Department of Economics and Finance Chair of Theory of Finance

FLASH MARKETS
AND A MARKET MAKING ALGORITHM FOR THE ROTMAN INTERACTIVE TRADER CLIENT

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ACCADEMIC YEAR 2016/2017

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TABLE OF CONTENTS

TABLE OF CONTENTS

To Oriana and Andrea.

INTRODUCTION

The presence of High Frequency Trading systems has been unveiled by the sudden, rapid and unmotivated Dow Jones *flash crash* that occurred on May 6, 2010[1]. *High Frequency Trading* is a mode of intervention on financial markets that uses sophisticated software and hardware tools to implement high frequency trading managed by math algorithms.

The crisis caused an immediate investigation by the Securities and Exchange Commission (SEC)[2] and the inevitable attention from media all around the world. *SEC*[3] established during the same month the involvement in the collapse of May 6, 2010 by high frequency trading systems, thus excluding the responsibility of out-of-control electronic systems.

However, it was difficult to find out if the impact of HFT systems on the market in that situation was positive or negative.

On the one hand, the presence of systems capable of performing high-speed operations has certainly aggravated the descent phase of the prices, but on the other hand, at the time of turnaround, those same systems have allowed a sudden recovery in only 10 minutes[4].

The simple observation of the discordant effects of High Frequency Trading systems is a sign of the complexity of the subject.

A "forerunner" of High Frequency Trading can be recognized in the "SOES Bandits"[5] phenomenon, in the mid 90s.

This is a particular type of *trader*, considered very aggressive, that carries out a number of transactions per day (hundreds) with the specific aim of capturing the slightest oscillation of the price of financial instruments or taking advantage by the delays of *market makers* in updating the ask or bid prices.

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[1] On May 6, 2010, the Dow Jones index lost around 8% within a few minutes, dropping from 10,650 points to less than 10,000 points, then recovering to 10,520 points in the next 10 minutes

[2] SEC is the US federal agency responsible for supervising stock exchange.

[3] *Security and Exchange Commission* "*Preliminary Findings Regarding the Market Events of May 6, 2010*"- *Advisory Committee*, May 18, 2010.

[4] Note that after the famous stock market crash of October 19, 1987 the Dow Jones index took over a year to recover a percentage of loss comparable to that recovered in just 10 minutes in May 2010.

[5] *Small Order Execution System*, *Harvey Houtkin* "*Secrets of the SOES bandits*".

In those same years, SEC contributed to the emergence of High Frequency Trading, allowing the use of *Electronic Communications Network*[6] (hereinafter ECN) as alternative trading systems compared to regulated markets.

By combining ECN and a Von Neumann machine[7] it was therefore possible to take advantage of an alternative market, where buyers and sellers could meet automatically without having to operate through brokers and dealers, as it happened on regulated markets. From the beginning of the new century, continuous technological and financial innovations have facilitated the spread of trading activities based on the use of mathematical algorithms that act on stock, options, bonds, derivatives and *commodity* markets with very similar goals of the pioneers "SOES Bandits". These algorithms have as *input* the data for any market in real time and as *output* precise trading decisions automatically initiated by the entry, modification or cancellation of orders on different trading platforms. The duration of the transaction is generally very short, investment positions are held for a variable time, from a few hours up to fractions of a second.

HFT is now responsible for major volumes in the main developed markets, in some stock exchanges it is estimated that high-frequency trading transactions are more than 70% of the total.

It also almost clear that these strategies can be used only by some market participants, or those who can afford the high cost of advanced technology[8].

The increasing spread of the phenomenon in the markets has given a major boost to the debate between supervisors and academically.

The economic literature, despite the absence of unanimity, identified the risk that the HFT amplify the systemic impact of shock and adversely affect the integrity and quality of the market (efficiency in price discovery, volatility and liquidity).

