies (e.g. arbitrage, trading on prices which appear out of equilibrium, trading on perceived trading patterns, etc.) but are generally geared towards extracting very small margins from trading financial instruments between different trading platforms at hyper fast speed.
ASIC (2010a) Australian Securities & Investment Commission	REPORT 215: Australian equity market structure	<p>Specialized forms of high-speed algorithmic trading are emerging—that is, the use of high-speed computer programs to generate, route and execute orders. High-frequency trading (HFT) is a subset of this. While there is not a commonly agreed definition of HFT, it is characterized by:</p> <ul style="list-style-type: none"> <li>(a) the generation of large numbers of orders, many of which are cancelled rapidly; and</li> <li>(b) typically holding positions for very short time horizons (i.e. ending the day with a zero position).</li> </ul> <p>HFTs employ high-speed, low-latency technology infrastructures:</p> <ul style="list-style-type: none"> <li>(a) they process direct market feeds to have access to the fastest market information available;</li> <li>(b) they co-locate their servers in the data centres with the exchange market’s matching engine to reduce access times;</li> <li>(c) they develop their own sophisticated trading strategies to trade on a short-term basis; and</li> <li>(d) they typically end the trading day with no carry-over positions that use capital.</li> </ul>
AFM (2010) Authority For the Financial Markets	High frequency trading: The application of advanced trading technology in the European marketplace	HFT is a form of automated trading based on mathematical algorithms. HFT is not a trading strategy in itself, but a means of applying certain strategies (market making and statistical arbitrage) in practice on trading platforms. These strategies concern only some of the strategies which may be deployed. In other words, HFT is certainly not the only way to operate successfully on trading platforms.[...] Positions as a result of HFT strategies are usually taken with the intention of being market-neutral (non-directional). They are as a rule hedged (delta neutral) and will in many cases be closed out at the end of the day (positions are rarely held overnight). The average holding period is usually of a very short duration, ranging from seconds to several minutes. Many of the orders placed are not executed (the order to transaction ratio is very high). The majority of orders are cancelled shortly after entry, as they are continually updated according to the continuously changing market conditions (in other words, newly available price information). The volumes of positions and the length of time for which positions are held are determined by the trading algorithm and may fluctuate during the day. “Bursts” of large quantities of orders, issued suddenly, are one of the main features of HFT. These bursts often alternate with periods of relative calm in which scarcely any trading occurs, in anticipation of a new trading opportunity.
European Commission (2010)	Public consultation: Review of the Markets in Financial Instruments Directive (MiFID)	A specific type of automated or algorithmic trading is known as high-frequency trading (HFT). HFT is typically not a strategy in itself but the use of very sophisticated technology to implement traditional trading strategies. Although there is debate about how it could be defined, it is perhaps best defined as trading that uses sophisticated technology to try to interpret signals from the market and, in response, executes high volume, automated trading strategies, usually either quasi market making or arbitraging, within very short time horizons. It usually involves execution of trades as principal (rather than for a client) and involves positions being closed out at the end of the day.
CESR (2010b) Committee of European Securities Regulators	CESR Technical Advice to the European Commission in the Context of the MiFID Review and Responses to the European Commission Request for Additional Information	Respondents to CESR’s Call for Evidence on micro-structural issues defined high-frequency trading (HFT) in various ways. Rapid, automated execution of trading strategies was one key theme (e.g. high velocity order entry), with HFT firms being highly sensitive to latency and regular users of co-location services. Many, although not all respondents suggested that HFT activity was characterized as being market-neutral, with positions closed out by the end of the day. Some noted that this type of trading was proprietary in nature. Importantly, though, no single, agreed definition of HFT emerged and estimates of its significance in the markets (provided mainly by trading platforms) varied from 13% to 40% of total trading.

