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High Frequency Trading: an analysis of the phenomenon and the effect of the human component

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Introduction

This thesis is the result of my passion about stock exchanges and capital markets. I've always been fascinated by them, since when I was a kid. For this reason, I decide to begin with a brief introduction about their history, passing through the open outcry system to finally get to the main topic: the high frequency trading.

Financial markets' development has always been directly related to evolution in commerce and technology. Until 1991 trades occurred with the so call open outcry method. Professional traders in a stock exchange used to shout and gesticulate to buy and sell shares on a trading floor of a physical stock exchange. In recent decades important and radical transformations of financial markets have occurred thanks to developments in technology: for more than 30 years trades have been taking place with computers. Nowadays, almost all stock exchanges are entirely automated, and humans are replaced by servers connected between each other with numerous wires.

The electronic revolution started in the '70s in the US. The first step of this process was the creation of the NASDAQ. In the '80s program trading emerge thanks to the spread of fully electronic financial markets.
The digitalization of the process allows for decentralization and the physical places are now replaced by virtual areas managed by computers; people can send their orders anyplace.

The most recent developments bring us to algorithmic trading and high frequency trading.
Algorithmic trading can be defined as "Computerized trading controlled by algorithms". Hence, we can deduce that AT is a process for executing orders using pre-programmed and automated trading instructions which takes in consideration multiple variables. Algorithmic trading uses complex formulas, mathematical and statistical models to make decisions to buy or sell an asset. Human oversight is not required but can be implemented.

Financial markets have always been a competitive environment, and competition

stimulates the progress. This process, guided by the desire to earn always more money, has led to the development of high frequency trading, with which institutional investors aim to gain more profits.
Every single instant in the world of HFT is important, and time represents the principal challenge for these algorithms where also a microsecond is important to beat the competitors.
Obviously, HFT is characterized by powerful and extremely sophisticated computers which allow to execute huge amount of orders at a very high speed. New investments and new technologies permit to reach execution time smaller than 1 millisecond.

As per every innovation, to avoid improper uses of this new technology, the phenomenon must be regulated and, in these constantly changing conditions, the regulator steps in to ensure an appropriate use of technology and protection to physical investors, responding to a need of appropriate regulation.

After having analyzed the rational side of capital markets identified in algorithms, I took in consideration the opposite side, the irrational one populated by human investors. During my master's degree I've studied behavioral finance, a subject that really intrigued me. I started introducing briefly the topic, analyzing the main biases which affect individuals. Then, I noted that emotions lead investors to compute an action which will have consequences in the market, indeed not every time people are able to develop an immediate and sudden strategy, and when this happen emotions play a very important role.
During my researches I was able to ascertain that humans are not particularly reliable when it comes to sticking to a process. Biases, like overconfidence, regret, cognitive dissonance and many others, introduce inconsistencies in financial markets.
On the contrary, computers do not suffer such subjectivity: they follow rules and form objective estimates of risks. Algorithms are more efficient and rational than human traders, and at the same time less prone to take emotionally motivated decisions.
However, some researchers have discovered that algorithmic trading does contain behavioral aspects. I found out that, in practice, is not possible to completely remove emotions through algorithms. In fact, algorithmic trading, in the broadest sense of the word, introduces new set of emotions.

1. Evolution of financial markets

Financial markets, as we know them today, seem modern and recent, but their origins are in the past and their development is directly related to evolution in commerce and technology.
The first trades of shares took place around 1500, in Belgium: the shares, exchanged by merchants, represented a credit, or a commodity coming from distant countries. The physical place, where all this was made possible, was a palace of the Van Der Bourse family, in Bruges.

Researchers agree to say that the first real stock exchange can be considered the one built in the German city of Antwerp in 1531. Here merchants and bankers could meet each other to make different type of exchanges.
During the second half of 1500 and in the following years, many stock exchanges were built in different European cities. Some of the most important stock exchanges built during that time were: London in 1564, Venice in 1600, Amsterdam in 1609, Paris in 1724, Vienna in 1771, Rome in 1802 and Milan in 1808. The most important stock exchange today, New York, was built in 1792.

As the years go by new financial instruments[1] emerge and in the 16th century in some stock exchanges people can find debt securities issued by monarchs and also shares issued by corporations.
At the beginning stock exchanges allowed the trade of both currencies and shares, but later, in 1913, there was the separation between commodities and stock markets, and from that moment on we can talk in a properly manner of stock exchange, meaning a place where only securities are traded.

The recent expansion of global financial markets started in 1973, at the end of the Bretton Woods monetary regime, and accelerated after 1989, leading to 189 stock exchanges around the world in 2015 and to a number of stocks and exchanges which

[1] Financial instruments are assets that can be traded, a monetary contract between parties. The IAS (International Accounting standards) 32 and 39 define them as: “Any contract that gives rise to a financial asset of one entity and a financial liability or equity instrument of another entity”.

are daunting.

1.1. Financial revolution

For more than 30 years trades have been taking place with computers. Almost all stock exchanges are entirely automated, and humans are replaced by servers connected between each other with numerous wires.

Until 1991 trades occurred with the so call *open outcry* method. Professional traders met each other in a stock exchange and used to shout and gesticulate to buy and sell shares on a trading floor of a physical stock exchange. Shouting was necessary to make bids and offers in the open market, giving all the participants a chance to compete for the order with the best price and thus for an efficient price discovery[2].
Those exchanges occurred in particular corral called *corbeilles*. Here took also place all the operations to check official prices and to draft price indices.

In recent decades important and radical transformations of financial markets have taken place thanks to developments in technology: during the latter part of the 20th century with the use of telephone and subsequently with the introduction of computers and hence electronic trading.

The spread of technology, however, was not homogeneous, and despite Europe was the place where stock exchanges were established, the electronic revolution started in the '70s in the US. The first step of this process was the creation of the National Association of Securities Dealers Automated Quotations, known as NASDAQ, the first example of electronic stock exchange in the world, which replaced the National Association of Securities Dealers (NASD). The NASDAQ introduced for the first time in financial markets' history a market-making system assisted by computers, creating its own Automatic Quotation[3] system (AQ). In 1976, the second step of the electronification process was the introduction of the Designated Order Turnaround

[2] Price discovery is the process of setting a proper price for a security, asset, commodity or currency.
[3] An Automatic Quotation system (AQ) is a computer system which shows the most recent prices of financial instrument traded.

system (DOT) in the New York stock exchange (NYSE), followed few years after, in 1984, by the Super-DOT system. The DOT system before, and the Super-DOT later, increased the efficiency by routing orders for listed securities directly to a specialist on the trading floor instead of through a broker, allowing orders transmission in electronic manner.

The revolution in Europe started with the so call *Big Bang*: the financial revolution of London stock exchange on Monday October 27th, 1986. It led to deregulation of financial markets, including abolition of fixed commission and the decline of the open outcry system. Another result of 1986 reform was the introduction for the first time of an electronic quotation system in Europe too, the Stock Exchange Automated Quotation (SEAQ), and the consequent end of the open outcry system and the beginning of electronic trading also in the old world. The same process of deregulation involved many other different countries during those years.

The consequences of deregulation were not only positive: in United States, in a year, commissions dropped by 40% and 35 brokerage firms went bankrupt.
With the new regulation the difference between dealer[4] and broker[5] stopped to exist. Now the intermediary can act in his own interest or in the interest of other people. He can also act as market maker[6], buying and selling specific financial instruments in every moment.

Always in the '80s program trading emerge thanks to the use of fully electronic financial markets. It is defined by NYSE as "placing of orders to buy or sell 15 or more stocks valued above $ 1 million total". It quickly gained popularity among traders who worked with S&P500 equity and the futures market, since it allows traders to buy or sell stock index future contracts and at the same time buy or sell a portfolio up 500 stocks at the NYSE matched against the futures trade. Moreover, to make things easier, with computers this procedure could be pre-programmed.

[4] People or firms who buy and sell securities for their own interest.
[5] People or firms who buy and sell securities on behalf of its clients.
[6] Firm or individual who actively quotes two-sided markets in a security, providing bids and offers along with the market size of each. The SEC defines a market maker as "A firm that stands ready to buy and sell stock on a regular and continuous basis at a publicly quoted price".

The digitalization of the process allows for decentralization and the physical places were replaced by virtual areas managed by computers; people could send their orders wherever they are, what was required were just two things: a computer and an internet connection.

Nowadays there are two different techniques that are currently available in stock exchanges around the world to buy and sell financial instruments: open outcry, still available in some stock exchanges like in the Chicago Board of Trade and in the London Metal Exchange, and electronic system. These methods summarise the financial markets' evolution and have in common three characteristics: the purpose, the means and the use of standard contracts. The meet of demand and supply happen with standard contracts, where the variables are only the underlying asset, the price, the quantity, and exclusively for derivatives, the maturity.

1.1.1. Open outcry

Open outcry was and still is a famous method to communicate trade orders. Key features of this method are hand signals and shouts used by traders to deliver information, intentions and acceptance in the trading pits[7]. The strong competition which characterise this method allows for efficiency, indeed bids and offers must be made out in the open market, giving all participants a chance to compete for the order with the best price.

With the open outcry method, the communication of trade orders take place face to face: a trader makes a contract when another trader declares he want to sell at a certain price, and the first accept to buy at the very same price. It is more or less like an auction where all participants have the chance to compete between each other.
Thanks to its characteristics open outcry system allows for transparency, efficiency in financial markets and fair price discovery.
The procedure is quite articulate and involves many figures: the investor transmits the purchase or sale order to his broker, the broker passes the order to his colleague, the floor broker, who is located inside the trading room. The floor broker sends the order

[7] Trading pits are physical sections of trading floors.

to the contractor who either shouts his offer or delivers the order to a specialist who works as a market maker. Once the counterpart is found, the order is executed, and the information goes back to the buyer or seller.

In the stock exchange the auctioneer announces the stock to be negotiated and proposes an initial price, which generally is the official price of the previous day. From this price the auction starts, with demand and supply of negotiators who announce loudly, shouting, their position as sellers or buyers, for a given quantity and price. If buying positions overcomes the selling ones the speaker increases the price and vice versa; the process is a continuous adjustment that lasts until when there are no supply or demand imbalances. The price can change only within the limit of about 10%. If the preceding conditions are met the price is declared and the auctioneer pass to next stock; if the percentage change in the price exceeds the limit, the auction of the security is postponed to the end of the list to give the intermediaries the opportunity to inquire about the reasons that led to the strong change in price and to consult their clients.

Obviously, speed and mental capacity were necessary to be a good trader but now they are not anymore sufficient, to beat competitors, traders need to be faster than a blink. The run-up to ever greater speed has been the main driver in the implementation of technology.

1.1.2. Electronic trading

As said before, things started to change in the latter part of the 20th century with the introduction of the telephone and starting in the ‘80s with electronic trading systems. The Globex was the first global electronic trading system developed by Chicago Mercantile Exchange (CME). Trading through Globex was, already at that time, available 24 hours a day, from Sunday evening to late Friday afternoon.

The first electronic trading platforms provided live streaming prices, on the contrary an order placed by a broker or a client could take some time before being confirmed.
Soon electronic trading platforms became more complex but at the same time more user friendly, and nowadays they are software programs that can be used to place

orders for different financial products, such as stocks, bonds, currencies, derivatives and commodities, over a network of financial intermediary or directly between participants in the market from any location. They stream live market prices and usually provide additional tools for their users like for instance charts, news, feeds and so on.

Even if electronic trading seems easy, indeed you just need to log in your account, select the security to buy or sell and click the mouse, or even touch the screen, behind the scenes there is a complex process managed by powerful computers. Some electronic trading platforms have built in scripting tools and even APIs[8], allowing traders to develop automatic or algorithmic trading systems. Some others are available, often for free, on home computers and smartphones too.

Electronic trading platforms may include Alternative Trading Systems (ATS), Electronic Communication Networks (ECN) as well as the so-called dark pools.
An ATS is a venue to match buy and sell orders to find counterparties for transactions, not regulated as an exchange but as broker-dealers. It must be approved by the U.S. Securities and Exchange Commission[9] (SEC).
The equivalent, in Europe is represented by Multilateral Trading Facility (MTF). It accounts for much of the liquidity in public markets.
Alternative Trading systems can be used for trading huge number of shares away from the normal exchange to avoid distortions in the market price. They are generally electronic but don't have to be.

An ECN is a type of computerized system that automatically matches buy and sell orders facilitating trades of financial products outside traditional stock exchanges. It shows the best available bid and ask prices and connects major brokers and individual traders, thus there is no need of a middleman, so that traders can deal directly with themselves all over the world. ECNs allow investors to trade outside traditional trading hours, avoid the wide spreads that are common when dealing with a traditional broker and thus provide lower commissions and fees. With ECN investors can also not reveal

[8] API stands for Application Programming Interface and is a computing interface which defines interactions between multiple software intermediaries.
[9] The Securities and Exchange Commission (SEC) is an independent American government regulatory agency responsible to protecting investors, maintaining fair and orderly functioning of the securities markets and facilitating capital formation.

their identity keeping a good level of anonymity.
Summing up, electronic communication network allows for automated trading, passive order matching and speedy execution, but on the other hand, one of the drawbacks of using an ECN is the price to pay for using it: access fees and commission can have very high costs, and they are also difficult to avoid, per-trade-based fee can be expensive and affect investor's profitability.
From a regulative perspective, in the U.S.A. the SEC requires ECNs to register as broker or a dealer.
ATSs can be distinguished from ECNs since the latter are fully electronic.

A dark pool is a private and organized financial forum, or exchange, for trading securities. It allows institutional investors to trade without exposure until the trade has been executed and reported. Dark pools also give certain investors the opportunity to place large orders and make trades without revealing their intentions during the process of searching a buyer or a seller. At the beginning dark pools were used only for large orders, but already in 2013, there were possible to trade only 200 shares.
A key feature of dark pools is that they charge lower fees than exchanges because they are often housed within a large firm, and not only a bank. In addition, through dark pools an institutional investor can make large trades without exposure while finding buyers and sellers avoiding price devaluation. On the other hand, even if dark pools are legal, they allow to work with little transparency.

Automated systems in trading reduce costs, improve the speed to conclude a trade, minimize possible manipulation and make it easier to gather all the information.
Some traders lament that electronic trading fails to capture the intangible information upon which pit traders relied: it doesn't depend on the mood of the pit, which traders found very useful.
Despite these romantic criticisms to new generation of trading method, it is impossible not to admit that trading today is far more efficient than in the past, as shown by reduced trading fees and increased velocity that allows even normal people to participate in the market.

1.2. Following perfection

The main aim of technology has always been to pursue efficiency. From its birth to present days, the organizational forms of the stock exchanges have changed, evolving towards systems that can be considered increasingly efficient. Theoretically, the maximum degree of efficiency is reached when all operators have same information, they are aware of the strategic possibilities of others and market behavior of each individual does not affect its general performance. On the other hand, the imperfection of the stock market is directly proportional to the number of operators who are unable to take a favourable position in time.
Discriminating, therefore, is the system of information flows within the stock exchange: essentially, the organizational structure of the stock market determines the amount of time and costs in the dissemination of information.
In addition, the level of efficiency of a stock exchange depends on the set of laws issued by regulators and supervisors. The regulatory function is expressed through regulations and provisions which implement the legislative standards.
In recent years, Information Technology (IT), has impacted all the system, and has started to replace human resources. Technology allows assimilation of huge amount of data and make more accurate decisions in a very short time.

Nowadays, the big part of market models relies on an Electronic Central Limit Order Book (CLOB), a method of exchange execution that matches all bids and offers according to price and time priority. It allows all users to trade with each other, and there is no need of being intermediated by a dealer.

The development and implementation of IT in financial markets has been slow and gradual, but in these recent years there has been an acceleration which has changed the financial framework and has led to new market participants, like Algorithmic Trading (AT) and High Frequency Trading (HFT). Algorithmic trading and high frequency trading are the last results of an evolution process that is still developing.

1.3. Algorithmic trading

There are many different definitions of algorithmic trading. We can find very simple one like “Computerized trading controlled by algorithms” but also more complex as “In algorithmic trading 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”.

Also the European regulator with MiFID II[10] gives a definition of algorithmic trading as: “Trading in financial instruments where a computer algorithm automatically determines individual parameters such as: whether to initiate the order, the timing, price or quantity of the order; or how to manage the order after its submission with limited or no human intervention; and does not include any system that is only used for the purpose of routing orders to one or more trading venues; or for the purposes of orders involving no determination of any trading parameters or for the confirmation of orders or the post-trade processing of executed transactions”. On the other hand, the definition given by the American regulator is contained in the Financial Industry Regulatory Authority (FINRA)[11] Rule and is “Automated systems that generate or route orders and order-related messages, such as cancellations”.

We can thus deduce that AT is a process for executing orders using pre-programmed and automated trading instructions which takes in consideration multiple variables like price, volatility, quantity and timing. Algorithmic trading uses complex formulas, mathematical and statistical models to make decisions to buy or sell an asset. Human oversight is not required but can be implemented.
Investment banks, mutual and hedge funds are the main users of these algorithms.
An important year for AT was 2001 for two specific events. The first one was the change in American decimalization from $0.0625 to $0.01 per share, promoted by the

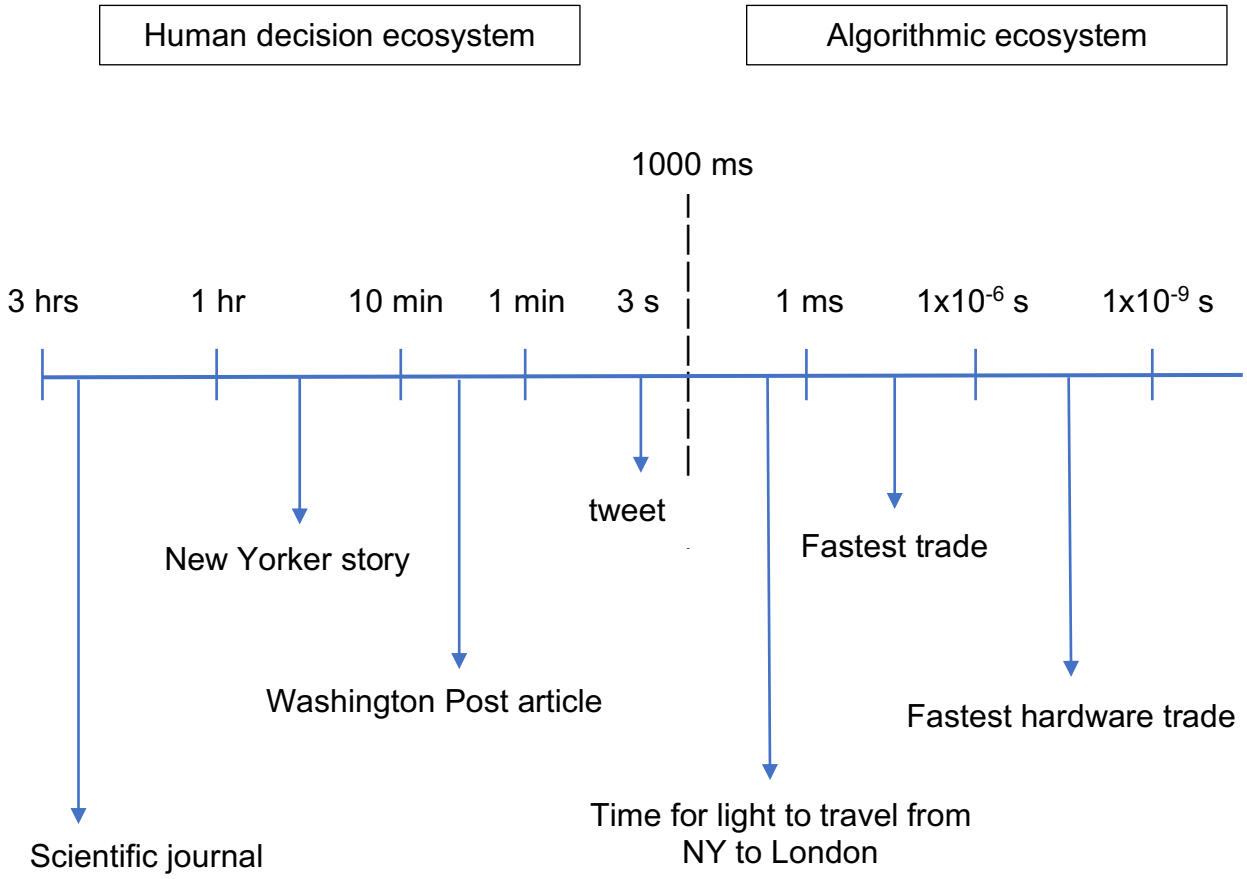
[10] MiFID II is the Markets in Financial Instrument Directive (2004/39/EC) and is the legislative framework of the European Union to regulate financial markets.
[11] The Financial Industry Regulatory Authority (FINRA) is a nongovernmental and independent organization that enforces rules governing registered brokers and dealer firms in the US.

SEC to conform the U.S. to international standards. This change in market microstructure encouraged algorithmic trading by permitting smaller differences between bid and ask prices, increasing market liquidity and decreasing the market advantage of market makers. The second one was a research of IBM where it was shown that two experimental algorithmic strategies outperformed human traders. These two events gave an important development and audience to algorithmic trading.

1.3.1. Algorithmic trading strategies

With the conversion of traditional stock exchanges into electronic ones, many different trading strategies were introduced, since complex tactics are easier to be pursued by computers, which require less time to evaluate multiple data coming from numerous markets. In Figure 1, is reported a comparison between human decision ecosystem, on the left-hand side, and algorithmic one, on the right-hand side. The time of 1000 milliseconds, i.e. 1 second, divide the two worlds. It is the limit of human decision making, meaning that no individual is able to take a decision in a smaller amount of time.

Figure 1: Comparison between human and algorithmic decision ecosystem



Source: My own reworked version of Dr. Sean Gourley speech at TEDXNewWallStreet – High frequency trading and the new algorithmic ecosystem - 2012

In the first decade of 2000, all the most important investment banks such as Deutsche Bank, BNP Paribas and Credit Suisse had their own proprietary algorithmic strategies.

Deutsche Bank developed *Stealth*, a strategy which silently executes orders in over 30 markets around the world. It is a liquidity-seeking strategy, designed to minimize the traders' market impact by trading only as opportunities arise and minimizing information leakage. The stealth algorithm was designed for rapidly changing markets characterized by wide spreads, fast quoting, and small top of book liquidity coupled with the enormous growth in off-exchange liquidity.

BNP Paribas developed three different strategies for different users: *Chameleon*, *Viper* and *Iguana*. The first one, chameleon, is an adaptive execution strategy which constantly monitor the current market condition, with the goal of maximise the spread capturing in a dynamic fashion while seeking price opportunities. Viper, instead, is a fast, and aggressive or passive, algorithm which is used across multiple trading venues. It is designed to work with mid to large size orders, seeking out optimal price execution. The last one, iguana, is a passive, aggressive and adaptive algorithm with dynamic participation rates that spread orders dynamically over a user-specified time interval. It uses an advanced logic that enables it to react favourably to market movements.
A comparison of these three strategies is possible looking at the figure below, Figure 2, which take in consideration their market impact with market risk and time.

Figure 2: Comparison between chameleon, viper and iguana strategies of BNP Paribas

Source: Cortex iX intelligent execution, BNP Paribas

Credit Suisse developed *Guerrilla* and *Sniper*. Guerrilla is designed to make orders without signalling the presence of the buyer or seller to the market. It has the power to slice big orders into smaller, not very noticeable ones. It works well with mid-cap and

small-cap shares. Sniper, instead, is a very aggressive algorithm that will trade until it either completes, or reaches, an investor's limit price[12].

We have just seen some real strategies adopted by investment banks but there are many different algorithms which pursue general strategies: arbitrage, mean reversion and trend trading are the most popular.
Arbitrage strategies consist in buy a stock, listed in at least two stock exchanges, at the lowest price in one market and immediately sell it at the highest price in the other market.
Mean reversion strategies rely on the idea that high or low prices of a share are a provisional phenomenon that revert to their average value periodically.
Trend trading is an algo-trading strategy which attempts to capture profits through the analysis of an asset's momentum[13] in a particular direction.

AT is used, as said before, in many forms of trading and investment activities. The time horizon involved can be different: short-term or mid/long-term.
Short-term strategies are pursued by market makers, brokerage houses, speculators and arbitrageurs, who benefit of automated order execution.
The mid/long-term strategies are often performed by mutual funds and insurance company to buy shares in big quantities when they do not want to influence stock prices with their huge investments.

It has been noted that systematic traders, as trend followers, hedge funds and pairs traders[14], find more efficient to write their own code for trading and let the program trade automatically.

[12] The limit price is the price below or above which one is willing or not willing to sell or buy a security.
[13] Momentum is the speed at which the price of an asset change, it helps to identify trends.
[14] A pairs trade is a trading strategy which involves combining a long position and a short position in two stocks with high correlation.
A long position consists in buying a financial instrument with the expectation that its price will increase while a short position consists in selling a financial instrument with the expectation that its price will fall.

1.3.2. Pros and cons of algorithmic trading

There are advantages but also disadvantages arising from AT.
Algo trading is manly used by institutional investors to cut down costs associated to trading, and it is particularly profitable in big size orders. Trades are executed at the best possible price.
It allows for easier and faster execution of trades ensuring efficient exchanges, trade order placement is instantaneous and accurate; this means that traders and investors can quickly obtain profits from small changes in price. The computational power of algorithms simultaneously checks multiple market conditions, use historical and real-time data and reduce the risk of manual errors, as the fat finger error[15].