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[6] ECN means an electronic network outside the regulated markets that allows exchanges of financial instruments. In the EU regulatory system ECN correspond roughly to the MTF (Multilateral Trading Facility) covered by MIFID.

[7] It is an architecture-based computer developed by John von Neumann, which consists of five core components: CPU (central process unit), random access memory (RAM), input unit, output unit and system BUS.

[8] Among the best known operators to make use of these technologies, are *Goldman Sachs, Morgan Stanley*, *GETCO*, *Renaissance technologies, Citadel Investment Group*, *Jane Street Capital*, *Wolverine Trading* e *Jump Trading*.

In particular, the increasing popularity of HFT could compromise the correct process of price formation, moving them away from the underlying economic fundamentals and reducing, significantly, the signaling value. In addition to this, there is a possibility that the degree of HFT participation in trading affects the volatility of financial instruments, amplifying any fluctuations.

As regards the impact on liquidity, some studies[9] show a positive effect, while the operational evidence instead records that in turbulent conditions High Frequency Traders (hereinafter HFTr) may lead to an absorption of liquidity[10].

Finally, one of the most relevant issues related to the risks arising from the use of HFT strategies is the possibility of implementing potentially manipulative pricing strategies by leveraging the higher operating speed and the high complexity of the algorithms.

The danger of such strategies has been implicitly admitted even by an operator such as Goldman Sachs in the embarrassing affair of Sergey Aleynikov[11], who was arrested in summer 2009, after leaving the company, on suspicion of having taken possession of the source code used for HFT operations.

This story ended with the intervention of the FBI.

On that occasion, to justify the severity of the incident and request the assistance of the Federal Bureau of Investigation, Goldman Sachs was forced to reveal the potential hazards arising from the possession of these codes, which gave the holder the power to subject the market to considerable disruptions[12].

From Goldman Sachs's statements it is clear that the possession of such source codes implies the possibility of altering the market, and thus the concrete confession and the real possibility, for this and perhaps many other companies, to manipulate the market.

The present work has the objective to analyze the functioning and the main strategies of HFTr, understand the scope, examine the effects and analyze the discussion on

[9] Jovanovic, Menkveld "*Middleman in limit order markets*" (2011),
Riordan e Storkenmaier "*latency, liquidity and price discovery*", *Journal of financial markets* (2011).

[10] In operating practice we refer to the liquidity offered by the HFTr with the term "*Ghost liquidity*" to highlight a seeming liquidity, ready to disappear in particularly turbulent market conditions.

[11] Russian programmer who emigrated to the United States in 1990, he worked for Goldman Sachs from May 2007 until June 2009, with a salary of $ 400,000. He was then arrested July 3, 2009 and sentenced to 97 months imprisonment.

[12] This affair was the starting point for the analysis of the famous writer Michael Lewis, "*Flash Boys: a Wall Street Revolt*".

regulation. Once described the phenomenon and the main features, it will be presented a market-making theoretical strategy as well as the construction step by step of an algorithm able to perform automatically negotiations (without any human interaction) on the Rotman Interactive Trader client (RIT), a software owned by Rotman University in Toronto. RIT is the market simulator that is used in the Rotman International Trading Competition (RITC)[13] and Rotman European Trading Competition (RETC)[14], the two largest and most important trading competitions at university level.

The first chapter will define the phenomenon and the diffusion of HFT and analyze the events of May 6, 2010 (*flash crash*).

The second chapter will analyze the effects and risks arising from the use of high frequency systems along with the international regulatory framework and the main legislative proposals to regulate this phenomenon.

The third chapter will present an overview of the main strategies of HFTr, to better understand the operational manner in which HFTr participate and influence the financial markets.

The fourth chapter will study in deep the main function of liquidity provision made by the HFTr and will present a theoretical market-making strategy.

Finally, the fifth chapter will describe the main features of the Rotman Interactive Trader Client and will be built on a market-making algorithm based on the previously described strategy.