## Appendix IV - Academic Literature Overview on High Frequency/Algorithmic Trading

Academic Literature Overview High-frequency trading						
Authors	Title	Year	Research Questions	Methodology/Data	Results	Assumptions/ Limitations
Jovanovic, Boyan; Menkeld, Albert J.	Middlemen in Limit Order Markets	2010	This paper studies HFT entry both theoretically and empirically: Are HFT traders better informed? Does HFT increase welfare?	Theoretical model, empirical analysis, regressions, cross market event study (Introduction of Dutch Stocks at Chi-X). Data includes the first 77 trading days of 2007 and 2008 from Dutch Stocks at Chi-X and Euronext. Belgian index stocks serve as an ‘untreated’ control sample as they had not yet been introduced in Chi-X.	Empirical record of a cross market HFT who holds positions only for short time periods. HFT is proved to be better informed. The model indicates that in a specific case HFT can raise welfare by up to 30%. On the negative side, they can create or exacerbate a pre-existing adverse-selection problem, in which case bid-ask spreads should rise and trade declines. The introduction of middlemen lowers bid-ask spreads but also lowers volume. The net effect is uncertain.	
Jarneic, Elvis; Snape, Mark	An analysis of trades by high frequency participants on the London Stock Exchange	2010	What is the magnitude of high frequency participation? What are the characteristics of trades in which high frequency participants choose to participate? And what are the determinants of individual high frequency trades?	Empirical analysis, cross-sectional regression on LSE Stocks from April 1, 2009 to June 30, 2009. HFT is identified by member data. This study has access to member categorization that allows the authors to directly examine the activity of a group of high frequency participants.	HFT varies widely across stocks and is more prevalent in large capitalization stocks with high on-market competition, high price volatility and strong off-exchange competition but less prevalent in stocks with high tick sizes and informed order flow. Propensity to participate in individual trades is related to a number of market conditions. HFT is more likely to smooth out liquidity over time and are unlikely to exacerbate volatility.	Firms may adopt high frequency strategies and can route their activity through another member’s identifier using direct market or sponsored access.
Cvitanic, Jaksa; Kirilenko, Andrei A.	High Frequency Traders and Asset Prices	2010	What are the effects of HFT on transaction prices generated in an electronic limit order market? Does HFT make prices more informative? Do they increase liquidity?	Theoretical model; There are infinitely many (slow) traders who submit limit orders into an electronic limit order book with the intent to buy or sell a single asset with the addition of one infinitely fast (from the point of view of other traders) high frequency trader. The machine mimics the so-called "sniping" strategy, a strategy designed to discover liquidity in the limit order book, or to "pick-off" orders already in the book.	As the proportion of transactions with the machines grows, forecastability of transaction prices should improve. Trading volume and intertrade duration, as well as measures of market liquidity based on them, should increase in direct proportion to how much humans change the speed of their orders when the machine is present.	The authors posit that during a short horizon, the impact of changes in the fundamentals is negligible. Therefore, they model the incoming human buy order prices and sell order prices during the period as two iid sequences, arriving according to exogenous Poisson processes. For tractability, they assume that the submitted orders are of unit size and at infinitely divisible prices.

Authors	Title	Year	Research Questions	Methodology/Data	Results	Assumptions/ Limitations
Brogaard; Jonathan A.	High Frequency Trading and its Impact on Market Quality	2010	What is the impact of high-frequency trading (HFT) on the U.S. equities market?	Empirical Analysis of 120 U.S. Stocks on Nasdaq. The group of HFT is identifiable in the data set. The order book data are from the first full week of the first month of each quarter in 2008 and 2009, 09/15/2008 - 09/19/2008, and 02/22/2010 - 02/26/2010.	(1) HFTs tend to follow a price reversal strategy driven by order imbalances, (2) HFTs earn gross trading profits of approximately \$2.8 billion annually, (3) HFTs do not seem to systematically engage in a non-HFTs anticipatory trading strategy, (4) HFTs' strategies are more correlated with each other than are non-HFTs', (5) HFTs' trading level changes only moderately as volatility increases, (6) HFTs add substantially to the price discovery process, (7) HFTs provide the best bid and offer quotes for a significant portion of the trading day and do so strategically so as to avoid informed traders, but provide only one-fourth of the book depth as do non-HFTs, and (8) HFTs may dampen intraday volatility. These findings suggest that HFTs' activities are not detrimental to non-HFTs and that HFT tends to improve market quality.	
Kearns, Michael; Kulesza, Alex; Nevmyvaka, Yuriy	Empirical Limitations on High-Frequency Trading Profitability	2010	What is the maximum profit for HFT?	Modeling profits of an omniscient HFT. Measuring her profits as an upper bound for HFT.	Upper bound for HFT profits of \$3.4 billion p.a.	Simple methodology. Only captures profits from one particular aggressive order strategy.
Kirilenko, Andrei; Samadi, Mehrdad; Kyle, Albert; Tuzun, Tugkan	The Flash Crash: The Impact of High Frequency Trading on an Electronic Market	2010	What may have triggered the flash crash? What role did high frequency traders play?	E-mini futures contracts from May 3rd to May 6th 2010	HFT did not trigger the flash crash but exacerbated volatility. Finds a so called "hot potato" effect of HFTs, repeatedly buying and selling from each other.	Covers an extreme event.
Hasbrouck; Joel, Saar, Gideon	Low Latency Trading	2010	What is the influence of low latency traders on the market environment? How does the combined activity of HFT and human traders affect short term volatility, total price impact, and market depth?	Statistical analysis of 500 Nasdaq Stocks of October 2007 and June 2008. Examines market quality by clustered liquidity measures. Describes the millisecond environment.	Improved market quality with respect to short term volatility and liquidity. Clock time periodicity is found in data.	Measures HFT activity by "strategic runs", patterns of submissions and cancellations
Ende, Bartholomäus; Uhle, Tim; Weber, Moritz	The Impact of a Millisecond: Measuring Latency Effects in Securities Trading	2011	The paper provides a performance measure on the effect of latency in the context of the competitive advantage of IT. What is the economic value of latency in securities trading?	Statistical Analysis of 10 trading days starting from August 31st 2009 and ending at September 11th 2009.	Day patterns of trading activity heavily influence the economic value of latency. Latency impact differs significantly among instruments. For each individual retail investor, who cannot make use of low latency technologies, price effects are neglectable.	Small data set. Missing execution probabilities prevents the full picture of a complete business case for latency improvements.