On the other hand, even if speed is a pro of algorithmic trading, it also is a drawback. Indeed, when numerous orders are executed in the very same moment without human control the consequences may be dramatic, as happened with the Black Monday in 1987, when all of the twenty-three most important markets experienced a huge decline due to some *stop loss*[16] programs which didn't worked correctly.

Liquidity can be seen as a disadvantage too, in fact since it is created through rapid buy and sell orders; as it is fast to appear it is also fast to disappear, eliminating the possible profit for trades. It can lead to a loss of liquidity too, indeed as researchers have shown, AT was considered the main factor which caused the loss of liquidity in currency market after the Swiss franc discounted its Euro peg in 2015.

Among other things, AT also requires technical requirements, such as computer programming knowledge, network connectivity and access to trading platforms, market data feeds and historical data, in addition to powerful computer and high-speed internet connection, which can make market inequalities even wider.

[15] A fat finger error is a human error caused by pressing the wrong key on the keyboard when using a computer to input data.
[16] A stop loss is a program that is able to close a transaction automatically when a specific financial instrument reaches a minimum prespecified value in order to minimize the losses.

1.4. High frequency trading

As said before, technological progress has heavily changed the functioning of financial markets, today humans' shouts and gestures are substituted by silence of computers and individuals' reasoning by algorithms.
Financial markets are a competitive environment, and competition has led to go further, implementing very fast strategies, trying to gain a competitive advantage against competitors. This led to development of high frequency trading.

Every single instant in the world of HFT is important, and time represents the principal challenge for these algorithms where also a microsecond is important to beat the competitors. From this, it follows huge investments in information technology, both at hardware and software level.

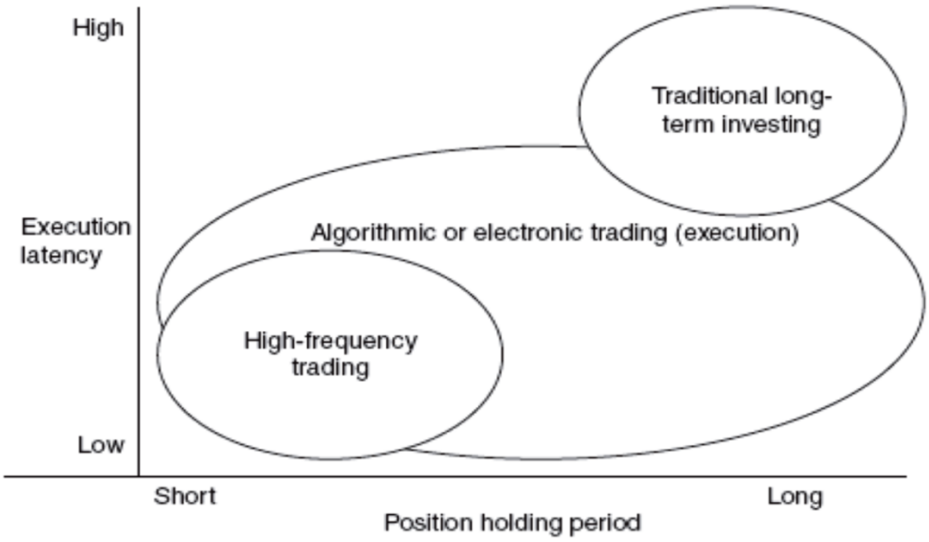
As happen with algorithmic trading, also for high frequency trading there are multiple definitions, which underlines the complexity of the subject. A first definition can be: "Real-time computer-generated decision making in financial trading without human inference and based on automated order generation and order management".
The European regulator, with the MiFID II, defines HFT as "A technique which executes large numbers of transactions in seconds or fractions of a second by using: infrastructure that is intended to minimise latencies such as co-location, proximity hosting or high speed direct electronic access; system determination of order initiation, generating, routing or execution without human intervention for individual trades or orders; and high message intraday rates which constitute orders, quotes or cancellations". The American regulators used a different approach and defines high frequency trading listing five characteristics that are often attributed to it: "Use of extraordinarily high speed and sophisticated program for generating, routing and executing orders; use of co-location services and individual data feeds offered by exchangers and others to minimize network and other latencies; submission of numerous orders that are cancelled shortly after submission; ending the trading day in as close to a flat position as possible (that is, not carrying significant, unhedged positions overnight)".
The SEC also emphasises the fact that not all of these characteristics must be present

for a proprietary firm[17] to be properly classified as HFT.

As it is possible to deduce, by comparing the aforementioned definitions of algorithmic trading and high frequency trading, HTF is a subset of AT. One important difference is that the latter is generally an agent trader, meaning that they make trade for their clients, they exploit technology to execute orders ensuring the best time and price execution in exchange for commissions, while HF agents trade in their own interest and at their own risk.

The two main differences between them are speed and holding period. As we can see from Figure 3 below, HFT requires a very small time to execute orders and also the holding period is very short, usually it varies from few seconds to few minutes. On the opposite side, traditional long-term investing obviously requires more time. In the middle there is AT.

Figure 3: HTF vs. AT and traditional long-term investment



Source: Aldridge, I. (2009), High-Frequency Trading: A practical guide to algorithmic strategies and trading systems, Wiley

[17] The SEC defines a proprietary firm as: "professional traders acting in a proprietary capacity that generate a large number of trades on a daily basis".

As AT and HFT diverge, they also have some common features: they are used by professionals, no human intervention is necessarily required, they rely on pre-determined trading decisions, both observe market data in real time, automatically submit and manage orders and they have direct market access.

1.4.1. Origins of HFT

As happened with algo-trading, high frequency trading become established after the stock exchange automation process. Two important phenomena which had an important impact on HFT are the already mentioned electronic communication network and the Small Order Execution System (SOES).

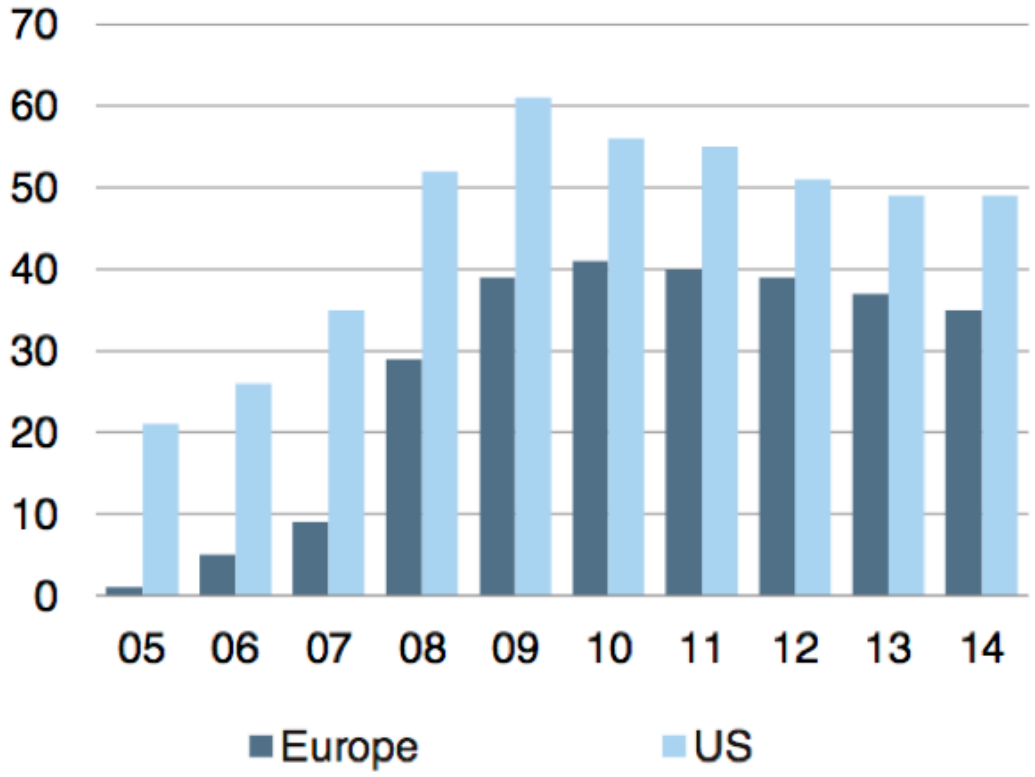
Electronic Communication Networks had the effect to increase the number of trades and reduce transaction costs. But they also had an important drawback: if there had been two different prices on an ECN and in a regulated market, more profitable in the second, the order on the ECN would not have been run at the best price available, creating the possibility of arbitrage opportunities. In these circumstances were developed the first high frequency algorithms able to take advantage from information asymmetry: the most informed traders were able to buy from non-informed operators and sell at the best price in the market obtaining a systematic profit free of risk.
The HFT phenomenon did not emerge all at once, the SOES Bandits are defined as the its precursors. In the ‘90s, they pursued particular aggressive trading strategies. The SOES bandits did hundreds of operations only to take advantage by the small changes in price. They could even gain from the delay needed by market makers to update prices. Hence, they were able to earn money by taking advantages of the small inefficiency present in the market.

One of the biggest drivers for the diffusion of HFT arrived in 2005 with the Regulation National Market System (Regulation NMS). It embeds a set of rules which improved the U.S. exchanges, improving fairness in price execution, displaying of quotes and amount and access to market data. It includes four main components, but two are the most important for the development of HFT: Order Protection Rule (Rule 611) and Sub Penny Rule (Rule 612).

With the first one the SEC established that every order must be executed at National Best Bid and Offer (NBBO), meaning every order must be executed at the best price. But there was an exception: the execution of an order at a price worse than the NBBO was allowed provided that this price was still the best in another market and that the transaction occurred no later than one second from the last NBBO. An example can be useful: if the best bid on a stock had fluctuated between $10.70 and $10.71 within a second, the sell order at $10.70 would not have violated Rule 611.
With Rule 612, all stock exchanges in the U.S.A. had to adopt the same decimal system to quote prices of shares higher than or equal to one.

Talking about the history of HFT, we can divide it in two periods: before and after the 2008 economic crisis. As we can see from Figure 4, the period before the crisis was characterized by a continuous growth of the transactions executed through HFT phenomenon both in America and Europe. In 2005, in the United States, high frequency trading algorithms executed only 20% of the total trades while in 2009 it reaches 60%; in Europe the percentage was very near to zero in 2005 and increased up to 40% in 2010. Looking at the NYSE data, trading volume grew up by 164% from 2005 to 2009, and the biggest growth was registered in foreign exchange and interest rate futures which reached peaks of 80%.
However, after the crisis, the growth of HFT slowed down and transactions executed by algorithms reduced to 50% in the U.S.A. and 35% in Europe in 2014.

Figure 4: Percentage of exchanges among the total executed by HFT from 2005 to 2014



Source: TAAB Group, Deutsche Bank research

The reduction in the use of high frequency algorithms can be explained by two factors: reduction of profits due to increasing infrastructure costs and competition, and a more stringent regulatory wave.

1.5. New risks

From many years the main goal of governments and central banks has been the stabilization of financial markets after the sub-prime bubble. But many evidences suggest that the next financial crisis can be fuelled by cyber-attacks.

Financial sector has always represented an important target for cyber-criminal, because institutions which work in this industry have access to a lot of money.

Since high frequency trading represents a profitable market, cyber criminals may want to steal and then sell algorithms to unscrupulous traders. In these recent years, there has been many attacks aimed at stealing the code, also from insider of the same company.
A solution for investors can be cryptocurrencies, indeed thanks to its structure cryptocurrencies are not subject to cyber-attacks. But, on the other hand, a jump of many investors towards cryptocurrencies would lead to increased volatility in the regular currency markets.
Obviously financial institutions like banks, mutual funds, hedge funds are already protecting themselves from cyber-attacks, but this is a difficult and complex practice with multi face problem.

Web application attacks are the biggest threat to the financial sector, accounting, according to the 2016 Data Breach Investigation Report, for 82% of data breaches.
Another type of attack is the Distributed Denial of Service (DDoS), which account for 34% of security incidents. A DDoS aims to render the website or service inoperable by overwhelm with more traffic than the server can accommodate to steal as many data as possible.
The Advanced Persistent Threats (APTs), instead, try to steal huge amounts of data over long period by maintaining ongoing access to the network. This is a particular underhand cyber-attack, indeed 69% of financial firms which were victim of ATPs, didn't discover the problem for weeks or months.

1.6. Future

The use of high frequency trading still plays a very important role in the number of everyday transactions, even if its peak was in 2009 and no longer reached. Many firms are adopting it, but it still faces numerous challenges and the future developments is not known yet.
A phenomenon that is taking pace is the integration between hardware and firmware, which would allow to reduce drastically the processing and decision-making speed of algorithms.

There are many new alternatives nowadays more accessible especially for individual investors, like social trading, but also for institutional investors, as implementation of machine learning and artificial intelligence. A new profitable phenomenon for people with programming knowledge is do-it-yourself algorithmic trading.

Social trading is a new way, especially for retail traders, but also for investors, to get start in financial markets. Social trading is similar to social networks, like Facebook and Twitter, where you can connect yourself with other traders worldwide; they can share their insight on the current market situation and also their trading strategies. The main idea is that collective talent of hundreds experienced traders is better than just one person's talent.
The recent developments of social trading platforms not only allow to view and comment the performance of traders present in the platform, but they also let the user automatically copy their transactions, you can hence decide to use their strategy without monitoring every instant the current situation of the market.

Machine learning and artificial intelligence is another emergent technology. Computer programmers thanks to new developments in artificial intelligence is now able to develop programs which can improve themselves through an iterative process called deep learning.

Do-it-yourself algorithmic trading is a new phenomenon which takes pace in these recent years thanks to the reduction of computer costs and the spread of high-speed Internet connection. Institutional investors like for example hedge funds, search algorithms from amateur programmers. This is a sort of competition and who win it will see his algorithm implemented and receive commission for writing the profitable code.

There are other alternatives that will play important role even in the future: the "old aged" momentum trading and automated news-based trading.
The "old" technical analysis is based on momentum identification and is one of the most valid alternatives to HFT. Momentum trading consists in find the expected direction that price will take, and since the position remains open for an interval of time, which last minutes or months, rapid algorithms are not necessary.
Automated news-based trading algorithms are already a reality and are becoming

always more spread, this is possible because news drives the markets. These new algorithms are able to read news and take instant trading actions in response.

Once again, most of the challenges may be caused by the specific market and its nature and can be resolved with its natural progression. Operational issues, entry barriers, risk issues and regulation impact, are just some examples.

When it is required to develop an algorithm in very short time, firms must be sure of their functioning and impact to avoid operational issues. They must test algorithms completely and thoroughly before implementing them on live systems. If this is not guaranteed we have already seen the consequences: in January 2010 a faulty algorithm of Credit Suisse received hundreds of thousands of erroneous messages, in February 2010 the trading program of Capital Management had to be shut down after five second due to erroneous trades and again in June 2010 a faulty algorithm of Deutsch Bank placed sell orders worth $182 million by mistake.

Since costs of technology have decreased, entry barriers have come down over the last few years, but some of them still remain to take in consideration if a firm wants to enter in the HFT market. They are significant investment in co-location facilities and high-speed networks to reduce latency and acquire huge amounts of market data.

Risk issues includes market, technology and compliance risks. Since HFT algorithms rely on market data and assumed market conditions, every change in the market can have an unexpected impact on the final result. In addition, there is always technological risks given the high dependence on technology and IT infrastructure: many time routers, internet connection and servers are down.
There is also compliance risk to close monitor, that is when an organization fails to act in accordance with industry laws and regulations, internal policies or prescribed best practice, it can face legal penalties, financial forfeiture and loss.

One of the biggest question marks is the impact of regulation. During the last years regulators have intervened to regulate the sector, and some rules had severely impact HFT and many other can do the same in the future. They may include banning specific trading strategies and impose a transaction tax: they can limit the profitability of the

industry.

2. Characteristics and profitability of HFT

As said in the first chapter, high frequency trading is a subset of algorithmic trading. While the biggest part of AT executes orders of clients, generally supporting traders' activities, HFT carry out proprietary strategies.

The characteristics that both methods have in common are:

- They are used by professional traders;
- No human intervention is generally needed;
- Use of pre-determined trading decisions;
- Observation and use of real-time market data;
- Automatic orders submission and management;
- Direct market access.

Algo-trading and high frequency trading have common features but there are also characteristics that are exclusive only to one of them. Algorithmic trading is an agent trading method and minimizes the impact of large orders. Algorithmic trading's goal is to achieve particular pre-determined benchmarks; its trading holding periods are longer than HFT going from days to week and even months.

On the other hand, HFT's main characteristics are:

- Proprietary trading method;
- It keeps a flat position;
- Very short holding periods;
- High number of orders;
- Low profit per trade generated through buying and selling orders;
- Focus on high liquid instruments;
- Low latency;
- Use of co-location and/or proximity services;
- High order to trade radio.

As emerge from the features of HFT, these algorithms are able to generate very small profits by buying and selling stocks, currencies, bonds and other financial instruments. They need to execute a high number of trades in order to generate satisfactory margins.

2.1 Properties of HFT

Obviously HFT is characterized by powerful and extremely sophisticated computers which allow to execute huge amount of orders at very high speed, even more than 5,000 per second. Speed is fundamental to make, modify and even cancel orders to quickly adapt the strategy to continuous changes of the market.
Even if HFT constitutes a minority of the traders, it generates the highest part of the total trading volume, in 2009, in the United States, HFT firms were only 2% but they represented 73% of all equity traded.

High frequency trading is a proprietary trading method, meaning that HF operators make trades at their own risk with their own money.

Talking about the holding period, many researchers specify that HFT strategies do not take *over-night position*. This means that the positions are always close within a day, but mainly they last few seconds or at most few minutes. The consequence is that there is a very high turnover of shares in portfolios managed by high frequency algorithms and, hence, a huge number of orders. This model leads to small revenues over a high number of trades, and for this reason high frequency traders (HFTr) buy and sell extremely liquid financial instruments, because they allow to easily exit from previously taken positions. Since high frequency algorithms are able to obtain only a small profit per each trade, only making a lot of exchanges they would be able to generate gains. It is estimated that $0.01 is the average net profit for each share traded in the market executed by a high frequency algorithm.

Like many other technologies high frequency trading requires to be connected to capital markets, faster is the connection, higher is the probability to beat the competitors. So, to execute strategies successfully, HFT needs low latency. In

addition, it can be required to use *co-location* services and continuously update feeds from the markets.

Latency, also called ping, of an informatic system is the interval of time that passes between a user action (input) and the resulting response (output). Hence, it measures the speed of response of an electronic system. In the past, a trader can realize his profits by using his physical characteristics such as mental and computing capabilities, his ability to run faster and shout loudly than other traders, but today thanks to electronic trading, physical qualities are substituted by low latency requirements.
In economics, latency represents the interval of time which is necessary to transform an economic decision into a negotiation.
Latency is important in high frequency trading in multiple moments, and it must be taken in consideration for:

- Time that passes between the moment in which the informatic system of HFT receives and merges all the data of the markets, and the moment when it ends to process them. Reduce this time interval means that the system will be potentially able to receive and process information in real time;
- Time within elaboration of markets' data and the order;
- Interval of time which separates the elaboration and transmission of the order to the market;
- Time requested by the order to be received by the market;
- Interval of time needed from the moment in which the market receives the order and its disclosure.

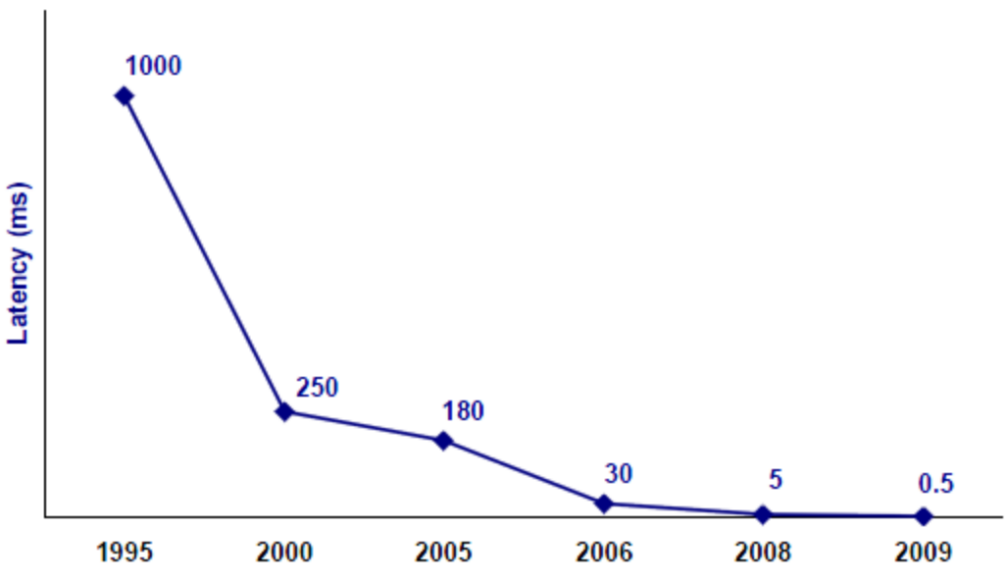
Smaller is the time necessary for all this procedure lower is the latency, vice versa, longer the time, higher the latency. Low latency theoretically meets the physical limit of the light speed, which is equal to 3 microseconds per kilometer.

Co-location is particularly related to HFT. It includes services offered directly by the same negotiation platforms to attract liquidity.
As already said, speed has a crucial role in HFT, and the speed of an order, meaning the velocity with which the electronic signal is transmitted in the optic fiber, its elaboration and the relative response from the informatic system of the market are key

features to develop a competitive advantage.

Thanks to recent electronic and IT developments, the pace of information is always faster, almost reaching the speed of light, but distance between servers is very important. Closer are the servers of trading agencies to the servers of the stock exchange, higher can be the velocity of the data transmission. Hence, physical proximity to stock exchanges' servers allows to HFTr to maintain a time advantage, even if infinitesimal small, with respect to other competitors and consequently place more profitable investments that otherwise would be impossible. In Figure 5, it is reported a graph showing the reduction of time, in microseconds, necessary to execute an order from 1995 to 2009.

Figure 5: Evolution of order processing time (1995-2009)



Source: NYSE

The co-location service permits to rent spaces, called *racks,* to place the servers of trading agencies near to the servers of the stock exchange so that the negotiation time can be reduced. The first market where it was possible to use co-location services was the NYSE Euronext.

Co-location has become a lucrative business also for stock exchanges; indeed, they charge fees of millions of dollars to give access, to HFT firms, to rooms where to place their servers as nearer as possible to the stock exchange servers.

In reality, market participants can also use *multiple co-location*. It gives the possibility to place servers in more than one place, positioning them near to multiple stock exchanges.

Very similar to co-location service is *proximity central hosting*. It allows to rent racks from third party, and not from the negotiation platform, as happen with co-location. Often institutions which use this service place their servers in just one place equally distant from the servers of more stock exchanges.

Algorithms of HFT allow to modify and cancel order quickly, too. The high number of orders submitted and then cancelled leads to a high order to trade ratio (OTR). It represents the percentage of how many orders are issued with respect to the number of orders effectively executed. Data suggest that only 1% of the total orders result in a trading contract.

An element that has had an important impact in the spread of HFT is the so-called *tick size*. It is the minimum price movement of a trading instrument; it can be the same for a specific category of financial instruments or it can depend directly on the price and/or indirectly on its liquidity; hence, a low tick is a characteristic of low priced and high liquid share. In some markets the tick size is regulated, while in some others it is not, and is determined by the actors of the markets.
The continuous reduction of the tick size has led to the development of specific HFT strategies, like the possibility to place orders in the highest part of the negotiation *book* or place orders for the purpose of verifying its dept, and thus attract more liquidity and volumes.
A reduction of the tick size allows investors to take two advantages: reduction of both the bid ask spread and the transaction costs. On the other hand, a small tick size, reduce the dept of the book because now it is less expensive to place new orders discouraging trades from firms which provide liquidity and inappropriately encouraging HFT firms to place orders and subsequently cancel them before execution. When the

tick is too small, limit orders[18] have very different prices and traders do not have any more interest in making their operations in a timely manner and they do not make any more orders.

Software play a crucial role in high frequency transaction, and it can be considered a distinctive element. They can be divided accordingly to their cost and personalization degree in: *in-house*, *tailor made* or *out of the box*.
In-house software requires huge investment of money to develop flexible and unique strategies; they can be used only by institutional investors. On the other hand, tailor made programs are developed by programming companies which create software based on the request made by the trading agency. Since it involves another company these type of programs do not allow for exclusivity in the strategies pursued but, it also costs less than in-house software. Finally, out of the box programs are developed by external companies, they cannot be re-programmed, and the degree of personalization is the lowest.

2.2. HFT how fast can you go?

Speed is crucial for high frequency trading. Speed or frequency is referred to insertion, modification, cancellation and execution of orders sent to market platforms.

Competition among traders has pushed the limit always further and further to ensure riskless profits by exit from taken position in a very small amount of time. New investments and new technologies permit to reach execution time smaller than 1 millisecond. As we can see in the figure below, the NASDAQ is the fasted exchange with just 0.177 milliseconds to execute a trade.

[18] A limit order is a buy or sell order at a specific price for a specific quantity. It is different from market order which is an order to buy or sell at the market price.

Figure 6: Time taken by exchanges to execute trades in milliseconds

Source: Mondo Visione

To make a comparison with the human brain, it needs about 3 hours to read a scientific journal, 5 minutes to read a newspaper article and a couple of seconds to read a tweet of 140 character. On the other hand, the time requested by algorithms is significantly smaller, as it is possible to see in the above graph, where the average speed to execute a trade in those 8 stock exchanges is 7 milliseconds.