[13] About RITC: http://ritc.rotman.utoronto.ca/

[14] About RETC: http://retc.luiss.it/about-retc/

Chapter 1

HIGH FREQUENCY TRADING AND THE FLASH CRASH OF MAY 6, 2010

"*What was meant by fast was changing rapidly. In the old days, before 2007, the speed with which a trader could execute had human limits. Human beings worked on the floors of exchanges, and if you want to buy or sell anything you had to pass through them. The exchanges, by 2007, were simply stacks of computers in data centers. The speed with which trades occurred on them was no longer constrained by people. The only constraint was how fast an electronic signal could travel between Chicago and New York" .*[15]

Optical fibers are filaments of glassy or polymeric materials, so as to be able to carry light within them.

After installing the optical fiber network between *Chicago* and *New York* (so as to link[16] the *Chicago Mercantile Exchang*[17] and *Nasdaq's stock exchange*[18] as straightforward as possible), trading quickly changed along with the same concept of transaction speed.

By utilizing the speed of electrical signals in optic fibers, it was now possible for a trader (or for a computer system) to enter an order in 12 milliseconds[19]. From the joint use of a trading system based on algorithms and an ultra-fast network, the phenomenon of *High Frequency Trading* was born.

The about two thousand workers who participated in the installation of the high-speed network and the whole world were not then aware of the usefulness of this monumental work.

The HFT phenomenon became public only after the misadventures of the Russian programmer Aleynikov and the events of May 6, 2010.

That day, the price of some stocks in the US market and in particular of *Dow*

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[15] Michael Lewis – "*Flash Boys*"

[16] The need to link the two cities in the most direct way was so important that not even mountainous obstacles were hindered.

[17] *Chicago Mercantile Exchange* is the largest US stock exchange devoted to commodities and commodity derivatives exchanges.

[18] *Nasdaq Stock Exchange*, the acronym for the National Association of Securities Dealers Automated Quotation, is the first example in the world of electronic stock market that is a market consisting of a computer network.

[19] About 0.012 seconds, about or less than 1/10 of the time it takes to close your eyes.

*Jones Industrial Average (*DJIA*)*[20]*, has experienced an incredibly rapid decline and an equally rapid upward trend.*

In a few minutes *DJIA* lost about 8% down from 10,650 points to below 10,000 points, before recovering in the following 10 minutes up to 10,520 points.

1.1 Definition of High Frequency Trading

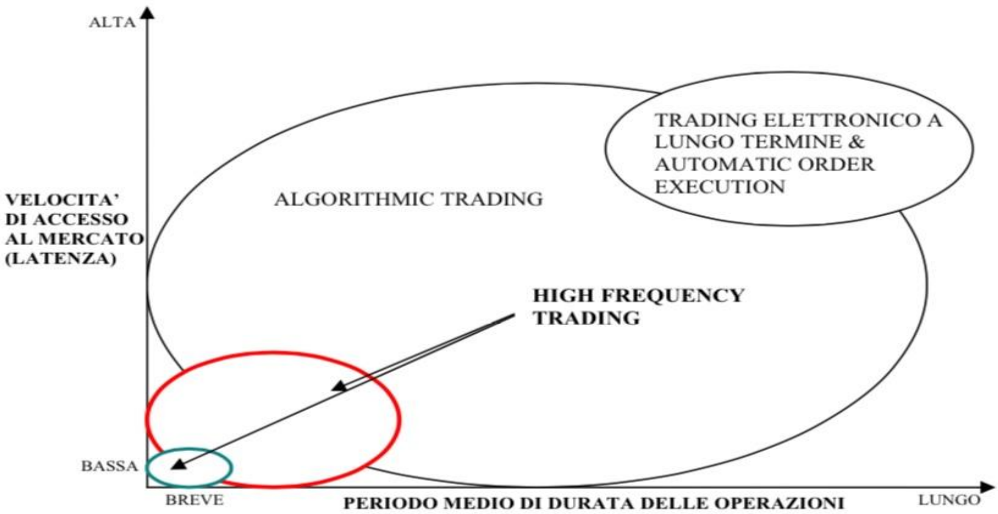
In recent years, the economic literature and numerous empirical studies have proposed several definitions, more or less extensive, of HFT.