Academic Literature Overview Algorithmic Trading						
Authors	Title	Year	Research Questions	Methodology/Data	Results	Assumptions/ Limitations
Hendershott, Terrence; Riordan, Ryan	Algorithmic Trading and Information	2011	What role does algorithmic trading play in the price discovery process in the 30 DAX stocks? Does it contribute more to the discovery of efficient prices than human trading?	Statistical analysis of 13 trading days of the 30 DAX stocks from January 1st 2008 to January 18th 2008.	Algorithmic trading contributes more to the discovery of the efficient price than human trading. It consumes liquidity when it is cheap and provides liquidity when it is expensive.	
Prix, Johannes; Loistl, Otto; Huetl, Michael	Algorithmic Trading Patterns in Xetra Orders	2007	Can traces of algorithmic trading be found in Xetra order data by studying the lifetime of cancelled orders?	Analysis of all no-fill-deletion orders with lifetimes equal to multiples of 60 seconds using Xetra order data from December 8th to December 15th 2004 and application of the findings to data from January 5th to January 12th 2005.	The findings indicate the existence of previously undiscovered patterns in the order book's structure when investigating the second and sub-second range of no-fill-deletion lifetimes.	
Chaboud, Alain; Benjamin, Chiquoine; Hjalmarsson, Erik; Vega, Clara	Rise of the Machines: Algorithmic Trading in the Foreign Exchange Market	2009	Do computer trades cause higher or lower volatility and do computers increase or reduce liquidity during periods of market stress? What is the relative importance of human and computer trades in the process of price discovery and are liquidity providers "uninformed"?	Empirical analysis of foreign exchange market. Quote data of the pairs euro-dollar, dollar-yen, and euro-yen from the Electronic Broking Services (EBS) of the years 2006 and 2007.	Empirical results provide evidence that algorithmic trades are more correlated than non-algorithmic trades, suggesting that the trading strategies used by the computer traders are less diverse than those of their human counterparts. No evident causal relationship between AT and increased market volatility is found. The results suggest that computers do provide liquidity during periods of market stress. Humans are the informed traders in the euro-dollar and yen-dollar market. In the cross-rate, the euro-yen exchange rate market, results show that computers and humans are equally informed.	
Domowitz, Ian; Yegerman, Henry	The Cost of Algorithmic Trading: A First Look at Comparative Performance	2006	What is the performance of algorithmic trading engines?	Study concentrates on performance along the dimension of transaction costs. Data taken from ITG's Transaction Cost Analysis Peer Group Database from January 2004 through December 2004.	Algorithmic trading is a cost-effective technique. Average performance differences across providers for very small orders are few, but gaps between providers grow as order size grows.	Data is limited to orders completed within a single day.
Hendershott, Terrence; Jones, Charles M.; Menkveld, Albert J.	Does Algorithmic Trading Improve Liquidity?	2009	Does AT improve market quality, and should it be encouraged?	Analysis of time-series evolution of algorithmic trading and liquidity for a sample of NYSE (common) stocks over the five years from February 2001 through December 2005.	For large stocks in particular, algorithmic trading narrows spreads by reducing adverse selection and increasing the amount of information in quotes as compared to trades. These indicate that algorithmic trading does causally improve liquidity and enhances the informativeness of quotes and prices.	AT is not directly observable. Instead a proxy, the electronic message traffic measure for the NYSE, is used.