2.3. Identification methods

High frequency traders share very similar operative characteristics, and these make it difficult to identify them, but there are two main methods that can be used: direct method and indirect method. The indirect method also includes identification of pursued strategies. It is important to note that these two methods often give different results in assessing the number of HFT firms in the market.

The direct method identifies HFTr using information given by trading platforms about operators that executes proprietary trading at high speed as principal activity. This approach can be divided in two identification categories based on two different aspects: the first rely exclusively on the core business of the trader, the second focuses on the use of services that allow to reduce the latency. With the fist category it is possible to identify *pure* high frequency traders, e.g. agencies whose main business is HFT excluding many different operators which executes high frequency operations but not as main business. It usually underestimates the number of the firms pursuing HFT activities.
Conversely, the second category do not require information about the trader core business, but it includes firms that use services to reduce the latency, such as co-location and proximity central hosting.
While the first method usually underestimates the number of firms pursuing HFT activity, the second one overestimate it.
Overall the direct method has the advantage to be very simple.

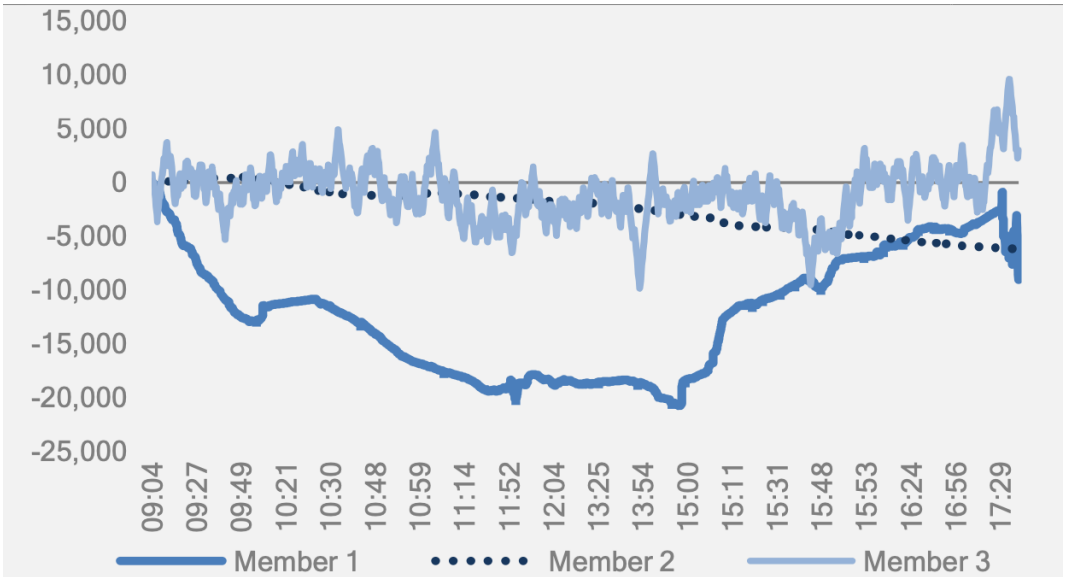
The indirect approach identifies HFTr analyzing the operating trading activities executed by the actor. These trading activities are intraday inventory management; lifetime orders; message traffic and strategies identification.

Knowing that a peculiar characteristic of HFT is to not be a net buyer or net seller, meaning that it principally keeps a flat position and do not have overnight inventory, it is possible to recognize a high frequency firm computing the intraday inventory management through mock-up data. A company will be identified as a HFTr if it uses an intraday inventory management compliant to HFT strategies. This method permits to identify some strategies, like for example market making, but conversely it fails to recognize some others. It is quite expensive, since it analyses huge amount of data trying to identify the underlying strategy, and unreliable because it may include in the HFT category also traders who are not.

European agencies take in consideration the intraday inventory management when they have to identify HF firms too. Looking at Figure 7, we can see the definition of

HFTr according to ESMA[19]. On the vertical axis it is possible to see the intraday inventory management while on the horizontal one we can see the time over an entire day. It is possible to identify three trader's behavior, denominated Member 1, Member 2 and Member 3. The first member, blue line, make a small number of trades and close the day in almost a flat position. We can define Member 2 as a net seller; indeed, the dashed line continuously goes down. Finally, member 3, can be defined as a high frequency trader since it executes a very high number of exchanges over the entire day and, most important, it tends to continuously level off its positions.

Figure 7: Intraday inventory management



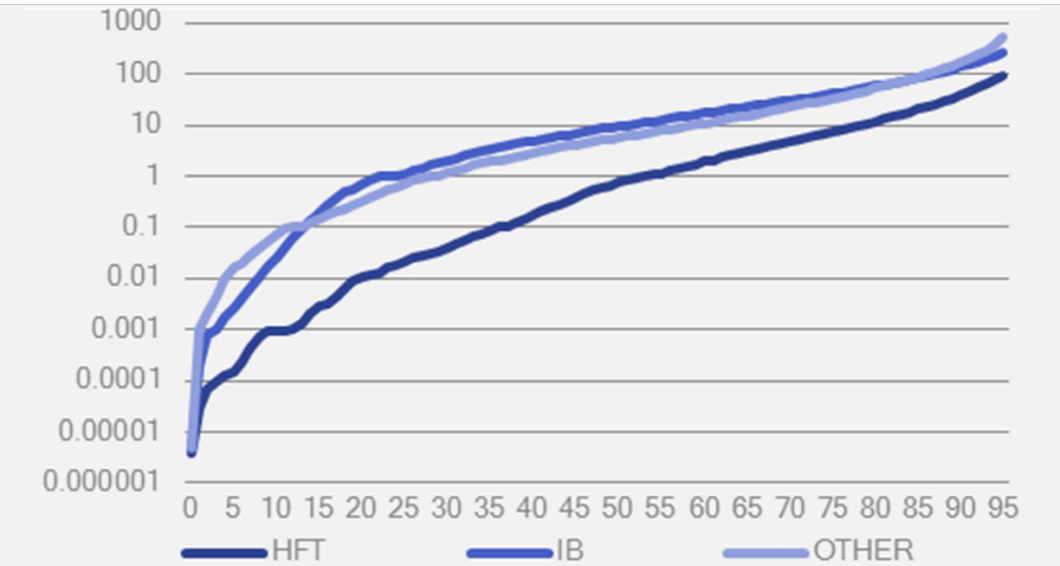
Source: Economic Report, High-frequency trading activity in EU equity markets, ESMA, 2014

Another method to identify HFTr consists in looking at the orders lifetime, that is the holding period of positions before the order is executed, modified or cancelled. Higher is the number of orders modified and/or cancelled, higher is the probability that the firm

[19] "ESMA is an independent EU Authority that contributes to safeguarding the stability of the European Union's financial system by enhancing the protection of investors and promoting stable and orderly financial markets."

is a HFTr. This method is quite difficult to use because it involves the analysis of each order for all securities traded for every trader. Figure 8 shows the lifetime of orders for different market participants: high frequency traders (HFT), investment banks (IB) and others (OTHER). On the vertical axis is reported the time in seconds, and on the horizontal one there are the percentage of orders modification and/or cancellation. The actor that is able to modify and/or cancel the highest percentage of orders in the smallest amount of time is identified as a HFTr. It is reported that firms identified as HF are able to modify and/or cancel 40% of the orders already sent in less than 0.2 seconds. Investment banks and other firms are able to alter and/or delete 40% of the orders already delivered in less than 5 seconds and in less than 3 seconds respectively.

Figure 8: Distribution of lifetime of orders

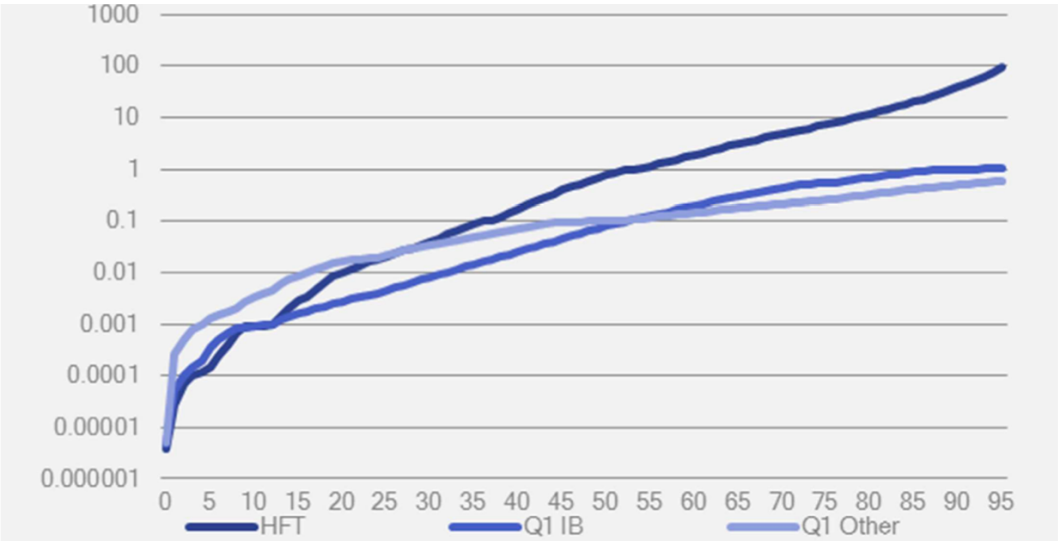


Source: Economic Report, High-frequency trading activity in EU equity markets, ESMA, 2014

The report also highlighted that 25% (first quartile) of the fastest investment banks, reported in the graph as Q1 IB, and of the quickest other firms, depict as Q1 Other, were able to modify and/or cancel their orders faster than the median of HFT

companies, as shown in Figure 9.

Figure 9: Quartile of lifetime of orders



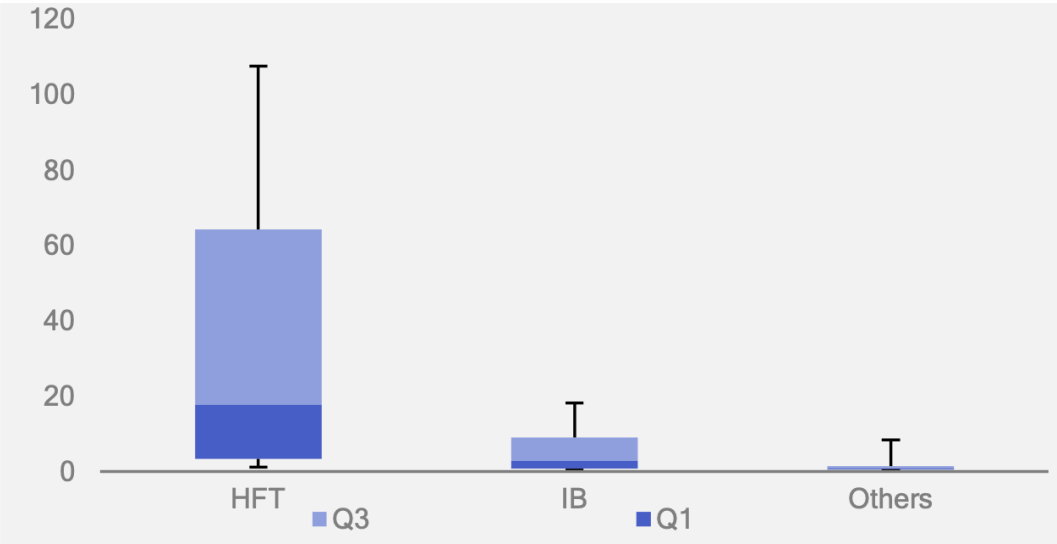
Source: Economic Report, High-frequency trading activity in EU equity markets, ESMA, 2014

An alternative is to compute the already mentioned order to trade ratio (OTR), but in this circumstance it represents a measure of message traffic rather than a measure of HFT because it depends on the strategies adopted by HFTr. Its formula is equal to:

$$OTR = \frac{ORDERED\ VOLUME}{VOLUME\ LIMIT}$$

The logic under this method is quite simple: higher is the number of massages and/or input send to trading venues during the day, higher is the probability that the trader in question is a high frequency one. According to ESMA's report and Figure 10, the median OTR is around 18, the first quartile is around 3 and third one around 64, leading to a not homogeneous category due to different strategies implemented. For investment banks and other firms the OTR is more center around the median.

Figure 10: Dispersion of OTR



Source: Economic Report, High-frequency trading activity in EU equity markets, ESMA, 2014

It is also possible to distinguish HFTr according to its operative characteristics. It can be defined HFTr those traders that: make proprietary trading; have position close to zero at the end of the day and execute high number of orders of small value. Each of which do not exclude the others.

It is important to remember that the use of direct or indirect method leads to conflicting results. Indeed, as reported in the 2015 Consob working paper of Caivano V., named *The impact of high-frequency trading on volatility*, using the direct system, HFT counts for 24% of all European trading activity in 2014, while, with the indirect approach the data was about 43%.

2.4. Fundamental electronic devices

The process of electrification has led to the use of specific drivers to facilitate the interaction between traders and trading venues. Smart Order Routing (SOR), Direct Market Access (DMA) and Sponsored Access (SA) are such important digital drivers.

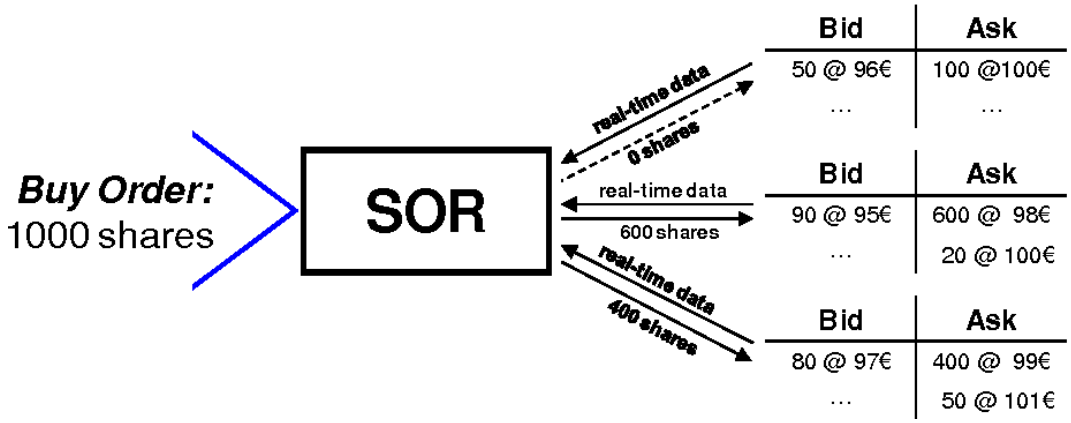
The SOR is able to guarantee to traders a quick and easy access to the best available price in every market and in every moment. It analyzes all the markets in real time to find the best bid and ask solution for a specific order, resulting in the best characteristics possible.

It helps to reduce the complexity of financial markets by giving multiple access to liquidity pools identifying the best venue to execute the order and optimizing its execution. The smart order routing is used to find the best solution in the smallest amount of time possible.

It was the direct consequence of the NBBO in America and the best execution price in Europe.

Figure 11 below, shows the functioning of the SOR with an example. The order is to buy 1000 shares; the system analyzes all the markets, only 3 here, in real time and receive the bid and ask prices. As it is possible to see, the first market offers 100 shares for €100, the second has an ask price of €98 for 600 shares and €100 for 20 shares, finally, the last market offers 400 shares for €99 and 50 for €101. After making its computation to offer the best bargain the system suggests to buy 600 stocks from the second market and 400 from the third one, generating a total expenditure of €197, with an average price per share of €98.40 resulting from $\frac{600}{1000} \times €98 + \frac{400}{1000} \times €99$, which is the best possible execution price.

Figure 11: Example of the function of a smart order routing



Source: Smart order routing technology in the new European equity trading landscape, Ende B., Gomber P., Lutat M., 2009

The direct market access is a particular service offered by some brokerage firms that permits to private traders to place buy and sell orders directly to the trading venues' book without being registered as a broker. High frequency traders which use this method are able to control each step of the transaction rather than passing the order to a broker for its execution. DMA provide the conduction of pre-trade risk check.

The sponsored access is another possibility to enter a market available on the buy side. It is alike DMA; the difference is that investor does not use the broker's infrastructure, but it uses the intermediary's membership ID. The agent that provide sponsored access to its clients can conduct pre-trade risk check only whether the execution venue provide such service, in this case the access takes the name of Filtered Sponsored Access.
With Unfiltered Sponsored Access, also said naked SA, the brokerage firm only receives a copy of each order send by the investor to the trading venue, and the control is executed by checking this information.

Direct market access and sponsored access have the advantage of lower costs and anonymity; the main advantage of unfiltered sponsored access is time, indeed with this

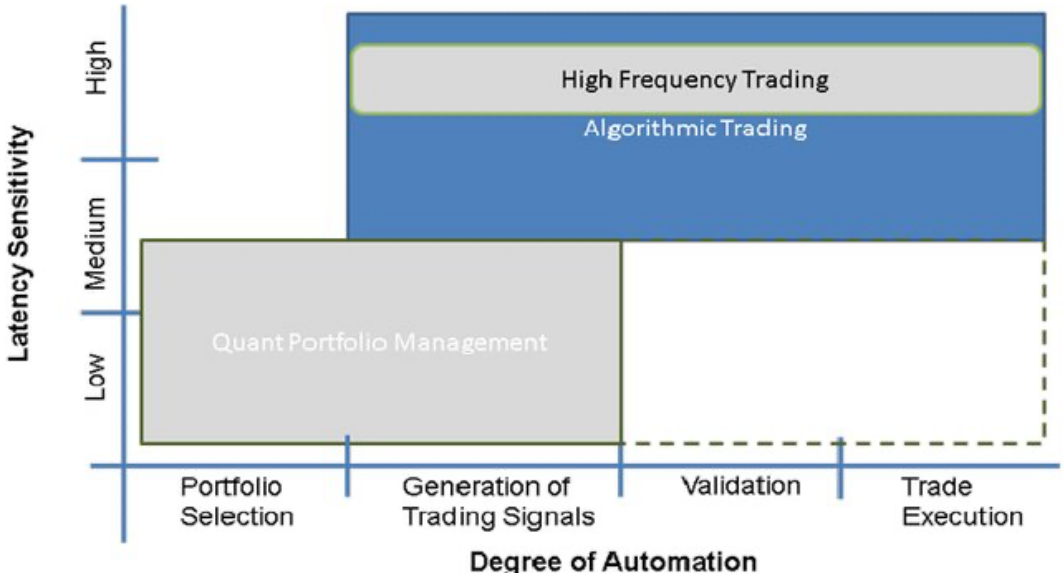
method there is a reduction in the time of order submission thanks to the lack of broker's pre-trade check.

2.5. Quantitative portfolio management

Similar to HFT is quantitative portfolio management (QPM). This approach can be confused with high frequency trading since both systems use complex tools with computers, but QP managers use quantitative models to design their quantitative portfolios. The securities included in these portfolios are selected through a deep quant analysis. This analysis is used to evaluate many variables, then the quantitative model will compute the profitability of the investment. The final decision to buy or sell is based on the model used but, differently from HFT, humans intervene with their knowledge. Hence, QPM has a high degree of men intervention.
Another difference with respect to HFT is that quantitative portfolio strategies keep securities for longer period, their focus isn't liquidating position within a trading session.

In Figure 12, reported below, it is possible to compare the automation level among QPM, AT and HFT. For the first method, the automation process regards the selection of the securities in portfolio, but the validation of the results obtained and many times the execution are not automated, but rather they are executed by a human trader.

Figure 12: Automation degree in QPM vs. AT and HFT



Source: High frequency trading, Gomber P., Björn A., Lutat M., Uhle T.E., 2011

Typically, these quant strategies are run by highly educated teams which use their own models to try to beat the market.
Furthermore, there are evidences which highlight that quantitative approach perform well in bull markets and not so good in bear ones.

2.6. Profitability

As already said, HFT industry is able to obtain a very small profit for each transaction, but how small? In a first analysis it seems clear that profit of HFTr depends on three main factors: market size, number of trades and bid ask spread.

In their analysis, Brogaard, Hendershott and Riodan analyzed 26 high frequency traders which made their operations on NASDAQ from 2008 to 2009. It emerged that the average net profit was $173.77 per day for each company for a medium size transaction, $6,651.03 for large trade and only $29.86 for small volume deals.

However, three other researchers, Kearns, Kuzleska and Nevmyvka, in their paper

Empirical limitation on High frequency trading profitability, showed that high frequency industry is able to earn only "surprisingly modest" profits. In their analysis the three defined an upper bound of $21 billion for the entire American stock market with long holding period; for short holding period it was fixed in $21 million. According to them both values overestimate the profit that is possible to realize in the real world.

On the other hand, not all researches agree with the preceding statement. Baron, Brogaard and Kirilenko compared the high frequency industry to large and organized distribution where the high level of competition brings down the revenues. However, in their paper *The trading profits of high frequency traders,* the same authors showed that even if HFT firms face system and credit risks, among others, they are able to generate a high Sharpe ratio[20], where a higher Sharpe ratio indicates a better risk adjusted performance. They concluded saying that the net profits of HF industry are significant even if they were not able to compute exactly them after including all the costs arising from informatic systems, labor, supervision and risk management systems.
But let's go deeper: in his paper *High frequency trading and its impact on market quality*, Brogaard tested the null hypothesis that HFT is not profitable. As already happened with other research papers, also in this one he took in consideration only trades on the NASDAQ, and again 26 HFT firms had been analyzed. In the paper the profit is computed as:

$$Profit = \sum_{t=1}^{T} \left[1_{sell,t} \times Price_t \times Shares_t - 1_{buy,t} \times Price_t \times Shares_t\right]$$
$$+ E\,(Price) \times \sum_{t=1}^{T} [1_{buy,t} \times Shares_t - 1_{sell,t} \times Shares_t]$$

where: 1_{sell} and 1_{buy} are dummy variables, the first takes value of 1 if the HFTr sells a stock in the operation and 0 otherwise, and the second works in the same manner but if the HFTr buys a share, $Price_t$ is the price at which operation t is executed and $Shares_t$ is the number of share in trade t. If we sum the profit for each share in a specific day, we are able to compute the total gain of HFT in that day. The result is a daily average

[20] The Sharpe ratio compare the return of an investment to its risk; it is a measure of performance of a specific investment, adjusted for its risk, in comparison to a risk-free one.

profit of $298,000 for 120 stocks exchanged. We can safely assume that this result underestimate the real profitability of entire HFT industry for at least two simple reasons: it takes in consideration exclusively the NASDAQ, which represents only 20-30% of all the negotiations, and 120 shares are not sufficient to represent the entire investment landscape.

Moreover, he computed the annual profit as:

$$Annual\ profit = \frac{1}{2}\sum_{i=1}^{N}\sum_{t=1}^{T}[HFT_{i,t} \times DVOLUME_{i,t} \times 0.000072]$$

where 0.000072 represents the profit per dollar traded.
The paper leads to the conclusion that the gross profit, hence the one which embed transaction costs, of HFT is around $2,8 billion annually on $39.3 trillion traded in a year. No adjustment was made for commissions since the author explained that they are relatively small, taking advantage of the fact that HF traders pay trade only when they take liquidity, while they receive a discount when provide it. To make an example, the NASDAQ charges $0.25 per 100 shares for who take liquidity, while it offers $0.20 for the same amount of stocks to liquidity providers.
The author also estimated that given the transactions of HFTr the fees almost cancel each other.

Tabb, Iati and Sussman, according to their analysis, estimated in a first analysis that the profits of HFTr are more than $21 billion, subsequently they revised their value lowering it at $8.5 billion. Shack and Gawronski suggested that the estimation of their colleagues was not correct because they have overestimated them. Finally, Donefer propose a value between $15-25 billion. Arnuk and Saluzzi took in consideration only aggressive strategies of HFTr and estimated $1.5-3 billion per year.

As a consequence of lower trading volume and volatility reduction, half compared to previous years, profits in the HF industry have declined. The reduction in volatility lead to contraction of the arbitrage profits while the diminution of trading volume cut the earnings from bid ask spread.

According to the preceding lines, Deutsch Bank in 2016 asserted that the profit of the American HF sector reduced from 7.2 billion in 2009 to 1.3 billion in 2014.
Even Rosenblatt Securities, agency broker and investment bank, emphasized the fact that in 2009 a HFTr traded 3,25 million share per day, while in 2012 only 2,6 million, resulting in $5 billion profit in 2009 and just $1 billion in 2012. The average profit dropped from $0.01 per share to $0.0005 per share.

The profit reduction has the consequence to move HFTr in other markets, which were considered not profitable enough until few years ago like for example currencies, options, futures and bonds, bringing to the so-called *colonization* of the entire trading industry.

In conclusion, it is important to note that the high turnover of shares that characterized HF portfolios generates high volume of fees for stock exchanges representing a big part of their profits. In 2011, on NYSE Euronext commissions were around $3,162 billion, 70% of all revenues of the year.

2.6.1. Does profitability change in long and short term?

Moosa in his research paper *The regulation of high frequency trading: a pragmatic view* showed that standard deviation is lower for shorter holding period since prices are less volatile in short intervals rather than long ones. In this circumstance the Sharpe ratio can be a misleading indicator, indeed since it can be computed as:

$$Sharpe\ ratio = \frac{Portfolio\ retun - Riskfree\ rate}{standard\ deviation\ of\ the\ portfolio'sexcess\ retun}$$

the presence of standard deviation at denominator, leads to higher value of the ratio with short holding period.