Some of these, for their extreme simplicity, fail to grasp the complexity of the phenomenon.

There is general consensus in considering HFT an operating mode and not a strategy in itself, focused on the speed of acquisition and processing of market information and reaction to such information (*low latency*).

The concept of HFT is often confused with *algorithmic trading* (AT).

Figure 1 – High Frequency Trading & Algorithmic Trading



[20] *Dow Jones Industrial Average* is the best known stock index of the New York Stock Exchange, created by *Charles Dow*.

However, high-frequency trading systems, although belonging to the algorithmic trading family, differ from the latter, representing a further step.

The substantial differences between the two methods are the average period of duration of the operations and the access speed to market.

Algorithmic trading is defined by Deutsche Bank as follows:

"A trading method whose parameters are determined by a specific set of rules in order to automate the investment decisions, eliminating the emotional and behavioral component. Trading algorithms typically specify timing, price, quantity and order routines, monitoring market conditions on a continuous basis".[21]

Or, in more detail, one of the most recognized definitions in the academic world:

"*In algorithmic trading (AT), computers directly interface with trading platforms, placing ordes without immediate human intervention. The computer observe market data and possibly other information at very high frequency, and, based on a built-in algorithm, send back trading instructions, often within milliseconds. A variety of algorithms are used: for example, some look for arbitrage opportunities, including small discrepancies in the exchange rates between three currencies; some seek optimal execution of large orders at the minimum cost; and some seek to implement longer-term strategies in search of profits*".[22]

While HFT means:

"A fully automated trading type (of the algorithmic trading family) capable of performing a multitude of calculations in a very short time; it has a rapid connection with the market, it analyzes data *tick by tick* thanks to technological and informatic infrastructures capable of performing operations in a few seconds.

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[21] *Deutsche Bank Research*, "*High Frequency Trading*" (February 2011).

[22] Chaboud et al. 2009, "*Rise of the Machines: Algorithmic Trading in the Foreign Exchange Market*".

A high frequency system is designed to run its own strategies autonomously by analyzing the market and sending thousands of buying and selling messages per second, and at the same time inserting execution, deletion or replacement orders that fit immediately the available information flow. The main objective of a high-frequency system is to identify and take advantage of rapid liquidity imbalances or inefficiencies in the very short-term rates: it usually closes the day of flat trading".[23]

An immediate contact between high-frequency trading systems and algorithmic trading is the use by both of the technology that automates decisions without human intervention through computerized processes.
Analyzing in detail and in the context of the definitions and wanting to define the algorithmic trading as a phenomenon that present most of the following characteristics, being the high frequency trading its subcategory, these must necessarily be valid also for it:

I. Pre-established trading decisions;
II. Tool used by professionals;
III. Real-time data monitoring;
IV. Automatic sending orders;
V. Automatic order management;
VI. No need for human intervention;
VII. Direct access to the market.

HFT and AT differ essentially for the holding period, as AT may have a variable holding period of minutes, days, weeks, or even longer, while HFT by definition holds the position for a short period of time, trying anyway to close the session in a neutral position (*flat position*).

[23] Fabozzi, Focardi and Jonas *"High-frequency trading: methodologies and market impact. Review of Futures Markets*" (2010).

In further analysis we can analyze the elements that distinguish HFTr from other participants:

I. High number of orders;
II. Quick cancellation of orders;
III. Proprietary trading[24];
IV. Flat position;
V. Low Profit Margins per Operation;
VI. Low-latency[25];
VII. Use of co-location/proximity service[26] and individual data;
VIII. Operations with highly liquid instruments.