Authors	Title	Year	Research Questions	Methodology/Data	Results	Assumptions/ Limitations
Brownlees, Christian T.; Cipolliniy, Fabrizio; Gallo, Giampiero M.	Intra-daily Volume Modeling and Prediction for Algorithmic Trading	2010	What are the estimates of intraday volumes?	This work proposes a dynamic model for intra-daily volumes that captures salient features of the series such as time series dependence, intra-daily periodicity and volume asymmetry. An empirical application on a set of widely traded index Exchange Traded Funds.	The application to three major ETFs shows that both the static and the dynamic VWAP replication strategies generally outperform a commonly used naive method of rolling means for intra-daily volumes in an out-of sample forecasting exercise.	
Foucault, Thierry; Kadan, Ohad; Kandel, Eugene	Liquidity Cycles and Make/Take Fees in Electronic Markets	2009	What are the effects of maker taker fees? What are the effects of the evolution of AT (increased trading volumes) on the trading rate, the bid-ask spread, and welfare?	Theoretical model; it includes a market for a security with two sides: "market-makers" and "market-takers." Market-makers post quotes (limit orders) whereas market-takers hit these quotes (submit market orders) to complete a transaction. The model is highly stylized but it captures "market monitoring" and "liquidity cycles" (i.e. low or high liquidity phase).	The model suggests two possible causes for increased trading volume in reality: (i) the development of algorithmic trading, and (ii) the evolution of the pricing policy used by trading platforms. In the model, a decrease in the monitoring cost for the market-making side or the market-taking side triggers an increase in the trading rate. The model also implies a positive association between the make-take spread and the tick size.	Model is not tested with respect to its predictive power on real data.
Groth, Sven	Does Algorithmic Trading Increase Volatility? Empirical Evidence from the Fully-Electronic Trading Platform Xetra	2011	What is the effect of algorithmic trading on short term volatility?	Empirical analysis of one week of DAX30 Stocks in 2007 from German Trading Platform Xetra	The results provide sufficient evidence that algorithmic traders do not increase volatility more than humans do. In particular, it is found that algorithmic traders in aggregate follow trading strategies that are as diverse as human strategies. Moreover, algorithmic trading participation does not significantly increase volatility levels. Algorithmic traders – as often blamed – do not seem to systematically withdraw liquidity from the market during periods of high volatility.	
Gsell, Markus	Assessing the impact of Algorithmic Trading on markets: A simulation approach.	2008	What is the impact of algorithmic trading on volatility? Does latency affect volatility?	A simulation approach to assess the impact of algorithmic trading models is conducted by comparing different simulation runs including and excluding a trader constituting an algorithmic trading model in its trading behavior.	Algorithmic Trading concepts have an impact on market outcome in terms of market prices and market volatility. On the one hand, low latency showed the potential to significantly lower market volatility. On the other hand, large volumes to execute had a negative impact on market prices. For lower volumes to work, high latency factors had a significantly positive effect on market volatility in the conducted tests.	Simulation approach with self generated data.

Authors	Title	Year	Research Questions	Methodology/Data	Results	Assumptions/ Limitations
Gsell, Markus; Gomber, Peter	Algorithmic trading engines versus human traders – Do they behave different in securities markets?	2009	How do algorithmic trading engines schedule their trading strategies and adapt their behavior to current market movements? To which extent is it different to the trading behavior of (human) traders?	Deutsche Boerse Xetra order book events for the DAX30 securities within the week from October 8th to 12th, 2007	Based on a dataset that – for the first time – includes a specific flag to enable the identification of orders submitted by algorithmic trading engines, the paper investigates the extent of algorithmic trading activity and specifically their order placement strategies in comparison to human traders in Xetra. It is shown that algorithmic trading has become a relevant part of overall market activity. Evidence is presented that algorithmic trading systems submit orders that are noticeably smaller. Additionally, they show the ability to monitor their orders and modify them to be at the top of the book.	



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March 2011

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