In addition, it is to take in consideration that also transaction fees heve a very important impact on high frequency trading profitability, this because huge amount of fast trade means equally high quantity of commissions.

The already cited author, pointed out that HFTr and long-term investors pursue two different strategies: the first ones take advantage of small differences in prices buying and selling shares quickly during the day, while the second ones take and keep a long position to benefit from the market cycles.

In conclusion there is no relationship between profitability and holding period.

2.7. Fees on HFT

Competition has a strong impact on commissions and lead to complex market structure which needs to be frequently revised and modified. New commissions were developed to allow HFTr to profitably work in the industry.

The empirical evidence shows that the market tries to attract high frequency traders applying special discounts in their tariffs to algorithmic orders. Volume of the trade and type of order, for a client or for HFTr own interests, are discriminating elements that allow the market to apply a differentiation in the prices.

Some Multilateral Trading Facilities (MTFs), among which the fastest in Europe is *Turquoise*, introduced very aggressive commissions and started to offer new tariff systems like for example *asymmetric pricing*.
Asymmetric pricing, also called *maker-taker*, divide market participants in two groups, the one which absorb liquidity by placing orders to execute proposal of the book, and the one that provide liquidity by insertion of high number of orders. The first group will pay commissions, while the second one can take advantage of a particular discount, called *rebate*.
Due to this aggressive commissions system some European stock exchanges reduced their commissions while others adopted the asymmetric regime.

Other type of commissions are *cliff-edge* and *cross subsidy*. The first one applies different fees taking in consideration the volume of the order and the time necessary to place it, while the second one applies different costs according to the liquidity of the specific financial instrument traded.

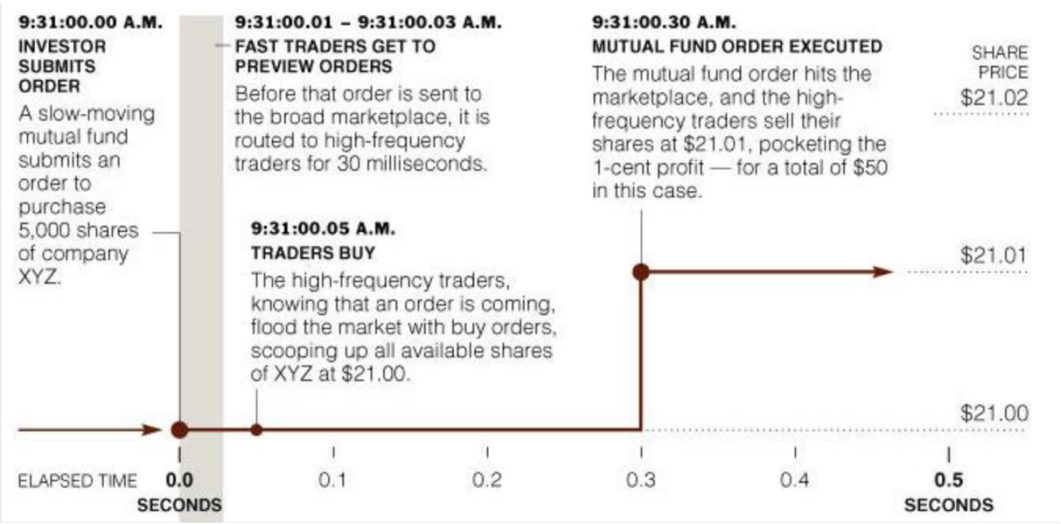
Asymmetric fees seem to encourage HF operators, since they boost liquidity provision and thus give a sort of advantage to more liquid securities negotiation, which in turn are the preferred financial instruments' category of HFTr.

2.8. The advantage of being the fastest

The algorithms used by HFTr are also called *quant*. With this name, it is identified those algorithms which require from 3 to 5 microseconds to execute an order.

Below, in Figure 13, is reported a typical order execution on NYSE managed by a HF algorithm. At 9:31:00.00 in the morning a mutual fund sends an order to buy 5,000 shares of a specific company, called XYZ, whose price in that moment is $21.00. In 30 milliseconds the HF trader intercepts and analyzes the order before it becomes public, and then it executes its strategy: first, since the order previously analyzed is a purchase order, it buys all the shares of company XYZ at $21.00, hence no more stocks are available at that price. Then, the order of the mutual fund reaches the market and the HFTr sell the shares at $21.01 realizing a profit of $0.01 per share, yielding a total profit of $50.
Meantime, the process of price discovery has been influenced by the huge amount of acquiring orders placed by the algorithm with the result that it reaches $21.02 forcing a potential investor A to pay for XYZ share 0.02 more than the previous price.

Figure 13: The 30 milliseconds advantage



Source: New York Times, 23th July 2009

The consequences of this type of algorithms are clear: their automatically generated orders confuse institutional investors, alter the prices and divert any program which observe the movements of the main market actors.

3. Computers' strategies

There are many institutions, with different business models, which use HFT and there are many associated hybrid forms. For that reason, to analyze the phenomenon all HFT strategies must be taken in consideration regardless of whether they are core business or simply a way to execute negotiation strategies. Therefore, we should adopt a functional, and not an institutional, perspective because the purpose is not to identify the users, but rather, to identify the strategies.
It is quite important to recognize as many strategies as possible, since different approaches have different consequences in the market. It is feasible to distinguish strategies executed by computers analyzing their effects in the marketplace, like for example, taking or adding liquidity. Furthermore, algo-traders can act as a price taker[21] or as a liquidity provider[22]. This allow them to issue marketable orders, and also orders which are not matched but positioned on the trading book waiting for matching.

As it is possible to imagine there are many different strategies, but there are two common elements: the ability to issue, modify and cancel orders at a very high speed and the nearly continuous trading activity.

Not all algorithmic strategies belong to the high frequency category. Algorithmic strategies used by AT have the main purpose of reducing the market impact of large orders, they split a huge order into smaller ones and distribute them over time.
Some algo strategies, with some small changes, can be applied to HFT, where the only difference is low latency.

3.1. Algorithmic trading strategies

Algorithmic trading strategies support human traders granting the best execution. Their main goal is not to make profit but to execute trades in the client's best interest.

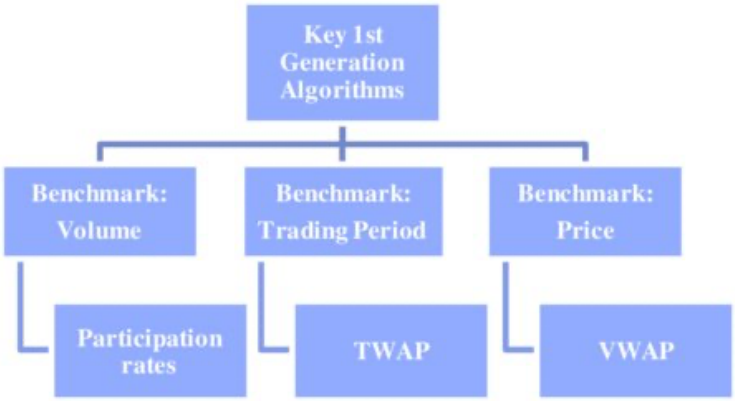
[21] A price taker is an individual or a firm that must accept the prices of the market because they don't have the power to influence them.
[22] A liquidity provider is an individual or a firm that do not want to deal at the market prices, hence it places orders in the book at better prices waiting for another operator who accept their conditions.

According to Almgren R. and Johnson B. but also Gomber P., Björn A., Lutat M., Uhle T.E., it is possible to classify algorithmic strategies into four generations.

3.1.1. First-generation algorithms

The first-generation algorithms focus only on benchmarks based on market data and are independent from actual order and order book situation at order arrival. They are developed to reach specific benchmarks, like volume, trading period and price as shown in Figure 14 reported below.

Figure 14: First-generation algorithmic trading strategies



Source: High frequency trading, Gomber P., Björn A., Lutat M., Uhle T.E., 2011

There are three type of algorithms in this category:

- *Participation Rate Algorithms*: programmed to participate in the market up to a prespecified volume. This algorithm reflects the current market volume in their orders;
- *Time Weighted Average Price Algorithms (TWAP)*: split big size order into small size ones over equally distributed time intervals. Before the execution takes

place, the algorithm decides the size and the time interval but later, they can be modified to avoid detection from other market operators;

- *Volume Weighted Average Price Algorithms (VWAP)*: try to match or beat the weighted average price which represents the benchmark for a specific time interval. They are developed using historical volumes profiles to estimate target period and volume.

3.1.2. Second-generation algorithms

The second-generation algorithms try to define the benchmark based on the single order and handle the trade-off between market impact and timing risk. They try to minimize implementation shortfall. At the arrival of an order the current price represents the benchmark to be met or outperformed. Taking in consideration potential negative price movements during the execution process, which represent the already cited timing risk, the algorithm tries to minimize the effect of large order in the market. To provide protection against negative price trend, the algorithm split an order into as many as necessary but as few as possible sub orders over a long enough period of time to minimize the market impact of the overall order.
They differ from the first-generation algorithms for the longer period of time used.

3.1.3. Third-generation algorithms

The third-generation algorithms are characterized by the capacity to adapt to their own performance during executions. Instead of using a predetermined program, these algorithms adapt their own execution plan during the same execution process adapting to continuously changes of the market. They are also able to use a more or less aggressive strategy.

3.1.4. Fourth-generation algorithms

The fourth-generation algorithms are also called newsreader algorithms and are the most similar to high frequency strategies. They take inspiration from the fact that investment decisions have been always relying on news. They go beyond the limit of

human mind in the quantity of data it is able to process and its speed.
These algorithms are able to read news at high speed through the implementation of statistical methods and text-mining techniques to estimate the impact that a news can have in the market. Exchanges have developed electronically processable news that allows these algorithms to work correctly.

3.2. High frequency trading strategies

The high frequency phenomenon includes a wide range of strategies and techniques that can be group according to their aggressivity and complexity.
Additional elements to identify HFT strategies rely also on goals pursued by the HF firm and the markets where it works. Different strategies involve different effects in the market and also different regulatory issues.

High frequency strategies take advantage of their very high speed and their constant operativity in the market, these two characteristics allow to quickly adapt to the changes of the markets and respond adequately to the needs of the market itself, they are able to understand the level of the liquidity and the dept of the negotiation book. The frequency in this situation is fundamental for rapid placement or modification.
In the big part of the strategies pursued by HFTr profits are realized on small changes in prices and with rapid capital rotation.

According with the SEC, Gomber et al. and Puorro, there are four macro categories of trading strategies executed by high frequency firms: statistical arbitrage, liquidity providing, directional and structural. Each macro category has subcategories which lead to different strategies that have different consequence on profit and market impact.

3.2.1. Statistical arbitrage strategies

Arbitrage consists in realizing profits taking advantage of price differences of the same financial instrument, exploiting market inefficiencies that cause different prices in different markets for the same stock. Theoretically arbitrage opportunities should not

exist since market absorbs every information immediately, but in reality, they are constantly present in the market due to temporary inefficiency.

Statistical arbitrageurs identify similar instruments that are mispriced and once they have identified them, they buy the cheapest and sell the most expensive one.
Obviously with the recent developments in capital markets it is always more difficult to detect and exploit arbitrage opportunities, since they are now able to absorb them very quickly, and for this reason it is necessary to be fast. Since HFTr are the fastest operators of the market they are almost the only actors able to take advantage of arbitrage opportunities, using their competitive advantage both in the identification and in the execution phase. High frequency algorithms are able to identify arbitrage opportunities in the same moment they appear in the market representing one of the most profitable strategies for HFTr.
Market neutral and cross arbitrage are sub-category of statistical arbitrage strategies.

3.2.1.1. Market neutral

It implies to hold a long position in an asset considered undervalued and at the same time a short position in a closely related overvalued one. The possible risks offset each other thanks to the two opposite position owned by the trader. When prices of correlated assets normalize in the estimated expected values, the high frequency operator liquidates the positions to obtain a profit.
Thanks to its computational power high frequency actor can manage a portfolio of hundred securities and, by frequently change the shares in it, can eliminate the exposure to market risks.

3.2.1.2. Cross arbitrage

Cross arbitrage is possible thanks to the fact that the same financial instrument can be traded in more than one trading venues, due to market fragmentation, and in each of them it can have different prices. Cross arbitrageurs are able to make profits by buying the asset in the venue with the lowest price and sell it in the platform with the highest price.

Cross arbitrage strategy is also applicable in ETFs[23] always taking advantage of price differences.

3.2.2. Liquidity providing

High frequency traders can act as market maker, and like them can offer liquidity to the market when it is low. The main difference is that a high frequency trader is not obliged to comply the provisions and the regulations of a real market maker, such as continuous two-sided quotes, quotation timing, maximum spread and minimum quantity; thus, they can strategically decide of which order be the counterparty.

High frequency firms trough liquidity providing strategies are able to place their orders in the first part of the book, meaning at the best price another operator is willing to buy or sell a financial instrument.

Low liquidity is a basic requirement for an efficient liquidity providing strategy, indeed if there will be high volatility it can be not profitable since the result would be an increasing spread penalizing HFTr which act as market maker.

The only risk arising from this strategy is an unexpected increase in volatility, but it can be easily hedged through modification or cancellation of orders thanks to high speed of algorithms. In this way the risk is substantially zero.

High frequency traders can earn profits with liquidity providing strategy in two ways: from the spread between the bid and ask, called spread capturing approach, and from incentives from trading platforms in form of reduced trading commissions or rebates, called rebate driven strategy.

3.2.2.1. Spread capturing

As real market makers, HFTr after having analyzed the conditions of the market, are able to earn profits through the bid ask spread, indeed they can place buy and sell orders in the same moment in the book generating profits arising by the difference between bid and ask prices. It is possible to realize earnings thanks to the fact that market makers can buy at lower price at which they can sell.

Traders of high frequency can program their algorithms in a way that they are able to

[23] An ETF (Exchange Traded Fund) is a type of security that includes a collection of securities, which often track an underlying index.

work automatically. They earn a lot of money by continuously placing thousands of orders on a daily basis.
As already said, HFTr are not subject to market maker regulation therefore they can freely abandon positions if a difficult market situation is expected to occur thanks to their speed.

3.2.2.2. Rebate driven

Rebate driven strategies try to realize profits by taking advantage of different commission regimes present in different trading venues. Since trading platforms realize the biggest part of their profits with commissions every venue wants to attract the largest amount of trades possible, and the rivalry among them led to market fragmentation. Ability to absorb large amount of orders and liquidity without compromise operability, very liquid and depth book are key elements to attract HFTr.
During recent years trading fees have steadily decreased especially for operators who bring liquidity to the market; sometimes they have even been negative.
The consequence of such close competition on trading fees guided to develop *ad hoc* commission trying to attract as many clients as possible, so that to attract liquidity providers some trading venues use asymmetric fees: market participants who take liquidity from the market are charged of higher fees, while members who offer liquidity are charged of lower commission or they can receive a discount, the already cited rebate. With this strategy, called *maker/taker*, the traders accumulate rebates offered by trading venues.
As already said, there are other two main commission systems: cliff-edge and cross-subsidization.
Thanks to their high-speed algorithms HFTr are able to reduce the risks arising from this strategy at the lowest level possible, indeed if the situation become complicated, they will be able to modify or cancel the orders already send to the trading platform.

3.2.3. Directional strategies

Directional strategies usually involve a long or short position to benefit of an intra-day price movement, upward or downward. These strategies are executed with

aggressivity, by taking market liquidity in order to obtain a profit thanks to short time market trends.
They include strategies that can be easy but also complex, like anticipating other traders that will affect prices, such as large traders.

3.2.3.1. Momentum trading

Momentum trading strategy is also called trading on news. As we have already seen, it is also implemented by the fourth generation of algorithmic trading strategy but with small differences. It is one of the simplest and intuitive approach available, indeed, its focus is the news able to modify the prices of financial instruments present in the market generating a possible trend. After processing and analyzing all the information deemed important the algorithm takes the best strategy in order to realize a profit. To make this strategy works it is necessary to implement newsreader algorithms, which are able to understand the news and millions of data present in the market. Just to clarify how this strategy works, it analyzes how many times a specific word, sometimes entire sentence, is present in the news and then it processes a specific strategy. Here is a real example: on August 23th, 2013 the news on resignation of Microsoft Corporation's CEO, Steve Baller, were published and suddenly an important increase in the Microsoft share price occurred. In this situation HFTr read the news, analyzed them and took advantage of upward trend buying the shares before other traders.
But algorithms are not able to verify if a news is real or not. On April 23th, 2013, when Associated Press published a tweet regarding explosions inside the white house, which in reality were not occurred, HFTr closed all long positions to exploit the possible downward trend. This event was the trigger of the successive flash crash during the same day.

3.2.3.2. Liquidity detection

With liquidity detection high frequency operators observe the behavior of other actors and gather liquidity offered by the market. Liquidity detection systems verify the

presence of stop loss and take profit[24] orders by sending to the book small orders to test specific price levels. Liquidity detection algorithms are also able to evaluate the presence of big orders in the book, meaning orders which are too large to be executed all at once. It is fundamental because once price levels are detected, they allow to HFTr to know other traders' order position. Knowing the positions of other participants permit to high frequency operators to interfere with competitors' strategy. Once HFTr detect the already mentioned price levels they just need to bring the price of the financial instrument to the right level in order to automatically trigger stop loss or take profit orders of competitors, which start to release their liquidity.
The trader which decides to execute this strategy acts as price taker since it benefits from liquidity that other traders offer to the market.
Both stop loss and take profit orders are very predictable and are easy to be find by HFTr.

3.2.3.3. Ignition momentum

It can be considered a subcategory of liquidity detection strategy, but at the same time there are two different features: ignition momentum requires a very aggressive long and short position and it is more complex. It consists in influence other traders' behavior through its aggressivity. Thanks to the long or short position the price of the financial instrument in question changes and the high frequency trader closes its position at advantageous price. The momentum ignitor trader places orders very quickly to obtain a large position and immediately generate an increase in volatility. The increased volatility can induce other market participants to execute more aggressive strategies or stop loss orders and hence emphasizes the price movements. Since HFTr has previously establish other positions, it tries to obtain a profit when it subsequently liquidates the position after it has spurred the evolution of price movement on the expected side.

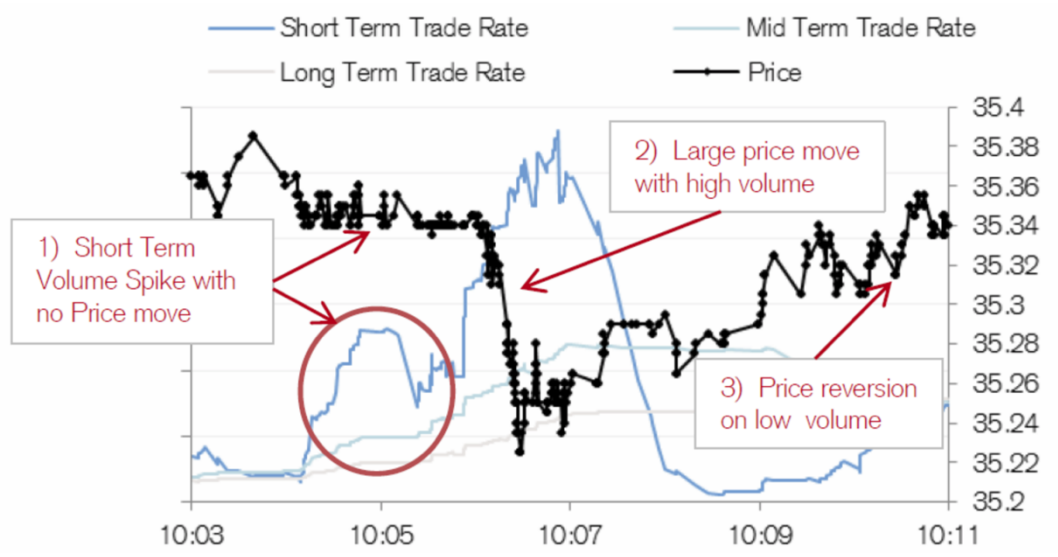
This strategy has three main characteristics as it possible to see from Figure 15: the price doesn't change even if the volume traded increased, large price movements are

[24] A take profit order automatically closes its position as soon as the price reaches prespecified level in order to generate a profit.

due to high volume and the reversion to the starting price is caused by low volume.

The trader which execute the ignition momentum strategy prefer to execute this approach when the volatility is low and the market has small volume orders so that the effect of its strategy will be amplified.

Figure 15: Ignition Momentum strategy and its effect in the market



Source: Credit Suisse AES Analysis, 2012

The phase with high volume and price movements is due to the fact that stop loss orders were triggered. Indeed, they start to release all intrinsic liquidity that accelerate the trend of the price.

3.2.4. Structural strategies

They are strategy executed only by high frequency traders which try to take advantage of structural vulnerabilities of the market or of its participants. They allow to benefit from the presence of less evolved traders and usually have not positive impact in the market. Most famous structural strategies are latency arbitrage and flash trading.

3.2.4.1. Latency arbitrage

Thanks to latency arbitrage strategies, high frequency traders are able to take advantage of small price dissimilarities in financial instruments among different markets arising from extremely little time differences in the prices that they report on the same securities: it exploits a market inefficiency. Latency arbitrage is possible only if the trader in question have a high frequency system able to satisfy the low latency requirements, indeed, to successfully execute this strategy the arbitrage opportunity must immediately be recognized as soon as it appears, since it usually lasts only few milliseconds.

Once again arbitrage opportunities are made possible by market fragmentation. Drivers that allow to fast exploit arbitrage opportunities are fast access to the market, direct data fees and co-location services.

3.2.4.2. Flash trading

It is one of the most aggressive approach that a HFTr can execute. Aggressivity is fundamental for a right execution of this strategy.

It is defined as limit case of latency arbitrage. Even if profits are huge and free of risks, the threats for the market quality are high.

Who decides to execute this strategy takes advantage of market fragmentation and try to earn as much money as possible in the time interval between the private vision of orders and the moment when these orders became public.

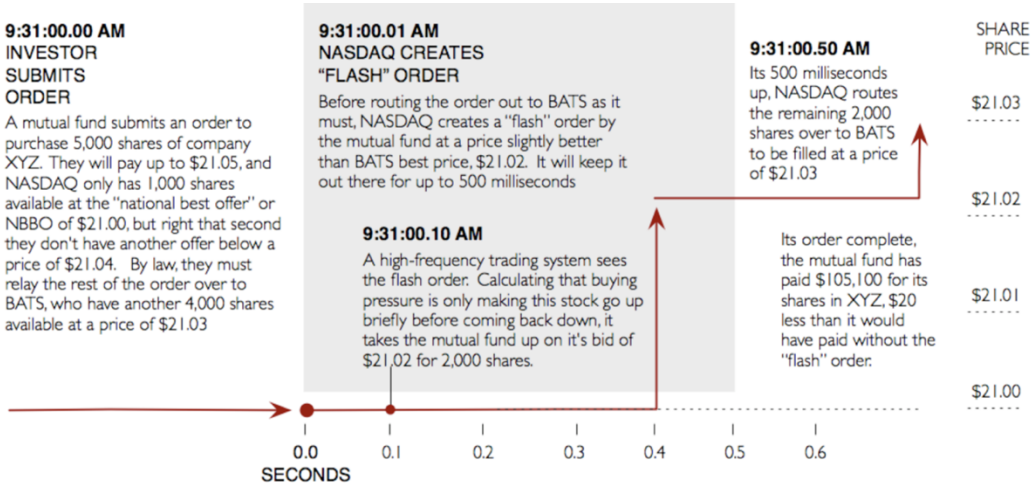
How does it work this strategy? As soon as the market or an ECN receives an order that cannot be executed at NBBO, it is not automatically transferred to the market where NBBO is present, but instead it is offered in visibility to HFTr. The possibility to privately view the orders before all other traders is ensured by ECNs, which provide a specific service for a fee. This service is called flash trading, and the orders that can be seen before they became public are called flash orders.

Sometimes it is possible that these orders are not executed since the NBBO price condition is not present, in this case they are available for high frequency traders giving them an informational advantage.

Even if this strategy has collected numerous criticisms, empirical analysis shows that

it is an opportunity for better market conditions, increasing the liquidity and improving the price discovery process.

Figure 16: Example of flash order



Source: How Flash orders Work, Sharp A., Seeking Alpha, 2009

Above, in Figure 16, is reported a deeper analysis of a flash order strategy, reported also in previous Figure 13. First, an investor sends its order to buy 5,000 shares up to $21.05 each. On NASDAQ there are only 1,000 shares at $21.00, which represents the NBBO. The second-best available price in the American market is $21.04. According to the law 1,000 shares are bought at $21.00 on NASDAQ, and the remaining 4,000 are bought on BATS[25], where the price is $21.03. Before sending the order to the BATS platform, the NASDAQ creates a flash order for 4,000 shares at a lower price than the BATS, meaning at $21.02 and offers it to high frequency operators for a very small amount of time, i.e. 500 milliseconds. Then, a HFTr sees the order and decide to be the counterpart, but only for 2,000 shares, since algorithms have detected little profitability. Finally, the NASDAQ sends the order for the remaining 2,000 shares to the BATS for a price of $21.03.

[25] BATS is an exchange based in the US where are traded many different types of financial instruments.

Thanks to flash trading the initial investor pay $105,100 in total, saving $20 which are the ones that it would have paid without the flash order.
The high frequency trader always earn money, independently from its position, indeed:

- If it had been short, it could exploit its informational advantage closing immediately its position avoiding losses;
- If it had been long, it represents an opportunity to close or diminish its position at a good price;
- If it had been flat, exploiting its velocity it could have found a seller of the share in question at a price lower than $21.02 and then sell it at $21.02 being sure that the shares would be bought.

3.2.5. Layering, pinging, quote stuffing, smoking and spoofing

These high frequency strategies are the best to exploit the predictability of traditional traders. They rely on market simulations to bring traditional traders to execute hasty and wrong choices so that HFTr are able to realize suitable strategies to realize profits free of risks.
These approaches have in common the use of limit orders. Once high frequency traders place their orders, they quickly modify and/or cancel them to create distortions for traditional operators who react to false input of the market.

Ch 3.2.5.1. Layering

The HFTr places limit orders at different price levels, different from current market price and away from it, and most of the time cancel the order in the very near future and send the order again.
In this way the high frequency operator misleads the traditional traders who erroneously think that the market is ready for a trend and in turn suspect an error. In this case the high frequency trader will be able to buy or sell stocks at an affordable price.

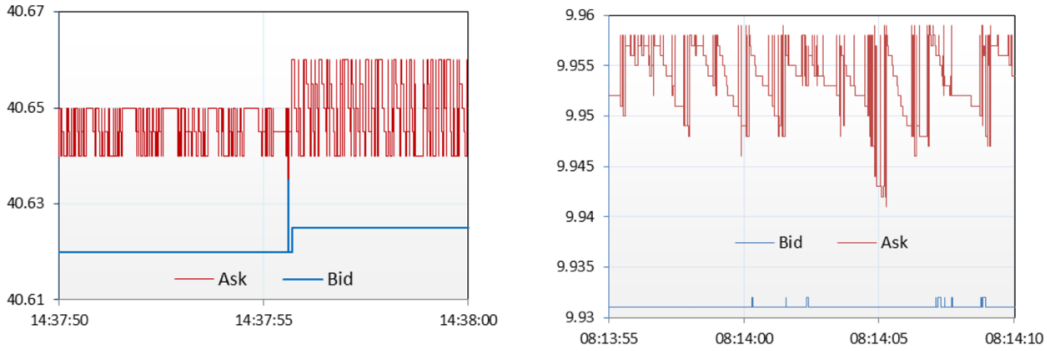
3.2.5.2. Pinging

According to Xu J. we can define pinging as “limit orders submitted inside the bid-ask spread that are cancelled shortly thereafter”. The aim of this strategy is to verify the presence of hidden orders, non observable to other market actors, and ascertain the presence of potential large traders in the market. The pinging strategy allows to trade ahead and capture a price movement in the direction of the large traders’ interest.
Thanks to this strategy, the HFTr try to understand the highest or the lowest price that a counterpart trader is willing to accept to respectively buy or sell a stock through the insertion of high number of orders but of small amount.
It analyzes the presence of limit orders and marches against them creating a profitable, but temporary, market condition for small gains. The HFTr which use the pinging strategy start analyzing the market by placing sell or buy orders to find big operators in the market. Once the big operator has been found the pinging trader cancel all the orders previously sent to the market and take the same position, long or short, of the big operator. The high frequency traders are able to anticipate the moves of big operators by selling and buying at prices respectively lower and higher with the final goal of dealing directly with big size traders to ensure a risk-free profit.

3.2.5.3. Quote stuffing

Through the quote stuffing strategy, the high frequency trader place huge amount of orders, false or empty, with the aim of slow down the market, trading platforms and analyzation process. In this way it is able to make it difficult to other market participants to access the market, so that it will be able to choose the most profitable position without competition, indeed, the huge amount of data to be processed and analyzed slow down traditional traders, trading platforms but also other high frequency operators. Who can take advantage of this strategy is only the HFTr which firstly use it. The power of high frequency systems is reported below, in Figure 17, in two real life examples when HF actors sent to the markets thousands of orders: on Heineken, right-hand side, happened on May 2nd, 2011 and on Telefonica, left-hand side on August 10th, 2012.

Figure 17: Quote stuffing on Heineken (left) and on Telefonica (right)



Source: Credit Suisse AES Analysis, 2012

3.2.5.4. Smoking

The smoking strategy is very similar to layering one. It consists in placing very tempting orders to attract the so-called slow traders. Before the order is executed the high frequency trader modify the conditions of the order in profitable ones for itself but at worst conditions for the slow trader.

3.2.5.5. Spoofing

The spoofing strategy involves numerous orders of huge quantity, which will be subsequently cancelled, to deceive other market participants, letting them know that there is a big pression on the buy side or sell side so that the price will soon increase or decrease respectively.

In this way, the deceived traders buy or sell, accepting the price of the spoofing trader, which, once the orders are accepted, quickly cancel all positions and opens new ones of the opposite sign. To make it clearer, here is an example: the spoofing trader place huge amount of order on the buy side to let believe other market participants that there is a strong pressure on the buy side so that the price will soon increase generating an upward trend. These market participants accept sell proposals of spoofing trader, which previously placed sell orders. Once the selling proposals are accepted the spoofing trader cancel all huge orders placed to fool the market and starts to use the

same strategy on the other side.
The spoofing was the strategy pursued by Panther Energy Trading LLC, which was sanctioned to pay $1,4 million, to reimburse $1,4 millions of profits and to not operate in the market for a year as spoofing is an illegal practice.

3.2.6. Front running

It essentially consists in entering in a transaction using foreknowledge, sometimes non-publicized, which will be able to influence the price of the underlying asset. Using front running strategy, a HFTr takes a position in a financial asset just slightly before all other traders, before the price moves in a predictable way. Information can be obtained legally, observing demand and supply in the market, or illegally. Front running is illegal when the trader is acting on non-public information, while it is legal when the broker uses public information.
In practice high frequency operators are able to notice when other market participants will move huge number of shares and take a position before this happen. Then two things occur: the non-high frequency operator places its order in the market and most likely it will have a price lower than the optimal one, and the market will show higher request of liquidity from price taker operators.

As we have seen during this chapter HFT involves the use of very sophisticated technologies and strategies. In addition to the preceding strategies, HF firms can also use their own proprietary strategy.
Some trading strategies can have positive effects in the market while others can have negative consequences, therefore it is important that regulators intervene, limiting or prohibiting strategies which are not good for the entire market, keeping in mind that such decisions affect the future developments of the market itself. Moreover, it is important that algorithms technology make it easier to implement strategies and not that they create an unfair playing field, increasing the gap within market participants.

4. Regulation of HFT

Difficult task for regulators is to ensure that financial markets support real economy. Financial markets have the role of group investments and savings in order to facilitate the efficient allocation of resources and risks. Thus, to ensure that, financial markets should be fair, organized and transparent so that investors will be able to compute the right price available easily and quickly and have direct access to it. An efficient market, assimilates information as soon as they become public, minimize transaction costs and reduce information asymmetry.

Even if the technological evolution of financial markets has led to more efficiency, thanks to increased competition, reduction in transaction time and costs, positive aspects must not hide the risks of these innovations on integrity and stability of financial markets, like for example flash crashes, runaway algorithms and manipulative conducts.
As always, new advantages and new opportunities determine new risks, especially due to lack of knowledge of the phenomenon, leaving less informed traders exposed.

In these constantly changing conditions, the regulator intervenes to ensure appropriate use of technology and protection to physical investors, responding to a need of appropriate regulation. Since markets are highly correlated usually it is necessary a join activity among legal authorities.
Policy makers began to develop proposals, consultations and initiatives to supervise capital markets. The International Organization of Securities Commission (IOSCO) developed recommendations on global level; in the United States the SEC and the Commodity Futures Trading Commission (CFTC), while in Europe the MiFID II take care of the HFT phenomenon.

4.1. Policy approach

Develop and define a proper regulation to establish systems and controls that financial actors must implement is fundamental to ensure the good functioning of capital markets. The main policy interventions suggested by the British Government for

Science regard: notification of algorithms, circuit breakers, minimum tick size, minimum resting time, order priority rules, periodic call auctions and others.

4.1.1. Notification algorithms

The first intervention is an obligation for market operators which use high frequency algorithms to send information about them and their risk management systems to supervisory authorities. The goal here is to attract the attention of all market participants and regulators on HFT, so that a better knowledge of the phenomenon will lead to more effective defensive actions. Moreover, this principle force high frequency operators to use more stringent risk policies.
On the other hand, the costs of transmitting such big volume of information would be very high and given the nature of the algorithms that change very frequently, would make the transmission of information in vain.

4.1.2. Circuit brakers

They are part of the broader trading interruption mechanism category. The trading interruptions can be divided into automatic and discretionary. The automatic one permits to market to react in the smallest time possible to market imbalances most of the times generated by high frequency operators while the discretionary one is used when there are expected news that can create extreme decisions. An important drawback is that the interruptions are decided by humans and the slow decision process can lead to delays in its adoption.
The automatic interruption is a negotiation suspension based on non-discretionary preset parameters; it can be used when, for example, the price fluctuation of a stock can create disorder in the market. The discretionary interruption, instead, are for instance stops related to dissemination of illegal information material, incapability to satisfy specific standards and obligations, and other extraordinary events.

We can compare a circuit braker to a switch, it can stop trades of those stocks which are experiencing fast and continuous changes in price.
They exist from October 1987, and from that moment they represent the most used

technique to fight volatility and other panic situations.
The circuit brakers continuously control the market and impose a stop in transactions if the price of a financial instrument goes or is expected to go above or below a specific predetermined level. The interruption can be temporary, or in extraordinary situations it can anticipate the closure of the trading session. The stop can vary according to the specific time slot: it lasts 30 minutes if it happens from 2 p.m. to 2.30 pm, it lasts an hour if it happens before 2 p.m., but if it happens after 2 p.m. the exchanges of the stock in question close for the rest of the day.
The introduction of circuit brakers allow to “cool” the market, dosing the negotiations, determining the best price execution and lower volatility, and avoid trend not justified by real liquidity needs, which usually hurts small investors, who need more time to analyze what it is really happening.

There are also negative aspects related to circuit brakers. The first one consists in the so-called *magnet effect*, which happen when traders know the intervention threshold of circuit brakers and anticipate them closing position quickly, which have the effect to increase the volatility. Moreover, sometimes they slow down the process of price discovery and they can limit the operativity of market maker exposing them to huge losses.
Empirical analysis also highlights the fact that these switches determine a reduction in the dept of the book the day after their use since traders do not want to deal with expired orders.

4.1.3. Minimum tick size

The minimum tick size is the minimum price movement of a financial instrument.
The optimal width of the minimum tick size is difficult to establish since it is not clear how it can influence liquidity, indeed different assets use different minimum tick size, but for the most of them it is $0.01.
What it is known is that a larger tick size increases trading costs by widening the bid ask spread.
In most important trading venues, where there is the price/time priority (PTP) rule, the priority of an order depends on two factors: time and price. An order, placed fist, can

be overcame by another if its price is better than the first one, hence the price allows an order to be executed before another even if the fist has been sent to the trading venues some time before. The reduction of the tick is able to make this operation less expensive. Moreover, if a well-chosen minimum tick size is adopted, it can prevent market operators like exchanges, market makers and HFTr to make excessive profits at the expense of the final investors.
On the other hand, reducing too much the tick size will result in wider bid ask spread and less transparent market favoring market makers.
An excessive tick size on one market may induce trades to be execute in other venues, boosting unhealthy competition among stock exchanges.

4.1.4. Minimum resting time

It represents a minimum time that an order must remain in force, this necessity arises from the fact that nowadays a large number of orders are almost immediately cancelled after their submission. The consequence of this practice is an increase in the costs of monitoring the market for all its participants.
With the introduction of a minimum resting time the authorities would try to reduce the *ghost liquidity*[26] phenomenon and other abusive strategies.
The goal here is to reconsider the HFT phenomenon, reducing the possibility of quick cancellation of orders just after their submission, which lead to a distort vision of the depth of the book. Moreover, the minimum resting time might reduce the risk of crashes of informatic systems due to huge volume of empty orders.
A drawback is the influence on the price formation process, because imposing a limit time that an order must remain in the book, the information would not be able to be immediately absorbed by the market and hence by the price of the financial instrument. Furthermore, the market maker can find the process of giving liquidity to the market more expensive since the risk of adverse selection increases.

[26] With ghost liquidity we mean a liquidity that is just apparent, that tends to disappear in moments when the market needs it.

4.1.5. Order priority rules

They determine the sequency in which orders, already submitted, are executed. The biggest part of exchanges uses the PTP rule, meaning that an order is queued and executed when there is the possibility of a trade at that specific price on a first-come first-served basis. Usually hidden orders take a lower priority and partially hidden ones are separated in two queuing priorities.
The main advantage of a PTP rule is that it treats every order equally, but conversely it encourages the competition for speed and fosters investments in technologies which allow fast order execution, like co-location.

4.1.6. Periodic call auctions

They represent an alternative trading mechanism which can minimize the advantage of speed and other negative outcomes of the continuous trading model. The proposal involves a sequence of intraday auctions of random starting point and duration, to discourage the use of HFT and to focus the attention of traders on fewer, centralized events.
The main aim of periodic call auctions is to reduce the race for speed and high-performance computers; it can also have positive effects on liquidity reducing the likelihood of short and dramatic deteriorations in it.
Conversely, periodic auctions can increase execution risk that investors face if they don't know when the auction will take place. In addition, they would have a strong impact on market makers' business model reducing the incentives to give liquidity to the market.

4.2. IOSCO recommendations

The IOSCO is the international organization that brings together many countries' regulators. It was established in 1983 and today groups together 115 nations and their supervisory authorities, counting 224 members in total in 2019. Its role is to promote high regulatory standards and collaboration among regulators of different states.
In these recent years, we have seen the issuing of many recommendations from

specific international organizations with the purpose of making clearer the impact of HFT on market integrity and efficiency.

After a specific request of G20 members in November 2010, the IOSCO in October 2011 published a report called *Regulatory issues raised by the impact of technological changes on market integrity and efficiency* where it was included all the measures necessary for regulators to reduce the risks in financial markets due to technological developments.

The report included five recommendations that can be grouped in three categories: for trading venues, for market participants and for regulators.

The first recommendation suggests to regulators to require fair, transparent and non-discriminatory access to trading venues, potentially it includes data feeds and co-location services; the second one requires to policy makers to ensure that trading venues have in place appropriate trading control systems to deal with volatile conditions, hence the trading algorithms should be able to deal with evolving market conditions, in addition, legal authorities can require functional or stress test to trading venues to assess their capability to work under pressure; the third recommendation imposes that all orders must be subject to *ad hoc* controls, including automated pre-trade ones, and highlights the worries of IOSCO about naked sponsored access, emphasizing the fact that all the orders must be controlled to ensure market integrity and stability.

The fourth and the fifth recommendations are for regulators: the fourth one suggests that market authorities should constantly evaluate the influence on integrity and efficiency of AT and HFT; the fifth one proposes to monitor new forms or variations of market abuse that can arise from technological developments and to take appropriate standards, intervening with measures that include changes of regulations, guidelines for market operators on what is possible and not possible to do, update surveillance systems according to new forms of market abuses and punishes who violate the laws. Since markets are connected, also regulation must be, hence authorities should share information and real-life experiences to avoid market abuses.

4.2.1. IOSCO principles on dark pools

Dark pools and dark orders have seen a rapid growth caused by HFT. The increased

competition and market fragmentation have led to fracture in liquidity and information; thus the research of the best price takes now in consideration multiple liquidity sources and require higher resources to find these opportunities. New liquidity alternatives to traditional stock exchanges are ATS and MTF and brokers' internal crossing networks[27]. All this has led to increased use of dark pools.

The phenomenon of dark pools saw an increase in recent years, but they were established with the first automated transactions. According to Bloomberg, the trading volume of dark pools in USA was around 20%, while in Europe it counted for 8% in 2016. The advantage of dark pools is that the transactions are anonymous and not traceable, allowing institutional investors to reduce the market impact and implicit transaction costs. They are usually used to trade financial instruments with low volatility.
The main problem of using dark pools is that they affect the prices on transparent markets, and since the latter don't have sufficient information, price financial instruments wrongly. Moreover, dark pools can increase volatility especially if behind the exchange there are algorithms of high frequency.

The IOSCO intervened with its *Dark Liquidity Principles* to help regulators dealing with them. The principles are six: the first one emphasizes the fact that the volume and orders of a firm should be transparent and public, but sometimes regulators for some specific orders can choose to not require the pre-trade transparency control; the second one, according to IOSCO, underlines that the orders, even the ones executed in dark pools, should be transparent to the public. The third principle suggests that where dark trading is permitted, regulators should support the use of transparent orders which should have priority over dark orders at the same price within a trading venue; with the fourth one it is established that legal authorities should keep record of all dark transactions; the fifth one emphasizes that both dark pools but also transparent markets which offer dark orders should provide sufficient information to market actors; and the last principle suggests that the regulators should periodically monitor the dark pools and orders developments, and ensure that these do not affect the efficiency of

[27] A broker's internal crossing network is an investment firm system which matches clients orders internally.

the market, especially for the price formation process.

All these principles will help to ensure a fair, ordered and efficient market.

4.3. American regulation

In the United States, the country where high frequency trading born, the existence of the phenomenon became known to everyone during the May 6th, 2010 flash crash. After that, the SEC and the CFTC published a document to rapidly respond to this new phenomenon.

The first step chosen by American authorities was a mechanical approach to identify large traders, investors able to influence prices easily thanks to huge volume orders. This move allowed the regulators to simplify their tasks of data collection during their supervisory activities, therefore they would be able to respond faster to illegal practice. The legislators made it easier also to identify the consequences of high frequency transactions, and compared high frequency operators to large traders, subjecting them to the same regulation.

This new wave of legislation was wanted by the former American president, Obama, to provide a wider regulation for American's capital markets and provide a better protection of consumers.

The other most important regulatory interventions introduced are:

- The SEC can require reports to hedge funds, and all other investment firms and information necessary to provide their correct evaluation;
- The establishment of the Financial Stability Oversight Council (FSOC) to supervise on market stability and surveillance;
- A more stringent regulation for commodity markets, which forbid the cancellation or withdraw of orders before execution.

Moreover, the SEC introduced new rules, Rule 13h and Rule 13h-1, which establish:

- The duty for brokers and dealers to provide, against specific request of the SEC, the data about particular transaction executed by large traders;

- The obligation for brokers and dealers to keep and constantly update accounting books which contains this information;
- The duty for large traders to be identified through a specific practice to obtain the Large Trader Identification Number (LTID), which is necessary to operate in the market;
- The obligation for large traders to provide their LTID to all brokers and dealers.

The main aim of the Dodd-Frank Act, this is the name of the regulation, was to reinforce the informational regime, and obligations for the largest entities, which are able to affect the correct functioning of the market.
Also, transparency was improved, limiting the informational spread between high frequency users and supervisory authorities, even if the latter continues to show difficulties in identifying HFTr and their strategies.

With the new Trump administration, the Dodd-Frank Act was modified in 2018, and provide a freer market, less subject to controls and it made quite difficult to avoid the implementation by HFTr of very aggressive strategies.

An important update for American regulators comes from the CAT, Consolidated Audit Trail, which allows to fully track trading activities and boost transparency, in addition it heralds new obligations and reporting requirements for companies. The CAT is a supercomputer, a central repository, capable to monitor in real time orders and negotiations at the same speed of high frequency operators or even faster, allowing the SEC to closely monitor any abusive practice and retain trades and orders. The CAT regulation also required to exchanges, brokers, dealers and self-regulatory organizations to submit order lifecycle information each trading day. It officially started to report on June 22nd, 2020.
The most important limit was represented by the costs of this supercomputer, which must be borne by stock exchanges, brokerage firms and FINRA. These costs, some economists say, will inevitably fall to the final consumers affecting the efficiency of the market.

4.3.1 Co-location

The CFTC in 2010 proposed a rule to provide fair and equal access to co-location and proximity hosting services. Knowing that these two services provide competitive advantage to HFTr, the CFTC wanted to provide equal access to all market participants. To ensure that the legislator proposed to marketplaces and third parties to list significant price discovery prices to implement uniform commissions for co-location and related services. These costs should not represent a barrier for some market participants.

Another provision of Commodity Futures Trading Commission was to make more transparent the latency, thus it proposed to make available to all interested investors its time, from the smallest to the largest and the average one.

4.3.2. Stub quotes

After the flash crash the SEC prohibits to place stub quotes, preventing that contracts are executed at irrational prices. A stub quote is an offer to buy or sell a share distant from the prevailing price of the market so that the trade is intended to not be executed.

4.3.3. Naked access

In 2010 the SEC with the *Market Access Rule* obliged registered brokers to execute specific risk management controls and supervisory procedures to prevent erroneous orders and to ensure the presence of correct requirements. In this way the legislator stopped the possibility for high frequency operators to reduce latency avoiding the compliance with specific risk checks and capital requirements.

4.3.4. Access to information

In 2011, it was the turn of the *Large Trader Reporting Rule* which imposed the identification of large traders, and reporting obligations for them. According to the new rule, large traders are recognized according to their exchange volumes and values; in this way the regulator included also high frequency traders in this definition.

Later, in 2012, the *Consolidated Audit Trail System Rule* was adopted. Its goal was to give regulators the ability to monitor and analyze unusual events in the capital markets. The norm requires to all American stock exchanges to establish a market-wide system to collect and identify every single order, cancellation or modification and execution.

In 2015, the SEC imposed to some brokers and dealers to register themselves with the FINRA. In this way those entities were subject to specific examination and requirements.

4.3.5. Compliance systems and integrity

In 2014 the Securities and Exchange Commission published the *Regulation System Compliance and Integrity* (SCI). With it the political authority created new standards to maintain and testing the trading systems used by trading venues and brokers. These new rules were intended to improve the resilience when system problems occur and reduce the likelihood that system issues take place. Furthermore, the SEC enhanced its oversight and enforcement of stock market technologies.

4.4. European regulation

The European institution which has given an important contribution to HFT regulation is the ESMA. It has three important goals: investors protection, orderly markets and financial stability.

The ESMA started in 2010 to analyze the phenomenon of HFT, and in April of the same year it published a paper with the aim of collect all information available on it and its strategies. Just a year after, the regulator published some guidelines for the phenomenon. These rules are eight and summarizing them we can say that the ESMA highlighted two important principles: ensure a fair and orderly market, giving importance to equal condition and information among all market participants so that a correct price formation process can take place; and avoid and forbid that high frequency operators can affect market integrity through market abuse strategies.

To comply to these guidelines trading venues must ensure that they have specific filters on quantities and prices to execute pre and post negotiation controls and adopt

mechanisms to suspend or to limit the negotiations to avoid crashes of the platform. With respect to the ESMA recommendations, market participants must have systems capable to identify potential market abuse strategies rapidly so that they will be able to inform supervisory authorities and should not execute illegal strategies.

The most important contribution to HFT's regulation in Europe comes from MiFID II, introducing requirements to be met by investment firms which apply algorithmic and high frequency trading. It represents a new version of financial market directive and proposes a greater protection for investors, new internal systems and controls, imposes duties regarding information, records and specific requirements on investment firms. It establishes new obligations for brokers and provides direct electronic access to HFT companies.
Thanks to it, the European authorities:

- Are now able to identify correctly high frequency traders;
- Define a better commissions' structure;
- Impose the adoption, for investment companies, of appropriate control systems to ensure resilience to trading platforms;
- Ensure the continuous activity of marker making, also for HF firms, to provide liquidity to the market;
- Activate systems able to test algorithms to limit the percentage of orders not executed.

Even if with the MiFID II the European regulators emphasized the risks arising from these new technologies, they also reported an improvement of the economy for all market actors.
For what concern transparency the most important innovations regarded:

- The obligation for brokers to send complete and detailed documents to supervisory authorities, and the duty to identify clients;
- The introduction of new transparency rule pre and post trading, also for no-equity and over the counter transactions.

The MiFID II also increased the powers of ESMA, indeed now the regulator can issue

regulatory technical standards on AT and HFT. The specific standards can regard only determined aspects, which the regulation cited in the article 17. Once the ESMA release the technical intervention, to be effective the European Commission must adopt them formally.

4.4.1. Direct electronic access

The second version of the MiFID imposes specific rules for providers of direct electronic access (DEA), involving controls, information and identity of their clients. The rule has focused on specific systems and controls which should ensure an adequate assessment and review of the clients which use the service in question. It avoids that pre-set trading and credit thresholds are overcame, and that clients correctly use the service which, in turn, should be adequately controlled and monitored against risks of trading that can create disorders in the market.
The DEA provider should monitor the transactions of its clients to verify the presence of broken rules, inappropriate trading conditions or market abuse practice.
The control executed on sponsored access should be at least equivalent to those applied to direct market access.

4.4.2. Information and records

MiFID II gives a lot of importance to information, indeed every firm which uses HFT or AT has the duty to report records to the competent national authority and to the trading venues where it makes its exchanges. The investment firm, if requested, must provide on a regular basis a description of its algorithmic strategies, parameters or limits of the system, and compliance practice which are open, but also the results of the pursued risks and tests controls.
Moreover, the regulator imposes to HFT operators to keep accurate and time sequenced records of all trades, even the ones send but not executed.

4.4.3. Internal systems and controls

Investment firms with the new regulation must adopt internal systems and controls.

Those systems and controls ensure that the trading methods used by investors are resilient and have adequate performance, have specific thresholds and limits, and avoid sending erroneous orders.
The firm must test its algorithms and ensure their correct functioning, also through stress test. However, if algorithms do not work properly, they must be changed.

4.4.4. Market makers and trading venues

Firms which pursue market making strategies are required to satisfy specific criteria, taking in consideration liquidity, scale and nature of the specific market and financial instrument traded. The obligation to continuously make two sides prices is not absolute, and there are some exceptions, such as extreme volatility and political problems.

The MiFID II also includes rules for trading venues which deal with AT and HFT. Trading venues must ensure effective systems, arrangements and procedures to provide efficient platforms able to deal with huge amount of orders. In addition, they must develop systems capable to reject orders that exceed pre-specified trading volume and price limits, and orders which are clearly wrong. Moreover, it is important that they are able to temporarily stop or limit the transaction of a specific financial instrument if specific conditions take place, like significant price movements.
Trading venues have to ensure also fair and non-discriminatory fees structure and co-location access.

4.5. Transaction fee on HFT: the Tobin tax in Italy

The Tobin tax was proposed for the first time, by its creator James Tobin, in 1972. It was initially proposed as a tax on all transaction in financial markets to penalize short time speculation. Its revenues will be given to international community.

In Italy, the government decided to use the Tobin tax starting from 2013. In this case, for all high frequency operations, i.e. orders automatically executed by algorithms, the legislator apply a tax of 0.02% on cancelled and modified orders which in a trading day

overcome the specified threshold established by Italian legislator.

Since high frequency traders are characterized by huge volumes and small profit, to reduce the risks they bring to the market, it seems a good proposal a tax on every single transaction. But to make it works, and not generate migration of traders to non-taxed stock exchanges, it is necessary that all states adopt it, but at the moment only Italy, France, Germany, Greece, Portugal, Belgium and few other charges it.

5. Pros and cons of HFT

The rapid spread of HFT has been possible thanks to huge investments in technology over the last two decades. Just to have an idea, the division of applied technology to finance has grown from $930,000 in 2008 to $12 billion in 2014 reaching an estimation of $45 billion in 2020. The main supporters are investment banks, as UBS, Goldman Sachs and J.P. Morgan, hedge funds, like Citadel, LLC, Getco LLC, and investment funds. Goldman itself has invested $800 million in 2014 and $810 million in 2015.

The HFT phenomenon allows to its users to take advantage from every single, even small, opportunity. Using different strategies, it is able to gain money at the expense of other market participants. At this moment an important question can arise: are HFT's benefits higher than disadvantages? Researchers and specialists of the sector are interested in finding the consequences of the phenomenon on market structure, especially after the 2010 flash crash many companies are reluctant to share their own data about high frequency algorithms and results, and therefore some opacities are still present also nowadays. Academics have tried to reply to the previous question under different assumptions and models: someone focused on market quality[28] parameters, like liquidity, volatility, bid-ask spread, transaction costs and/or price discovery process, while others focused on the profitability of the industry and relationship with traditional traders, or on the behavior during difficult market period.

The idea that HFTr have a positive impact on the economy is mainly due to the belief that liquidity is good for investors no matter what, but even if the utility in real economy is a function of liquidity, which suggest that the two are positive related, we don't know whether it exists a point beyond which liquidity is not anymore exploitable by real economy and no one would take advantage from its increase, and its growth can bring only to higher correlation which can lead to systemic instabilities.

[28] With market quality, it is meant the ability of a market to execute financial trades with efficiency and in a fairly manner, ensuring traders the best trade possible. Researchers and academics when dealing with market quality take in consideration liquidity, volatility and price discovery. They also analyze the information efficiency, which includes the risk to compromise the correct price formation due to the fact that software is not able to give an informational contribution regarding the economic fundamentals of a stock only looking at prices and volume observations in a specific moment in the market.

However, due to the complexity of the phenomenon, the results are heterogeneous. This outcome is not unexpected, because high frequency traders operate in many markets, from derivatives to currencies, from equities to bonds, and the analysis are specific for the analyzed situation and market; but the main problem researches face is the separation of HFT's effects from all other factors.

The results are also controversial, indeed some economists suggest that the HFT practice bring positive effects in the market, especially for market quality, such as liquidity, low volatility and efficiency. On the other hand, opponents of the phenomenon suggest that it embitters the market quality, especially during turbulent trading sessions. They suppose that it can create significant risks for market stability and efficiency since HFT strategies are more correlated than traditional ones, and especially when market conditions are unstable, they show that HFTr can further worsen the movements in the prices and generate disorders, as happened during the May 6th, 2010 flash crash when the Dow Jones Industrial Average Index lost 1,000 points in less than 30 minutes. It is believed that HFTr amplified the downward movement. Opponents also suppose that HFT strategies can increase the systemic risk, spreading shocks that happen in a single market. For example, if a high frequency firm is experiencing a hardware malfunction, it can affect the strategies of other HFTr present in the market generating undesirable effects in a market that can be spread among more trading venues. This happened in 2012 to Knight Capital, that due to an error in its new software, which bought and sold 6 million stocks generating a loss of $460 million in the first 45 minutes from the opening of the market.

Nevertheless, different results can come from distinct approaches used to identify high frequency firms and even for diverse models used to estimate their activities and make it difficult to compare the results because of different underlying assumptions used.

Also the American and the European regulators analyzed the phenomenon and defined that in short period aggressive HFT strategies can improve the price discovery process for large firms, while for small firms the effect are less significant. Moreover, they highlighted that traditional strategies affect the price formation process over long period, meaning longer than two minutes, while the high frequency strategies have a strong impact in short period, i.e. up to ten seconds, and increase the costs of adverse

selection that traditional operator face.

5.1 Possible positive aspects of HFT

As just said economists do not have a common idea on the HFT phenomenon effects. One of the most influential figures, Brogaard J., in his work denominate *High Frequency Trading and its impact on Market Quality*, conclude that, taking in consideration price information efficiency, liquidity and volatility, HFT tends to improve the market conditions.
The main positive effects from the high frequency implementation are:

- Reduction of commissions;
- Increased liquidity;
- Better efficiency, mostly on prices and price discovery process;
- Reduction of short-term volatility;
- Increased connection among trading venues;
- Reduction of average bid-ask spread.

5.1.1. Commissions reduction

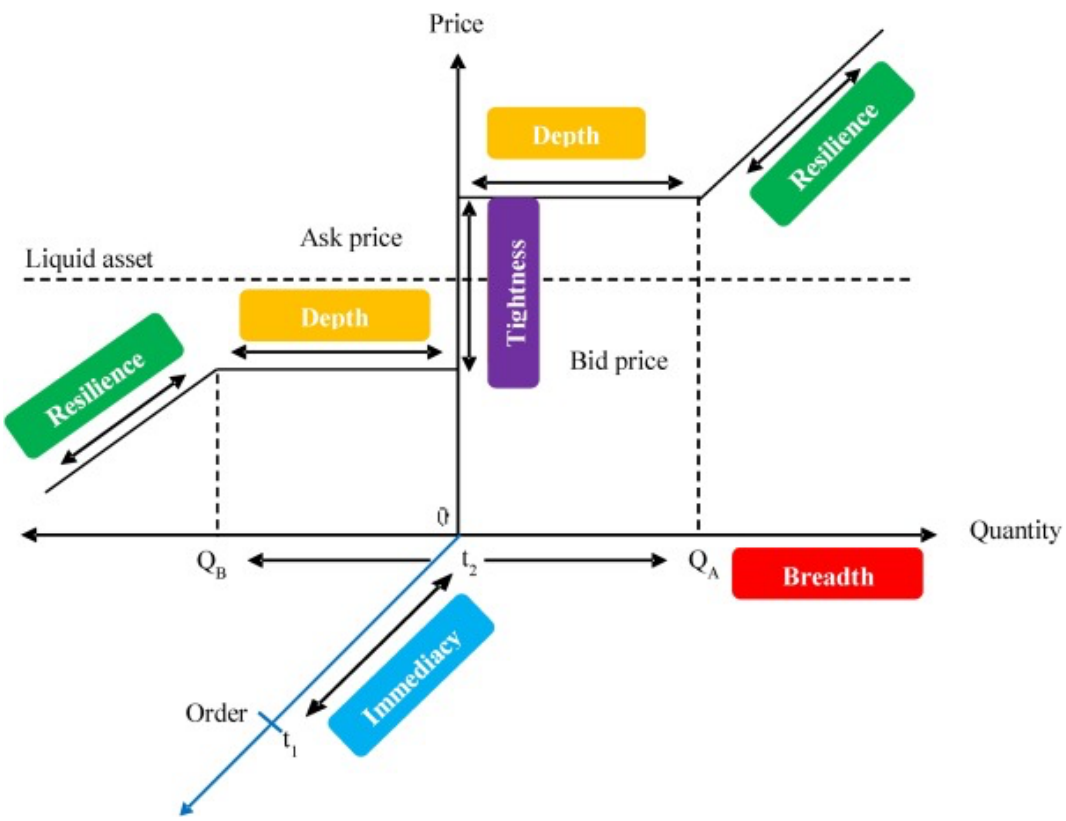
A better access to the market is assured by high frequency operators, indeed thanks to the direct market access, it is not necessary to deal with a broker to execute trades. This allow to reduce the transaction fees because there is no need of an intermediary. In their research, Cvitanic and Kirilenko, found out that the presence of HFTr modify transaction costs and its distribution. Moreover, they discovered that with the presence of high frequency operators in the market, transaction costs are more concentrated around the mean, and thus have a lower standard deviation, and the capacity to forecast transaction costs increases.
In addition, also Conrad, Wahal and Xiang, showed that frequent price updates are associated with lower transaction costs: in their research they saw a reduction from 0.6 to 6 basis points.

5.1.2. Increasing liquidity

Liquidity refers to the ability to trade large orders at a low cost, it is the ease with which market participants are able to sell their financial instruments, transforming them into money at a price as closest as possible to market price.
Generally speaking, a liquid market, is a market with low volatility and many bids and ask offers, which reduce the spreads. It is a positive aspect for every actors in the market: regulators love liquidity since a liquid market is generally less volatile than illiquid one, traders enjoy liquidity because it allows to implement their strategy in a cheaply manner and also stock exchanges like it because it attracts more traders in their venues.

Liquidity is positive correlated to high turnover, narrow bid-ask spreads, low commissions and resilient prices; it includes several dimensions, as it is possible to see from Figure 18, reported below, covering depth, tightness, breadth, immediacy and resilience. In Figure 18, Q_A and Q_B represent amounts that could be traded at bid and ask prices of the moment. The depth indicates the order volume at specific price. The difference between bid and ask represents the tightness. The market breadth, instead, is the number of orders at different prices and represents the cost of doing a trade; the resilience represents the capacity of the market to recover from unexpected events. Immediacy describes the speed at which orders are executed.

Figure 18: Liquidity dimensions



Source: Measuring the multi-faceted dimension of liquidity in financial markets: A literature review, Díaz A., Escribano A., 2019

We can use the liquidity as an indicator for market health, but we have to take in consideration all the elements that constitutes it, because a single indicator is not sufficient. For example if we take in consideration only trading volumes, an excessive amount on one side might cause a widening of bid-ask spread, and again the bid-ask spread alone can be small, but if there is just a single financial instrument in the specific market, it cannot be considered liquid.
Anyway, the most used measure to understand if a market is liquid or not is the bid-ask spread.

We already know that high frequency operators work in liquid market, since it is easier to quickly enter and exit positions and this reduce the risks of exchanges.
Numerous researches, manly based on the bid-ask spread observation, showed that

one of the most important impact that HFT had on markets is the increased liquidity. This result lead to conclude that a reduction of the bid-ask spread is possible through the presence of HF operators which also reduce the implicit transaction costs.
The high frequency actors are able to reduce the spread thanks to their strategies, indeed thanks to their algorithms they are able to understand the level of liquidity present in the book and decide to take the market maker position in order to exploit the spread and provide liquidity to the market.
In addition, thanks to their computational power, the prices displayed by HFTr can be safely assumed to be the most reliable, since they promptly embed all information in the prices, allowing also to all other market actors to benefit of prices with high information efficiency.

In the paper *High Frequency Quoting, Trading, and the Efficiency of Prices*, of Conrad J., Wahal S. and Xiang J., the authors did two different tests to understand the impact of HFTr in the market. They used American and Japanese data, from 2009 to 2011 for the American market, and from 2010 to 2011 for the Japanese one. They saw that continuously updating their orders, HFTr improve the liquidity and quickly embed the information into prices, increasing the market efficiency.
Brogaard, Hendershott, Jones and Menkveld support the idea that HFT has increased the liquidity in the market, and of the same idea are Boehmer, Fong and Wu, who analyzed 21,507 shares from 2001 to 2011 in 42 stock exchanges observing liquidity enhancement and a more efficient price discovery process thanks to high frequency traders.

Even if HFT is believed to provide liquidity by increasing the number of trades and reducing transaction costs, it is important to highlight that these effects strongly depend on the role of the high frequency operators and their strategies: market making, and therefore providing liquidity, or opportunistic strategies, and consequently absorb liquidity. In addition, it is important to keep in mind that the behavior of HFTr can change accordingly to sudden variations in the market.
Despite all this, some market participants continue to ask themselves if HFTr provide liquidity to the market on a consistent basis, or only when it is convenient for them, indeed they do not have to respect all the obligations of traditional market makers.

5.1.3. More efficient price discovery process

The price discovery process determines the price of a financial instrument through the interaction between buyers and sellers: the best buyer meet the best seller and the market discovers the financial instrument's price.
In an efficient market, the price reflects all information about a security, but the most informed and quick trader can take advantage of more information he knows to improve the price discovery process and impose costs of adverse selection to uninformed traders.

Until few years ago, traditional market makers facilitate the incorporation of information in the prices, today, this role is performed mainly by HFTr.
The SEC, in its *Concept release on Equity Market Structure*, realized that when most exchanges are based on statistical and short-lived correlation in security returns, and investors do not hold stocks for investments purpose, the process of efficient price formation might be not anymore present. Indeed, also researches define the contribution of HFT to efficient price discovery process ambiguous: if on one side HFTr contribute to spread information and to establish efficient prices across different trading venues, reducing the effects of market fragmentation, on the other side arbitrage opportunities would be equally exploited, perhaps in a slower manner, by traditional traders. Maybe this would lead slow traders to prefer to trade heavier in transparent markets rather than in dark pools.
Empirical tests showed that when HFTr use directional strategies or momentum ignitor, the short-term price movements can be amplified even if the true value of the stock can be not affected by new information, leading to worse price discovery process.
How can HFT influence the long-term price discovery? It is not an easy task to reply this question. Even if on a daily basis HFTr are able to quickly respond to market changing conditions, thanks to their speed, and rapidly update the prices bringing them very near to their true market values, it is not simple to determine their effects over long periods.
As already said, according to Brogaard J., HFT increases the liquidity and slightly the bid-ask spread, thus in long-term period, the first can allow investors to easier adapt their portfolios to company performances. On the other hand, as high frequency

operators are not interested in the destiny of the firms traded, prices can also deviate from their fair values.

In a 1992 research of Froot K.A., Scharfstein D.S. and Stein J.C. named *Herd on the Street: Informational Inefficiency in a Market with Short-Term Speculation*, they supported the idea that traders with short holding period can give too much importance to brief term information, which are not fundamental for firms, and lead to less efficiency in the market.
Zhang X.F. in his work suggests that HFTr can impede the correct price formation process in the long term, due to overvaluation of the news present in the market. This can happen independently from other traders' behavior, in fact HFTr react first to news, then the price moves in a specific direction; lately slower traders, when become aware of the information, trade the stock in question. Trading the security, without adjusting for the first price, changed due to HFTr operations, generates an overvaluation of the information and a not fair price.

Brogaard, Hendershott and Riodan, analyzed 120 shares on NASDAQ and NYSE from 2008 to 2009 and noticed that stocks more traded by HFTr are more efficient in their price discovery process. In addition, Chinoque, Hjlmarsson and Vega found out that HFT allows a reduction of arbitrage opportunities and hence a better price formation process.

5.1.4. Volatility reduction

Volatility represents the tendency of prices to change unexpectedly in short time intervals. Prices are affected, and hence change, according to demand and supply, but also to new information. High volatility usually represents an uncertain situation, instability and turmoil of both markets and traders resulting in the possibility to trade with impaired prices. It is not appreciated either by investors or by traded companies. Indeed, risk-averse investors require a high premium to take an investment characterized by high volatility and it seems that they react slower to information regarding high volatility instruments, and for a firm having a high volatility increase the cost of capital since it appears risker than other companies.

Moreover, high level of volatility represents an opportunity for speculative traders to gain money thanks to arbitrage opportunities that can be present in the market and other aggressive strategies.

Zhang X.F. in his *The Effect of High-Frequency Trading on Stock Volatility and Price Discovery* showed that HFTr reduce the volatility of financial instruments, especially when they provide liquidity to the market.
On the other hand, in the same work the author, defined that high frequency traders can amplify the effect of volatility exacerbating the fluctuation of prices. Opponents of this technology suggest that it may increase the possibility of flash crashes.
Find a correlation between volatility and HFT is not easy and the results are discordant. This happen because HFTr can execute many different strategies adapting to changing market conditions. In fact, when a high frequency operator executes a strategy of market making, providing liquidity to the market and allowing other traders to executed trades, even of huge volume, without significantly affecting the price, it induces a reduction of volatility. In this context HFTr are not interested in price oscillations indeed they make profit on bid-ask spread, hence they continue to keep the volatility low.

It is also true that when institutional investors deal with HFTr, the volatility can increase. This can happen because the huge volume of trades generated by high frequency operators is not always a reliable liquidity indicator, especially when the volatility is high. Hence, the automatic execution of large amount orders which use the number of trades as evaluation of liquidity, can lead to high price oscillations, increasing the volatility.

The relation between HFTr and volatility must be analyzed in two ways: how high frequency operators behave in a high volatility context and how HFTr influence price volatility. Empirical tests suggest that a huge number of high frequency traders affect the volatility amplifying abnormal price movements, and that high frequency trading is more profitable when the volatility is high. Brogaard showed that the profitability doesn't increase significantly when the volatility is high, while he noticed that an increase in the number of HFTr reduce the intraday volatility. He showed that, if on one side the increased volatility stimulates more HFTr to operate in the short-term, conversely the

increased number of high frequency operators determine a reduction of the intraday volatility. To demonstrate his theory, he studied the change in volatility after an endogenous shock on volumes traded with high frequency strategies. He specifically analyzed the stop imposed to short selling in 2008 by the SEC, and the results showed an increase in the intraday volatility after a reduction of HFTr activities.

5.1.5. Increased relationship across markets

A positive aspect of HFT is that the interactions among markets are intensified and connections are always faster and more efficient.
Since the creation of the first ECN and MTF, the competition among them and regulated markets always strengthened, and at the same time new technological developments reduce the time necessary for transactions.
Today MTF, like regulated markets, can offer trading platforms and services able to reduce the latency, such as co-location and proximity central hosting.
The competition among markets and the introduction of HFTr was like a trigger to foster the market very quickly.

5.1.6. Average bid-ask spread reduction

Together with all the other improvements that HFT has brought, there is the reduction of the bid-ask spread. Hasbruck and Saar analyzed the exchanges occurred in the NASDAQ from 2007 to 2008 measuring a reduction of the average bid-ask spread. Moreover, Conrad, Wahal and Xiang, studied 3,000 stocks in the American market between 2009 and 2011, and saw a reduction of the bid-ask spread, confirming the idea of Hasbruck and Saar.

5.2. Possible negative aspects of HFT

Many economists are still doubtful about the positive aspects of HFT but, Jarrow R.A. and Protter P. are two important opponents of this new way of trading. They concluded their research in 2011 and support the idea that HFTr tend to artificially create, evenly through illegal practices, market conditions that can be exploited only by them. Indeed,

market inefficiencies are the easiest way for high frequency operators to generate profits, which otherwise would be not possible.
The main negative consequences of HFT are:

- Adverse selection;
- Front running and ghost liquidity;
- Information asymmetry;
- Systemic risks;
- Market manipulation and two-tiered market.

5.2.1. Adverse selection

It is the natural consequence of HFTr operative characteristics and the implementation of aggressive strategies. Aggressive strategies include pinging and liquidity detection, but the most dangerous is probably the first one due to the fact that it enables high frequency operators to manipulate the market to create illusory situations only to take advantage and earn money. The final costs of these strategies are born by traditional traders.

In his research paper, Puorro A. highlights the fact that slower traders, which focus on short term operations, mainly search the presence of microtrend in the market. He noticed that HFTr thanks to their high speed and through the use of pinging strategy can easily simulate a reduction on the ask side. In this way, traditional trades follow the microtrend and start to sell. In that moment the HFTr can be the counterpart of traditional traders, hence they can purchase stocks at a lower price than before the execution of the strategy. The same strategy can be executed simulating a reduction of the bid side, in this case the HFTr will sell at higher prices than before to slow traders. The effects are clear: high frequency operators are able to sell at higher prices and buy at lower prices deceiving traditional traders; the profits of HFTr are the losses of traditional operators.

5.2.2. Front running and ghost liquidity

The front running practice allows HFTr to generate profits in context of strong information asymmetry. Thanks to foreknowledge high frequency actors can decide to execute the order with precedence over other traders. If the high frequency trader decides to not execute the order the effect would be an immediate reduction of liquidity.

The informational power of the negotiation book is progressively reduced with the introduction of high frequency trading. Due to the simulation used by HFTr the proposals of the book are now variable, increasing the possibility that liquidity can disappear.
With ghost liquidity economists indicate a situation where there is not a clear representation of the depth of the book, and liquidity is just apparent, meaning that it can disappear in few seconds. The presence of this phenomenon determines a very uncertain market which push traditional traders to close quickly their positions using market orders.

In 2012 Van Kervel V. showed how the operations of HFTr lead to an overestimation of liquidity present in the market, indeed HFTr can place numerous orders in more trading venues to increase their chances to find a counterpart; when one would be found all other orders will be cancelled creating a strong reduction of the liquidity.
A problem related to ghost liquidity is the reduced efficiency in the price discovery process. In fact, when HFTr place numerous orders which do not have investment purpose the representation of demand and supply is distorted, and it is more likely that the price does not reflect the fair value.

5.2.3. Information asymmetry

It occurs when two individuals have different degree of information.
The information asymmetry influences the characteristics of the contract. In latency arbitrage strategies the informational advantage plays a very important role, indeed just few milliseconds are sufficient for HFTr to generate profits. But the advantages are not only on capital gain, it can lead also to save money.

Obviously, an increasing information asymmetry can affect market transparency. Jovanovic and Menkveld in their research *Middleman in Limit Order Markets* found out that HFTr have more information, indeed their average reaction time is smaller than traditional traders and their decisions are almost all in the correct direction.

5.2.4. Systemic risk

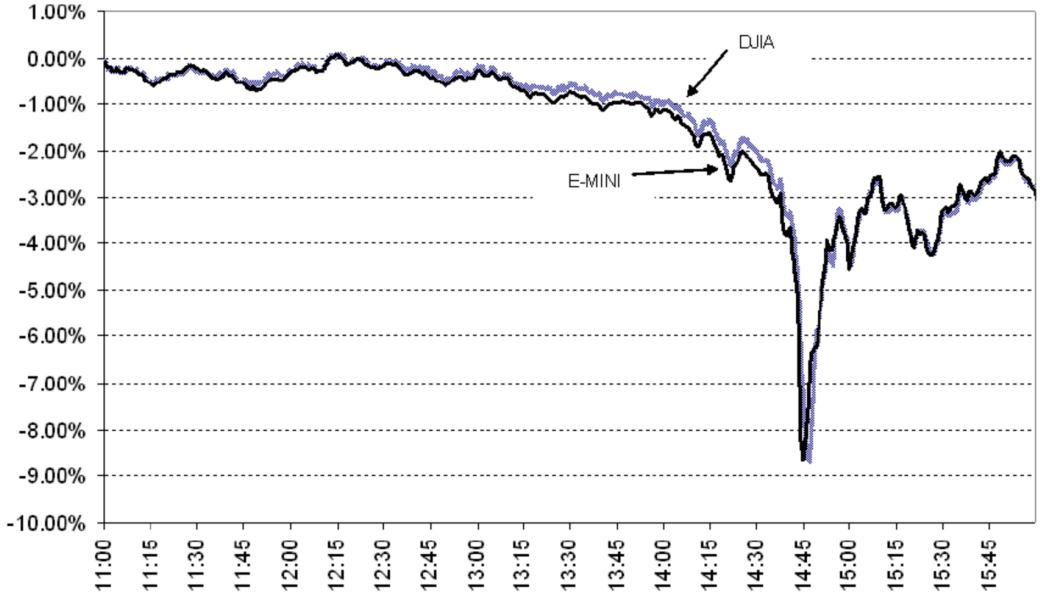
It represents the risk which depend on factors that affect the general functioning of the market. The HFT phenomenon has increased the systemic risk, since it has increased the connection and dependance of markets, and a single shock can affect more than ones. A serious concern arises because of such correlation: a shock that hit a small number of active HFTr can affect the entire market and even hurt more trading venues. Another type of systemic risk is the amplification of bullish and bearish pressures in the market increasing the speed and the width of prices.
One more concern is that high frequency operators are often lightly capitalized, which in turn result in possibility of bankruptcy and even manage the counterparty risk can be a very expensive task.
Jain et al. showed that the introduction of the high-speed trading platform *Arrowhead*, adopted by Tokyo stock exchange in 2010, increase the shock propagation risk, increasing both autocorrelation and cross correlation. Quote stuffing risk, measured by quotes-to-trade ratio, doubled and also probability of flash crashes grew.

Flash crash can be considered part of the broader category of systemic risk. It consists in a rapid and sudden decrease of one or more financial instrument's prices or indexes, usually not due to economic causes but rather to mechanical effect of the market, followed by a rebound in the following minutes, or hours, which brings the situation back to the previous levels.
Even if the presence of algorithmic and high frequency traders is not fundamental for the occurrence of the flash crash, they can amplify the movements and the speed of price changes and the successive rebound. The consequences of the phenomenon affect all market participants, which in turn tend to close all their positions due to sudden increase of volatility.

The May 6th, 2010 was the flash crash that bring the attention to HFT. During the day many of the 8,000 stocks and ETFs exchanged, showed a price decline between 5-10%. In that day, an American mutual fund sent an order to sell 75,000 E-Mini futures[29], worth about $4 billion, through an algorithm (not high frequency) that uses only volume parameter and not also price and time. Because of this move, other market participants started to sell those contracts, including high frequency traders. Due to the orders of high frequency firms the price of the contracts in question rapidly diminished. From 14:45:13 to 14:45:27 more than 27,000 contracts were traded, causing a 600 points drop of the Dow Jones Industrial Average, almost 9% of its value. More than one trillion dollars was burnt. Stocks like Procter & Gamble, American blue-chip company[30], lost slightly less than 40% of their value. In Figure 19, it is possible to see the huge drop of the index, highlighted by the light line, followed by a rebound. It was possible thanks to the fact that at 14:45:28 the trades were suspended for 5 seconds, and after the re-opening the prices increased almost at the same level before the crash.

[29] They are electronical traded futures contracts, one fifth the size of S&P futures.
[30] With blue-chip company it is defined a corporation which is known for its quality, reliability and the ability to operate profitably in good and even bad times.

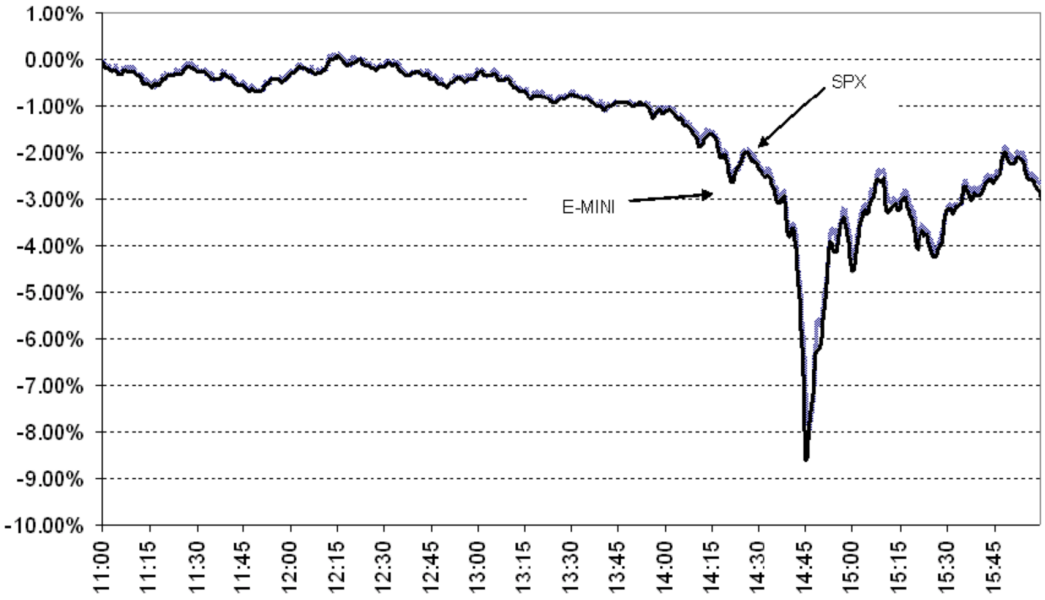
Figure 19: Decline of E-Mini and DJIA



Source: Testimony concerning the severe market disruption on May 6, 2010, Mary L. Shapiro, U.S. Securities and Exchange commission, 2010

The flash crash affected also the S&P500 index, as it is possible to see from Figure 20 were the SPX line drops together with the E-Mini futures contracts one, and the NASDAQ, showing a very connected, but also a very fragile and instable market.

Figure 20: Decline of E-Mini and S&P500



Source: Testimony concerning the severe market disruption on May 6, 2010, Mary L. Shapiro, U.S. Securities and Exchange commission, 2010

In the first moment the press blamed the Greek debt, which in those days received a downgrade, and the fact that Greece was near to default. Indeed, during the morning of that day the American markets opened negatively due to the uncertainty present in the eurozone. But these events were not sufficient to determine such reaction.

After five months the SEC and the CFTC published a joint report to clarify what happened. They noticed that at 14:30 the VIX index, which measures volatility on S&P500, rose by 22.5% and a downward pression pushed the Dow Jones down by 2.5%, moreover the liquidity on E-Mini futures diminished by 55%. Then the order of the mutual fund impacted the market, but it was not divided in more than one. Thus, the order was fully executed in less than 20 minutes. In the first moment, until 14:40, the counterparts of the order were high frequency traders and traditional arbitrageurs. The strategy of the cross-market arbitrageurs was to buy E-Mini futures and selling SPY[31] or individual shares in S&P500, but in this way the sell pressure was transferred

[31] The SPY is an ETF that tracks the S&P500 index.

also on the equity market.
Then from 14:41 to 14:44, the HFTr started to sell aggressively to diminish the pressure on their long positions. They were followed by all other market participants. Subsequently, the original algorithm, which had the duty to sell 75,000 futures, reacting to its only volume parameter, started to increase its activity and sold 35,000 contacts in 13 minutes.
The only operators in the market were, at this point, HFTr which started to buy and sell more than 27,000 contracts from 14:45:13 to 14:45:27 generating, the *hot potato* effect. Then, five second stop, caused by excess volatility, was imposed by a circuit breaker. In this short time interval, the pression on the demand side started to increase and the prices began to rise. The sell algorithm continued to sell up to 14:51.
The final result was a loss of only 3% from the prior day stock exchange's closure.
The analysis of the SEC showed that from 14:43 to 14:46 the activity of HFTr increased while in other moments they executed trades in lower amount, in addition two major high frequency firms stopped trading at 14:47 and remained inactive for the rest of the trading day. The American regulator also highlighted that HFTr were major sellers during that day and particularly they sold very aggressively during the rapid price decline ended at 14:45, causing a significant reduction of the liquidity present in the market. This happened because high frequency operators always keep a neutral position, they are not willing to take long or short positions, and consequently this strategy may lead to sudden reduction of volatility, even quite difficult to manage.
From the SEC's report emerged the importance of HFTr for the very first time, and even if the fault of the event is not attributable to HF firms, they contributed to accentuate the effects, indeed 16 traders classified as high frequency that day exchanged more than 1,455,000 contracts. According to Nanex, a company which analyzed the flash crash, the time required by the shock to spread to the markets were just 20 milliseconds.
The SEC recognized that HFTr exacerbated the price fall, but on the other hand they were also able to realize a rapid recovery of the markets. On the contrary, during the black Monday 1987, the Dow Jones lost 510 points, and it needed more than one year to return to the previous levels.

In these recent years also many mini flash crashes occurred. They represent a collapse of financial instruments' prices which happen in few minutes. Based on Nanex

definition, a mini flash crash occurred when: price changes happen within 1.5 seconds; prices change of an amount higher than 0.8%.
During July 12th, 2011, Ennis, a printer company, just in a second saw its shares value fall from $69.28 to $16.64 and then $70, Google's shares on April 22nd, 2013 dropped more than 3% in less than a second, Apple on December 1st, 2014 saw its stock decrease by 6.4%.
Even commodity markets are affected by flash crashes. Indeed, in March 2011 the cocoa price fell by 12.5% in less than a minute and sugar by 3% in a second.
Mini flash crashes also hit bond market, for example American government bonds fell by 37 basis points in October 15th, 2014. Even gold, which is considered one of the most secure investments experienced its mini flash crash in 2013 when decline by 4% in 100 milliseconds.
There isn't a univocal explanation for the occurrence of mini flash crashes: Golub A., Keane J., and Poon S. suppose that they are the consequence of regulation and market fragmentation while Johnson et al. suggest that they are a result of interaction among algorithms or a positive feedback induced by the market.

5.2.5. Market manipulation and two-tiered markets

The risk of market manipulation is not new in financial markets, but fast algorithms may provide new tools to pursue unlawful behavior, which include false impressions of trading volume, prices and market depth. High frequency operators can use massive quote cancellation and hidden orders; manipulative strategies include front running, layering, quote stuffing, smoking and spoofing but also aggressive variation of momentum ignition.

Low latency, co-location and proximity central hosting can give some advantages to high frequency traders. It is important to understand when these competitive advantages can become unfair and go to the detriment of other market participants. The advantages of HFTr are mainly represented by real-time market quote, reduced transaction time and the possibility to receive information just few milliseconds before other operators. On these are concentrated the critics of many economists which suggest that high speed traders have an advantage at the expense of others, creating

a two-tiered market. Also regulators do not provide a clear rule, indeed, on one side they forbid to release important information to a subset of investors, on the other side, they allow market centers to sell data feeds to those who have subscribed the service. It is important to notice that these services, such as co-location and direct data feeds, are available to anyone willing to pay for them.
However, the presence of a two-tiered market is not new, financial markets have always been characterized by it, since when floor traders had preferred access to stock orders.

5.3. More on models on market quality

As saw in previous paragraphs many theoretical models were developed to try to understand the impact of HFT on market quality.

Cvitanic and Kirilenko developed the *benchmark model*, with it they simulate an electronic market populated by traditional operators and subsequently they introduced a HFTr. According with the classical notion that no market maker has any superior information, they considered the high frequency trader an uninformed trader, the only difference with traditional trader is the speed of order cancellation and execution. Together with the result previously reported, lower volatility and improved transaction prices forecasts, they noticed an increase of the trading volume and a reduction of the transaction time. According to this model the volume and the time interval between trades proportionally increase with the number of traditional traders present in the market.

Foucault et al. detected with their model that HFT creates information asymmetry and increase adverse selection costs. Since high frequency operators are faster than all the other ones, they perform better and are able to realize higher profits. On the other hand, HFTr also increase the cost of adverse selection indirectly imposing to other market participants to leave the market or invest in technology such the one of HFTr.

Cartea and Penalva elaborated a model with liquidity traders (LTs), professional traders (PTs) and high frequency traders (HFTs). With it they discovered that HFT

increases the liquidity and saw a reduction in the costs of exchanges. In the same model they also found some drawbacks of HFT: it increases price volatility and trading volume. The latter was not due the higher number of shares traded but only a consequence of high frequency traders' strategies.

A model where investors differ in the speed with which they are able to respond to news and consequently adjust their positions was developed by Hoffman. He gave a lot of importance to recent developments in technology, and in particular automation, which allows investors to react differently to new information. He showed that with this new improvements HFTr have an important advantage, indeed they are able to exploit their speed to access the best quotes available, which traditional operators are unable to do. He highlighted that even if HFTr increase the liquidity in the market, on the other hand they generate profits for themselves at the expense of traditional traders.

6. Behavioral finance and algorithms

Now that we have a deep knowledge of the HFT phenomenon, I was interested to detect the possible common features and differences with individuals. Thus, I start making a brief introduction of behavioral finance, which gives us the foundations to better understand the point of view of human investors.

Behavioral finance is a quite new discipline emerged in the '80s, that combine together psychology, sociology, economics and finance. It studies the effects that all emotional, social, cognitive and psychological factors have on the economic decisions of people. All the definitions of behavioral finance have in common irrationality, non-conformity to models and the existence of biases. Its starting point is the lack of empirical support for the deviations of standard models.
It can be considered, somehow, the opposite of algorithmic trading, since the last follow a pre-determined strategy, based on technical markets analysis and do not suffer any stress or emotions.

During the classical period economy was closely related to psychology. Indeed, Adam Smith, in his *The theory of moral sentiments*, wrote about specific psychological explanations to individual behavior, highlighting some concepts such as fairness and justice. A few years later, with the neo-classical economy, economists developed models were individuals are considered self-interested and fully rational agents. They sustain an economic paradigm were economy is a science, deducing people's behavior from assumptions; they also created the concept of homo economicus whose behavior is completely rational. The three main pillars of neoclassical economics are:

- People have rational preferences;
- Individuals always maximize utility while firms maximize profit;
- People make independent decisions based on all relevant information.

Neoclassical economy makes use of utility function, indeed, to arrive at the optimal choice, individuals evaluate all possible bundles of goods and choose the one that maximize their utility according to their budget constraint, which is usually represented

by the income. Neoclassical economists suggest that to make the optimal choice individuals use the full information set they have available. In this way they implicitly assumes that humans have unlimited computational capability; but information is not often free, there are costs to acquire them, and people are not able to evaluate a huge set, and even if they are capable to evaluate a subset, they can also face assimilating and understanding costs.
Moreover, people are not always self-interested, as neo-economists suggest, actually they care about others: the simplest example is charity.

6.1. A deeper analysis of behavioral finance

A theory by John von Neumann and Oskar Morgenstern called expected utility theory was promoted to define rational behavior when people face uncertainty. This is a normative theory since it describes how people should behave in their decision-making process under uncertainty, and not how people actually act.
In support to their theory, they mutated some axiomatic properties for preferences, the most important are order and independence. As far as concern order they established that a decision maker given any two prospects, can always state the one preferred to the other or indifferent. Associated to the order property, there are completeness and transitivity. The first one emphasizes the fact that all possible prospects can be ranked, while the second one suggests that if A is preferred to B and B to C, then also A is automatically preferred to C, avoiding the creation of cyclical preferences. In regards to independence they declared that adding some quantity does not alter the preference relation. Furthermore, preferences are assumed to be time invariant.

A contradiction of expected utility theory is the so-called Allais paradox. Maurice Allais showed that if we add or subtract but even if we multiply or divide the same amount to all outcomes people do not behave coherently, and he also noticed that transitivity can be violated. Moreover, some evidences highlighted that people's decisions are not always the same if the problem or question is presented in different ways, hence the frame, the decision-maker's view of the problem and possible solution, is affected by the presentation mode and the individual's perception of the question.
These are just few examples which researchers find to demonstrate that people do not

always behave accordingly to some assumptions.

An alternative, to this theory, is the prospect theory developed by Kahneman and Tversky. It is a positive theory since it describes how people actually behave and does not rely on rigorous models.
According to the fact that people, depending on the nature of the prospect, exhibit sometimes risk aversion and some other times risk seeking, prospect theory allows for changes in risk attitudes. Researches also find out that people do not care about the level of wealth itself, rather they take in consideration the changes in wealth from a reference point; moreover they also noticed that individuals seem to feel losses stronger than gains: people are loss averse, for them losses loom larger than gains.
In the prospect theory the utility function of expected utility theory is replaced by the value function. With it researches show that people manifest risk aversion in the domain of gain and risk seeking in the domain of losses, more specifically they noticed that when the outcome probability is high people are risk averse for gains and risk seeker for losses, while when the outcome probability is low, individuals show risk seeking for gains and risk aversion for losses.

Researchers discovered also two different phenomena that affect individuals: break even effect and house money effect. The first one suggests that risk increases after loss while the latter is said to be operative when someone increases risk taking after prior gains.
In addition, it was noticed that a method used by people to make decision making manageable is mental accounting. It is especially used by households and individuals to organize, evaluate and keep track of financial activities. Important moments in mental accounting are account assignment, closure and evaluation. It can be quite difficult to choose the moment when to close and account, especially when it is at loss, since according to prospect theory losses loom larger than gains. It is quite difficult to choose when close an account which is yielding a positive balance too, because individuals may decide to close it too soon. Shefrin and Statman observed that investors realize gains more readily than losses, thus they tend to hold on losing stocks for too long and selling superior-performing stocks to early. This tendency to avoid selling losers and to keep winners too short is known as disposition effect. The reason is that a loss is painful, and investors hold the stock rather than sell it and realize the

loss; they are averse to recognizing losses in their portfolios, so they hold the asset in the hope that the market will turn in their favor.

Traditional models do not survive empirical tests. It seems that people act in a way that is not rational. Unlike the concept of homo economicus, developed by neo-economists, individuals have shown that in some cases they unconsciously distort information to avoid inconsistencies, they often see what they expect to see, they view a sample randomly drawn from a population as highly representative. But, in the end, what matters is just how information is read and understood. Behavioral economists show that perception is strongly conditioned by one's desire and expectations, memory returns multiple imprecisions when someone tries to remember situations or events, the frame effect influence a lot perception and memory. Related to the frame, a number of studies highlight the primacy and the recency effect. These two effects show how important the mind is when people have to take a decision, indeed according with the primacy effect, if subjects are asked their impression of someone based on attributes what comes first often dominates; while the recency effect suggest that when items are temporally sequential so what come last has greater importance.

Since humas are imperfect, they have cognitive limitations and even limited time, it is impossible to evaluate all possible information, they develop shortcuts, also called heuristics, which allow them to take decision faster and easier. People also use anecdotes and stereotypes to respond to particular events. Humans, hence, search a satisfactory solution rather than an optimal one. This is a natural consequence of bounded rationality which lead to suboptimal decision-making.

Heuristics can be divided into two categories: familiarity heuristics and seminal heuristics.

Individuals are more comfortable with the familiar, they tend to stick with what they already have rather than check other options. They do not take new initiatives even if they could be worthwhile: the tendency is to seek comfort. Ambiguity aversion, diversification heuristic and status quo bias are part of familiar heuristic.
Ambiguity aversion is characterized by the fact that people prefer risk to uncertainty, in fact they have a preference to deal with outcome and associated probability. The

diversification heuristic suggests that individuals like to try a little bit of everything when choices are not mutually exclusive, also because it makes the decision to take a choice simpler and allow people to save time and reduce decision conflict. The status quo bias proposes to stick with what individuals have unless there are strong reasons for doing otherwise. People are resilient to changes they prefer the current state: individuals are very likely to continue a course of action since it has been the one pursued traditionally, even though it may not be in their best interest.

Seminal heuristics are composed by anchoring, availability and representativeness.
Anchoring refers to the tendency of sticking to an arbitrary reference point when making inferences, even when the reference point is not relevant for the decision, people makes estimates starting from an initial value and adjust it to generate the final result, but the adjustment can be not sufficient. The reference point in question can be suggested by the situation or can be completely random, but in both cases, it affect the estimates. The final result of anchoring is to lead to pay too little attention to sample data, and it can be explained with the fact that people economize the cognitive effort.
Availability heuristic suggests that events which are called to mind easily are believed to have greater likelihood to take place, therefore we can assess that individuals compute the probability of an event depending on the easiness with which similar occurrences come to mind.
The representativeness heuristic suggests that people categorize using prototypes and make judgements. Related to representativeness are conjunction fallacy and base rate neglect. The first one presumes that individuals judge probabilities of events based on their representativeness rather than consider the simple probability, the second one represents the failure to take into account base rate when computing conditional probabilities.
Other phenomena are represented by hot hand and gambler's fallacy. The first one represents an over inference of probability of a good outcome after a strike of good results, while gambler's fallacy instead suggests that when a number has not come out for a while, the individual feels that it has to come out.
The original program on biases and heuristics developed by Kahneman and Tvsersky relied on some assumptions: shortcuts economize on effort but may lead to suboptimal decisions, the logic and statistical influence should be considered the right tool for decision making and there is an efficiency/accuracy trade off. According to Gigerenzer

and Gaissmaier, a heuristic can be defined as “a strategy that ignores part of the information, with the goal of making decisions more quickly, frugally and/or more accurately than more complex methods”. They are a clear example of *less is more*.

Another heuristic, developed this time by DeMiguel, uses $\frac{1}{N}$ as a benchmark to assess the different rules for portfolio allocation suggested by traditional finance fare. It implies that investors simply divide equally the money they want to invest in different assets, without looking at any other information regarding performance. Analyzing 14 different portfolio models in the US equity market, looking at the Sharpe ratio, the results show that no models are better than the much simpler $\frac{1}{N}$ heuristic.

Lately, in 2014, Neth showed that heuristics can be useful especially when there are situations with high level of uncertainty and there is a large number of alternative options.

6.2. Heuristics and biases’ implications in financial decision-making process

Heuristics seem very often an excellent time and effort saving decision making system, but sometimes they lead investors to unfortunate decisions.

6.2.1. Familiar heuristic and financial decisions

The preference for familiar things is also reflected on investments, indeed researchers have found out that domestic investors hold mostly domestic securities. French K. and Poterba J. noticed that in 1989, a typical American investor held 93.8% in US stocks, a Japanese investor 98.1% in Japanese stocks and a British investor 82.0% UK stocks. This tendency to invest in familiar shares is evident even when people invest in the company they work or a firm whose brand is well known.
The tendency to overweight domestic stocks is called home bias.
The home bias can represent a problem since an excessive allocation in national securities leads to foregoing gains from diversification in different countries, but there are several explanations of the phenomenon. We can group them in two categories:

rational, based on implications of, including among others, crossing national borders, exchange rates, sovereign risk and border taxes; and behavioral explanations based on the preference for geographic proximity covering pure preference for the local or the familiar, informational advantages regarding local companies.

The rational explanation suggests that international investments might be less attractive due to the presence of barriers like for example capital movement restrictions, exchanges and interest rates, different trading costs and tax rates.
Rational explanation to invest locally is also hedging demand, indeed if you consume local goods at local prices, it makes sense to hedge by investing locally.
On the other hand, behavioral explanation includes optimisms, indeed one reason why investors might hold more domestic securities is because they are optimistic about their national market. Moreover, the preference for familiarity extends to language and culture, people prefer to deal with individuals who have similar mentality and history. Investors have a preference for geographic proximity too, they prefer to invest in shares of companies which are very near to them even on a national point of view, in fact Huberman G. reported a case of intra-national home bias: in 1984 AT&T was forced into a divestiture where seven “Baby Bells” were created along regional lines. At the time it was possible to see that a huge number of a Baby Bell’s customers held a disproportionate number of shares in the local one.
Another reason why investors favor national markets is because they may possess or might feel that they possess informational advantage. Geographical proximity can induce investor to feel that they are able to gain information easier, to access private information with less efforts. But this seems not to hold, as a matter of fact if investors have a sort of informational advantage, they should buy and sell shares as their price change, but evidences show that they buy and hold securities.
Furthermore, local shares preference is related to firm size, and small, levered companies which produce goods that are not traded internationally tend to be the ones where local preferences are the strongest.
Furthermore, there is evidence that investors overweight the stocks of companies with familiar brand or for which they work. According to comfort seeking and familiarity people prefer to invest in firms with brand recognition, because they are associated to more accessible information for average investors and individuals will demand more stocks when they have more precise information about the security. Investor distaste

outcomes that are framed in ambiguous terms.

Bet on the local economy is not a smart move if investors also work in the local economy, indeed in this way the two sources of income are highly correlated: if local economy is doing bad, both income and investment performance would be poor.

6.2.2. Representativeness heuristic and financial decisions

Representatives implies to give too much attention to sample information and to judge the profitability of an event according to some features that such occurrences share with the population.
In financial field, representativeness generates inferences on a stock's future performance based on some features of the company in question. For people not accustomed to finance, it seems evident that if a company has consistent growth in earnings, strong image and high-quality management it must be a good investment. But things are not so easy: the value of a company today is the sum of all its future cash flows discounted by the appropriate interest rate which takes in consideration the risk. All the attributes that make a company a good one should be included in the cash flows and risk-adjusted discount rate meaning that they should be already impounded in price. The natural consequence is that good companies will sell at high prices while bad ones will sell at low prices, but once the market has taken in consideration all the elements there is no reason to favor a good company over a bad one. Hence, it is a mistake to think that a good company is representative of a good investment.

Shefrin and Statman find very important results in their research based on a survey of Fortune senior executives: management quality and long-term performance are very highly correlate, even top managers believe that good companies are good investments; size is positive associated with quality, it is thought that bigger the company better the performance; but the empirical evidence shows exactly the opposite: small-cap value firms have historically outperformed big-cap ones.
In a related research, there is evidence that company image affects the perception of investment attractiveness: people are more likely to invest in firms with positive image than those with a negative one.

Furthermore, researches have sometimes seen the tendency to associate past success and past returns with future performance: this is called chasing winners. It appears that investors choose their investments based on securities' past performance. For these people past investment performances are representative of future ones. This tendency is also called trend following or momentum-chasing.
This idea shows a positive correlation for 3 to 12 months returns but for period longer than 3 years the evidences show negative correlation.

6.2.3. Availability and anchoring heuristic and financial decisions

When information of specific events are available people often get the impression that such episodes have more possibilities to occur. This is due to availability, which suggests that events which can be recalled in mind more easily are considered more likely to happen.
Availability can be called into question in financial markets since it is impossible to evaluate all possible financial instruments, like shares, ETFs, pension funds, mutual funds, investment funds, etc.

Barber B. and Odean T. analyzed the trading behavior of investors and argued that since attention is a scarce resource and there are endless investment opportunities, the investment decisions are concentrated in stocks whose information are freely available. They noticed that negative news are likely to be ignored, while positive ones may attract investors, especially purchasers; on the other hand, institutional investors are less subject to this phenomenon since they theoretically consider all the securities present in the market.

Anchoring implies that people tend to pay too little attention to sample data and sometimes they anchor their estimates and evaluations to specific figures, and this can have an even stronger role in economic decisions.
Northcraft and Nealy noticed in their research that listed price serve as an anchor among many investors, including professional financial analysts.
Moreover, analysts show that they are slow to change their initial opinion, and this can be seen as an example of anchor.

6.3. Behavioral explanation to investors' emotions

It is quite difficult to say if emotions are good or bad; it depends. They can be good because regret anticipation avoids excessive risk taking, while they may be bad because sometimes, they prevail over cognitive aspects.

The movements of the market are commonly attributed to the emotions of investors. There are evidences that, for example, good moods resulting from morning sunshine lead to higher stock returns, since a sunny day might make people more optimistic.

Moods are likely to have subconscious effects on behavior, indeed Hirsheleifer and Shumway find that there is a statistically significant relationship between cloudy days and nominal returns in 26 international stock exchanges. Kamstra et al. discover that the daylight-saving effect leads to large losses and very negative returns in the major stock market indices. Edmans et al. noticed that national stock markets earn a statistically and economically significative negative results on the day after a loss by the national soccer team.
Furthermore, some research show that happier people are more optimistic and assign higher probabilities to positive events, but they do not want to take a gamble, in other words individuals are more risk averse when they are happy: when a person is in good mood he doesn't want to bet because he does not to jeopardize the good mood.

6.3.1. Pride and regret

Two emotions which are very useful to understand the behavior of investors are pride and regret.
Regret is the feeling of responsibility for negative outcomes due to a choice; it is a negative emotion which is amplified if the individual has caused a loss to his spouse, friends or colleagues. An investor may regret for a bad investment decision and wish he had made a different choice.
On the other hand, pride can be considered the opposite of regret, it represents the satisfaction from own achievements.

Researchers recognize the importance that pride and regret can have on financial decisions, they think that people are strongly motivated to avoid the feeling of regret. It is important to notice that the effect of these two emotions are asymmetric and it seems that regret is felt more strongly. Once again it agrees with prospect theory.

6.3.2. Disposition effect

It is the tendency of investors to sell superior-performing stocks too early and hold too much losing ones. No rational explanations hold to explain disposition effect: no tax considerations, no transaction costs and neither portfolio rebalancing. On the other hand, gambler's fallacy, prospect theory and regret aversion are behavioral explanation of the phenomenon.

The gambler's fallacy suggests that investors know that losing stocks will outperform winning ones, but this happen in the long-run, while they are taking their decision with the wrong time, since they usually sell in the medium-run.
Prospect theory suggests that people, after large gain, move in the domain of gains, become risk averse and hence sell the stocks; while when they experience a loss, they move in the domain of losses and become risk seeker, hence people keep the losing stock in the hope that it turns into a gain or at least cover the loss.
Investors can decide to not close an account at loss for the fear of experiencing regret and for the desire of pride when realizing a possible gain.
We know that people can use a loss to offset the tax on gains, thus they can decide to realize the loss to pay a smaller amount of taxes. The tax-swap can be an incentive to sell the losing stock, realize the loss and pay less taxes, but also this time close a mental account at loss is difficult for investors even if it can lead to less taxes.

Another possible explanation has been proposed by Barberis Nicholas and Xiong Wei. They noticed in their two-period model that the investor prefers to buy after a gain and to sell after a loss.

A recent theory developed by Summers B. and Duxbury D. favors emotions to explain the disposition effect. They noticed that when a stock, which an investor own, is doing

poorly, he experiences disappointment, while when the same stock is doing well, he experiences elation. If the investor has chosen this stock himself, he will experience emotion with higher valence, leading to regret and pride respectively. They hypothesize that anticipated regret and pride are necessary to generate behavior which can trigger the disposition effect; responsibility for an outcome is its prerequisite.

6.3.3. House money effect and affective reaction

Individuals' decisions are influenced by what has previously transpired. Two researchers, Thaler R. and Johnson E., highlighted that people's behavior is affected by prior gains and losses. They particularly noticed that after a gain, individuals are more willing to take risk. This behavior is called house money effect.
On the other hand, they observed that after a loss two different behavior can occur: in some people a prior loss can induce them to take a risky gamble in order to try to break even, while some other people can increase their risk aversion. The last effect is known as snake-bit effect.

Emotional responses are caused by many different stimuli that people experience every day. An affective assessment is the sentiment that arises from a stimulus.
Rubaltelli et al. find that stocks belonging to industries and sectors that are socially responsible trigger more positive affective reactions and reach higher selling prices.

6.4. How to invest according to behavioral finance

With behavioral investing economists consider the attempt to enhance portfolio performance by applying the knowledges of behavioral finance.
Schewert W. wrote about a series of market anomalies like January effect, i.e. the tendency for returns to be higher in the first month of the year, the weekend effect, meaning the tendency for returns to be lower on Monday, and many others, and he noticed that once the anomaly is reported, it either disappear or reduces. This demonstrates an approach aimed at eliminating anomalies in the attempt to increase market efficiency.

Talking about investors, there are evidence that show overconfidence among them. The consequence of overconfidence is excessive trading. Many theoretical models confirm that result. With overconfidence it is meant an investor who strongly believes in his ability to correctly evaluate a security. Researches detected that higher the investor's level of confidence more responsive demand is to changes in prices. When the overconfidence coefficient is equal to 1 means that market price has no influence in demand, while when it is near to 0, the demand changes a little when the price changes. Higher the investor's overconfidence level, flatter is the demand curve.

Moreover, there are also proofs that men tend to be more overconfident than women. Barber and Odean reported that males traded 45% more than females, and they also incur in higher trading costs. Both genders reduce their net returns by trading, men do so by 0.94% more than women. The difference between single men and single ladies report that, the first trade 67% more, reducing their returns by 1.44% more than women.

Even professional traders are not immune to overconfidence; its dynamic is an important issue. It seems quite logical to think that people remember their successes and failures equally clearly, hence they should move to an accurate view over time, and experience would foster the process. Conversely, the prevalence and persistence of overconfidence suggest that it is difficult to eliminate it. Furthermore, we should remember that self-attribution bias induces people to remember their success with great clarity, hindsight bias induces them to idealize their memory of what we believe or forecasted previously, and confirmation bias highlights the tendency to search out evidence consistent with one's prior beliefs and to ignore conflicting data.

Gervais and Odean, denoted that past success amplify overconfidence and past failures tend to be downplayed. Therefore, we can deduce that those traders who have experienced good results and success might be more overconfident than other ones.

An error, related to overconfidence, that investors can make is the tendency to be under diversified. Undiversified investors are too fast to overweight or underweight stocks when they receive positive or negative signals respectively, and this practice lead to insufficient diversification. In addition, retail investors, who lack in time to analyze large set of stocks, have shown lack of diversification, since they believe that they have identify few winners and invest only on them.

The disposition effect can also be explained by overconfidence, indeed an overconfident investor overly wedded to prior beliefs may discount negative

information that push the price down and hold loses and take excessive risk. Evidence show that traders with mid-day losses increase their risk and perform poorly immediately after.
Related to under diversification, is excessive risk taking in the hope of finding undervalued shares.

6.5. Traders' brain

Some scientists assert that individuals have knowledge that they cannot put into words, for example traders have information about stock markets that cannot be adequately described in words, simply because markets are more complex than the language we have to describe them.
As always, excellence in most field requires expertise. But what makes a successful trader? Observing the market, we can see that a trader may instinctively know the strategy he wants to pursue, Steenbarger noticed that in many circumstances traders will make similar acquisition or sales, and then provide very different explanations of their moves. They saw the same information, acted in the same way but understood their behavior differently. We can assess that traders took their decisions based on instinct and not always on cognitive evaluation, but as always knowing the rules of the games and good amount of practice are key elements for success. Indeed, successful traders devote a lot of time to practice, which in turn gives them the ability to connect their knowledge to the action they should take.

Thanks to recent developments in neurofinance, scientists are able to examine how the brain behaves while an individual is dealing with financial decisions. Automatic responses often stimulate the amygdala, while controlled responses activate the forebrain, or prefrontal cortex. In his work, Damasio, noticed that people with lesions have shown that emotions and decision making are complementary processes.
Neuroscientists have investigated various questions, and it was found that those traders whose reactions to profits and losses are the most intense have the worst performance, suggesting the need of balanced emotions. Furthermore, Lo and Repin, showed that even the most seasoned traders exhibit significant emotional response when trading and experiencing unexpected price volatility. Moreover, scientists noticed that when gains are anticipated, a subcortical region called nucleus accumbens

becomes active. This region, rich in dopamine, activates only with gains and not with losses suggesting a differential experience among them.
Even risks and uncertainty are processed in different ways. Researchers show that when facing uncertainty, the most active regions are the orbitofrontal cortex and the amygdala, both regions integrates emotion and cognition, while when facing risk, the brain areas that respond are the parietal lobes. Hence, we can say that risk leads to a cognitive reaction while uncertainty seems to trigger emotional response.
During some researches, it has been noticed that when times become uncertain, as it can happen during crises, the inability of investors to forecast the distribution of future returns move them from rational response to emotional one, spreading the unwillingness to hold risky assets and exacerbating market declines.

In order to acquire expertise, it is important to know the fundamentals of the market and practice a lot, also through many simulations, under divergent market conditions will provide better decision-making during trading activities.

We can conclude recalling that individuals are subject to cognitive and emotional biases, and particularly emotions play a fundamental role in decision making, and in some cases they overrule cognitive aspects, for these reasons a successful trader must be emotionally stable, should be aware of these effects of emotions and try to mediate them with cognitive skills and abilities.

6.6. Flash crashes and individuals

Not every time people are able to develop immediately and suddenly a strategy, and when this happen emotions play a very important role. An emotion leads the investor to compute an action which will have consequences in the market.
When we deal with flash crashes emotions last very few seconds, even if fear may survive for the rest of the day, or even during the following days. It is different when investors deal with mini flash crash, indeed they are difficult to detect and many times they are ignored by emotions too, also because they are quite difficult to recognize.

Breakdowns[32] and breakups[33] may be present for some weeks, given their longer duration on a psychological and emotional point of view.

As we know, emotions can be positive or negative; when a positive emotion emerges, the attention focuses on the ongoing activity, while with a negative one people generally assume pessimistic view and the probability to not reach the purpose of the activity increases, hence many individuals change their goal.

Once a flash crash occurs, negative emotions take over and induce a change in the activity or in the strategy actually pursued by investors. Indeed, a flash crash impact the operators' conscience and lead them to reconsider their positions in portfolio. Often flash crashes affect the neural system leading to excitement. It is not every time a negative phenomenon, but it depends on its level: an optimal level of excitement can stimulate a positive reaction, while a lower than optimal level can involve boredom and sleepiness, and even distractions. A too high level, instead, generates a negative overexcitation at organizational level.

6.7. Financial crisis and individuals

Rezania O. analyzed the investors behavior during the financial crisis occurred in 2008. He examined the 2008 and 2009 years, known as one of the most volatile periods in the financial market history, and observed the behavior of individual investors during distressed moments. He used both a parametric and a non-parametric approach; the first one was based on multivariable regressions but showed unsatisfactory results. Indeed, in volatile periods there are many jumps in the data, and they are not stable which make the analysis less fruitful. Therefore, he decided to give more importance to data points nearer to the regression line and less weight to outlier. In this way he obtained a robust regression with statistically significant results. But, since with this procedure the utility of the model was limited, he decided to employ a non-parametric approach too.

[32] Extreme price decrease.
[33] Extreme price increase.

In the first quarter of 2008, investors largely disinvest from stocks, but as soon as equity market stabilized over the next quarter, some capital returned to be invested into equity. During the selling phase, occurred in the remainder of 2008, investors sold during nine consecutive weeks generating net cash outflow. During the successive fall, in January and February 2009 investors sell out again. In March of the same year, the market started its rally, but individual investors continued to sell for the next ten weeks, in the exact moment when it would be profitable to buy shares.

Rezania through a deeper analysis noticed that individual investors first sold after the fall in the market and then chased the market as it was going up again. The financial crisis started to intensify in September 2008, and individuals started to sell stocks. This practice continued through October but stabilized in November. Investors showed a reactive behavior in January starting to buy ETFs, then they lowered their position, about 10%. In February and in March they sold their holding stocks sharply, reaching the minimum. The researcher detected that individual investors have been reactive to the market rather than be proactively engaged with it.
Moreover, Rezania observed that in the second half of 2008 a contrast: investors shifted their positions in reaction to the market, as if they were looking to the past, while the net short interest across all stocks on S&P500 increased.

The researcher decided to test the existence of the disposition effect among individual investors; the approach was different from the traditional one, since he considered the performance of individual investors aggregate holdings. To evaluate the performance, he compared the performance of the investors' market portfolio with Russell 3000, which accounts for 98% of all US equity market capitalization. According to disposition effect individuals sell their winning positions too early, hence the researcher delayed the large sell trades by a few days, from 2 to 15 days, to test if the performance improves. The same thing was done in a declining market where investors sell their stock too late; to test this part he moved the large sell trades forward, from 2 to 15 days, to verify if performance improves.
The results showed that if individuals were to sell their winner stocks later than they did, and close their losing positions earlier than they did, they would have increased their profits significantly. The benefits would be present both on cumulative returns and in risk adjusted returns.

Since the disposition effect exists, if someone develop a model which operates contrary to investors it will be profitable. Therefore, Rezania looked at the market and took the return on S&P500 as benchmark. The results during the period of the test was extraordinary: if someone would have taken positions opposite to that of the individual investors it would be highly profitable, outperforming the benchmark by 148%. Noteworthy, the model gave its best result during the most volatile months: indeed, an increase in market turbulence increase the likelihood that investor sell their positions. Furthermore, the researcher highlighted that the sell off period occurred after long period of market decline indicating that investors held too much their losing stocks, once again in accordance with disposition effect.
In the vast majority of the cases when the individual investors had high conviction in their buy or sell operations, they adopt the wrong timing.

Researches have also demonstrated the evidence of feedback trading, which states that investors' decisions are mainly based on the immediate variations in the market and alteration in the prices. In addition, they also observed that individual investors show an excessive trading activity, emphasizing the fact that they change their holdings too frequently and trade more often than it needed.
In behavioral finance, feedback trading is known as that trading activity induced by reaction to changes in prices; some researchers define it as special case of herding behavior. Rezania tested also the hypothesis of the exitance of feedback trading, through a parametric and a non-parametric model. He noticed that, assuming no bid-ask spread the investors who frequently rebalanced their portfolio would have outperformed the benchmark, but if we take in consideration the average bid-ask spread, portfolio performance diminished, and the portfolio underperformed the benchmark. He concluded noticing that excessive trading of investors, which lead to frequently rebalance the market portfolio of individual investors, generated less profit compared to the investors which held the market portfolio, who rebalanced it less frequently.

6.8. Are algorithms free of emotions?

During the previous paragraphs we ascertain that humans are not particularly good at

sticking to a process. Biases, like overconfidence, regret, cognitive dissonance and many other are at odds with rule-based financial thinking. These biases introduce inconsistencies: in financial markets decisions are based on probability, but people are incapable of forming estimates without bias.
On the other hand, computers do not suffer such subjectivity: they follow rules and form objective estimates of risks.
Just to exploit human biases, automated trading programs perform the ambiguity alpha trading system to capture the utility left in the market by humans. They are able do to so, by process complex data, make fast computations and look at many hundreds or thousands of inputs beyond the ability of individuals.

Algorithms are more efficient and rational than human traders, and at the same time less prone to emotionally motivated decisions. Specifically, HFT and algorithmic trading are often lauded as ways to bypassing individuals' biases from the trading process.

However, some researchers have found that algorithmic trading does contain behavioral aspects. Kumiega A. and Van Vielt B., suggest that the behavioral aspects of trading systems are not in the emotional reactions to market moves but in the emotional responses to different facets of trading system project management.
Borch C. and Lange A. C. noted that the calm and disciplined approach of high frequency traders represent one way in which computer algorithms are believed to be a rational response for human's errors. Algorithms are seen as a mean to ensure rationality in the markets, while humans are portrayed as susceptible to follow crowd, fickle and easily swayed by emotions.
Several studies have demonstrated that emotions, mainly as excitement, outbursts and panic play a crucial role for traders and in financial markets; click, or screen, traders[34] are very strongly engaged in the exchanges and they experience joy, excitement and terror. It is generally believed that algorithms can remove this emotional dimension from trades, indeed trading through algorithms takes out human emotional aspect. Computer's decisions are based solely on data and not on the whims, dread and avidity

[34] Click or screen traders are the ones which work in large trading rooms and engage with the market via numerous computer screens and execute orders by clicking the mouse.

of human trader.
In an interview to a previous high frequency trader, done by Borch and Lange, he stated that machines never disobey their rules, and their rules are smarter since are not arbitrary, not based on emotions but on what the data says you should do.
Another trader said: “If you lost money yesterday, you might be pushing more to make it up. A computer program never pushes to make up for an error from yesterday. If it lost money yesterday, it’s not taking more risk to make more money. It’s going to take exactly the risk it is programmed to”.

However, in practice is not possible to eliminate completely emotions through algorithms. In fact, HFT introduces a new set of emotions. While algorithms do not suffer emotions directly, the programmer who code and monitor it may experience them. One of the most important challenge is to avoid adjusting the algorithms on the basis of emotions. A HFTr in the futures market describe that in the hour during which the market is close, they train themselves to not overreact. He specifically explains how difficult it is to keep calm during that hour, and, to avoid wrong decisions, he leave the computer to be less prone to do some adjustments by, for example, changing values or risk parameters of the algorithm.
Therefore, we can say that emotions do not fully disappear from financial markets, the technological developments merely shift the focus from traders to algorithms. Letting emotions interfere with an algorithm means affecting the gains in rationality and predictability that the same algorithm is supposed to yield.

Furthermore, even writing a code can create new forms of undesired emotions. A HFTr highlighted that he gets attached to the algorithm he developed. He literally said: “… if you see that it’s not working as you expected it to, you want to make it work. You know, rationally, it won’t. All the science tells you it won’t”.
I noted that HFTr demonstrate a personal attachment to the algorithm, and one of them defined it as a sort of an extension of himself.
This type of attachment is also highlighted by the fact that many algorithms have semi-personal names, and this personalization together with the inclination of HFTr to see them as extension of themselves, raises the challenge of how it is possible to ensure that emotions do not intervene in the code of the algorithms.

Hence, we can conclude saying that subjectivity is distributed across developer, programmer and financial analysts. Emotions are not only a problem of human, but even algorithms are, albeit indirectly, affected by them.

Conclusions

Numerous and articulate are the realities inside capital markets, but one of the most recent and probably most concrete is the high frequency trading. This new technology has been criticized many times and is still today the center of many doubts. But it represents such a large and deep phenomenon that it is impossible to find a middle point between critics and supporters: on one hand we have price efficiency, bid-ask spread and volatility reduction, increased market efficiency and liquidity, on the other there are some strategies at the border of legality and the creation of inequalities inside it.

We cannot ignore the role that technology plays nowadays in our lives, the internet has opened knowledge to the whole world and connected it, and today it is impossible to imagine a world without technology, and unthinkable to go back. At the same time, as happened in everyday life, there has also been developments in the capital markets, where algorithms have first helped men and now are slowly replacing them, at least for those transactions on the wave of milliseconds. Algorithms are just the last evolution of technology applied to stock markets. High frequency trading has given a substantial change on how trades are carried out, introducing a speed not even imaginable until few years ago. With high frequency trading we enter in a new world, which is radically outside human rules, quoting Sean Gourley, we enter in the “machine world”.
But it is important to highlight that an HFT algorithms require continuous adjustments: it is profitable only for 3-6 months, thus traders/programmers constantly have to develop new ones, and even a well-functioning algorithm need code revision about every two weeks, while new ones need constant attention.

Since markets are populated mostly by human investors, in the last chapter I introduced some concepts of behavioral finance. It is a new discipline that merge together psychology, sociology, economics and finance. It goes against the theory of homo economicus and highlights a series of biases that afflict individuals. These limitations lead them to suboptimal decision. Conversely, algorithms are supposed to take always the best decisions. Due to our cognitive limitations, technology was introduced in the capital markets, but if on one side we can consider algorithms

superior than us, since they are able to evaluate huge amounts of data very quickly, on the other, for non-professionals they can represent a limit: individuals are not so prone to give their money to computers for investments. At this point a crucial matter of trust in the algorithms can arise. Even if the most recent algorithms embed artificial intelligence, meaning that they are able to learn from the past and from past errors, and adjust automatically for the future to not make the same mistake again, win the humans' trust is a difficult task.
But despite all controls and revisions, errors continue to occur. For that reason, high frequency trading firms use their own capital to pursue that activity.

What mainly fear investors is the almost unlimited control the algorithm has: determine when to buy, when to sell and for how long to keep a stock. Investment firms, to increase the confidence in computers, may try to communicate how an algorithm works to make investors more aware, but algorithms are not an easy understanding for common people, indeed only a few are able to do so, and humans are scared of not finding answers to their questions and doubts. We, as individuals, seek and need that kind of interaction among us, even if it led us to not maximize outcomes.

Nevertheless, it seems that the quotes of high frequency transactions are diminishing nowadays, and some opponents already praise the end of this technology. Bloomberg is not of the same belief and affirms that it will play an important role in the capital markets also in the future, as it was in the two previous decades.
The famous information provider suggests that the focus of the competition will not be any more speed, but underpriced latency. This process leads to a reduction of the costs incurred by HFTr, but at the same time it involves more risk than old-fashioned high frequency practice and therefore high-speed operators will consequently need more capital.
Moreover, as already said, HFT practice is moving into other markets, markets with less liquid stocks and exchange-traded derivatives, cryptocurrencies and emerging markets. Indeed, the profits for supplying liquidity in these markets are much larger than liquid ones. On the other hand, in those markets it can be harder to get information and electronic execution may be not always available. Furthermore, in less liquid markets it can be required to keep a position longer than usual: it may need weeks or months before a counterpart of the order comes to the market. Therefore, it means that

HFTr must start to hedge the risks over longer period.

A crucial role for the future will be played by regulation, which can heavily limit the diffusion of the phenomenon. A key point that new regulations should consider is a greater transparency, it would also have the indirect effect of increase the positive beliefs on the phenomenon of common people.
Many experts agree with Bloomberg and believe that firms will continue to invest in technology in order to create greater profits and opportunities for all stakeholders. Looking at the future, new firms that want invest in the high frequency sector should take in consideration different aspects which, until today, have mostly be neglect: risk, quality and compliance management, code optimization and testing. Certainly, as regulatory burden increases, greater stress is expected on reporting, pre-trade controls and compliance. Moreover, HF firms must ensure that there are comprehensive tests of their applications and strategies in order to avoid losses due to malfunctioning algorithms as happened in the past.

Even if the main focus of the next future will not be speed, it will continue to play an important role and its run-up could lead from optic cable technology to microwaves. This could happen because the signals travel faster through air rather than through cables. Indeed, it has been calculated that microwaves systems reduce the time needed to access the market between New York and Chicago by 40%: the optic fiber requires 8.3 milliseconds while microwaves require a range from 4.6 to 4.74.
Obviously, the future of HFT is related to stock exchanges too. One proposal for the future is to implement a discrete-time trading model. With this model the trading day would be divided into extremely frequent but discrete time intervals. In this way, for example, all trade requests received during 100 milliseconds time interval are treated in the same way, meaning they are treated as being arrived at the same exact time. At the end of the interval of time, all orders are grouped and matched to balance demand and supply. The authors of this approach suggest that the price inefficiency would be cancelled and liquidity enhanced, while arbitrage opportunities for HFTr would strongly decrease.

In regard to the current, unexpected and unthinkable historical situation we are facing, with a new pandemic disease spreading all over the world, and still not under control,

I got interested in observing what algorithms did and how the managed the trading activity during this moment of chaos. Unfortunately, I found very few evidences about this phenomenon, but one of them is very interesting. Antonio Simeone is the CEO of Euklid, an investment fund, which operates only through algorithms, created in London in 2018. He claims that the panic has an equation, a formula. His algorithms try to capture that formula and attempt to understand and forecast the future developments. During the days when the market fell down due to panic triggered by the spread of the coronavirus, his portfolio moved in the opposite direction. He explains that this success was possible because, after analyzing the time frame before the crack, when all indexes were still rising, his algorithms started to notice some changes, impossible to be detected by human investors, and decided to go short, and, finally were right.
Simeone explains good performance thanks to the fact that his algorithms look at the psychology of the traders, not only humas, but also machine technology.
I can argue that algorithms performed better than humans because they do not suffer emotions, and the emotional pressure of an investors during that months would have been very high, especially because they did not know anything about the future, and be uncertain about it, is one of the worst thing that can happen to traders.

Knowing that HFT realizes small profits for each trade it executes, and that investors are impatient, thus not willing to invest huge resources to obtain little gains in the short time, I think that a profitable application of high frequency algorithms can be to pension funds. Realizing small profits over a very long-time horizon can be a good way to win the trust of humans. Maybe high frequency firms can start by managing for long time their own resources and when the results are profitable, they can try to sell this method to investors, showing the results they obtained. Since they are reluctant about algorithms, looking at good performance, and maybe, at lower costs than other pension funds, can be the right move to fight their distrust and create a profitable business for HFTr.

My personal opinion is that a compromise between humans and computers can be very profitable. Algorithms are undeniable able to evaluate higher amount of information and take decision in a smaller amount of time, but the human component of the market has always been present, and nothing can create a relationship of trust like a human one.

A good way of interaction between the two-opposite side of the capital markets can be an environment where humans are more supported by algorithms and vice versa. Hence, humans can correct or stop algorithm's decisions when they are wrong, especially in period of high volatility when they may heavily sell increasing the instability of the market or when an algorithm wrongly execute its trades. Algorithms, on the other hand, can support humans in computation and analysis of data to give them better instruments on which pursue their analysis to finally relate with investors, thus not losing the human approach and stimulate trust among investors.

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