Finally, we can define the HFT as an operating mode that presents most of the previous unique features in combination with the elements of contact with *Algorithmic Trading*.

1.2 Functional operation characteristics

HFTrs base their existence on a competitive technological advantage, without which they would fall into the category of simple algorithmic systems.
First of all, the fundamental feature is the use of both computer hardware and software[27] media, in order to be able to perform calculations with automated algorithms and submit orders to platforms.

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[24] It means the use of equity for the trading business.
[25] See the next paragraph.
[26] See the next paragraph for the definition of co-location, while for proximity service is the lease of some spaces to mount servers, from third parties other than the trading platform.
[27] Such software can be developed internally, or can be designed for HFT third-party companies (tailor mode) or finally can be marketed out of the box.

Secondly, HFTrs are characterized by a large number of orders placed in the unit of time (estimated to exceed 5000 per second[28]) and high execution speeds of entry, modification and deletion of orders.

HFTr also conduct proprietary trading and of course show a preference for the most liquid financial instruments. Operations require the possibility of getting out of a particular buying position at a high speed, and the more liquid instruments allow to invest quickly because the market can absorb and meet a significant volume of orders.

Also selected are instruments with particularly effective statistical techniques below the algorithms.

A further typical feature, as mentioned above, is the assumption of long or short positions on a stock for periods usually not longer than the duration of the stock market, with high turnover of the securities within the portfolio. Locations are generally closed at the end of the day, while the period of detention during the same session may vary from a few seconds to several minutes. In addition, cash and derivatives instruments are usually "*delta neutral*", ie hedged by the risk of change in value for minor underwriting variations (but there are also no dynamic *hedging* strategies[29]).

Finally, HFTrs are characterized by the creation of small profit margins per single transaction and the creation of high trading volumes.

Among these, the main characterization of high frequency systems is the rate of entering, deleting, executing and modifying orders sent to the market. Only such competitive advantage allows us to exploit inefficiencies and opportunities otherwise unnoticed.

In this regard, it is necessary to have technological/computer support capable of executing the operations in a few milliseconds. For this to be possible two requisites are needed:

I. *Low latency*;
II. *Co-location.*

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[28] *Survey "what did you say you were doing" Automated Trader Magazine Issue 18 Q3 2010*

[29] Coverage activities for the risk of oscillation carried out several times a day.

1.2.1 Low latency

Latency is the time it takes to implement the series of steps required to make a business decision effective bargaining (execution). Latency should be considered on different levels of analysis.

Firstly, it can be considered as the ability to analyze as much data as possible in real time and to turn the information flow into investment choices.

Secondly, it can be considered as the time between the processing of the data and its transmission to a broker (it takes a certain amount of time to arrange the bargaining order and more time to send order material to the broker).

Thirdly, it can indicate the time between the receipt of the order by the broker and the sending of the bargaining order to the trading venue by the broker[30].

Fourthly, it can be considered as the time that order takes to arrive on the market from the time it is sent by the broker.

Finally, it can indicate the time between the receipt of data from the market and dissemination of this to all participants. It is indeed important the time that the market itself uses to inform other traders about the characteristics of the new order.

A high-frequency trading system takes the least time to cover all the steps of the investment process just described.

It therefore appears clear that an HFT system, in addition to having a computer system capable of receiving, analyzing and processing data and market information in a considerably reduced time span, must also use an efficient broker. Efficiency means possessing advanced technology with the aim of minimizing the latency of its processes.

[30] Broker IT systems need time to recognize the type of order received (BUY or SELL), the type and amount of financial instruments traded, the technical features of the order, the market on which the instrument is treated.

1.2.2 Co-location

In physics time can be defined in terms of speed and space to travel. The stock market orders are electrical impulses that, while traveling at high speed, always meet the limit of space.

Co-location means the commercial service offered by trading platforms that allows market participants to lease their spaces near market platforms, in order to place their servers and thus minimize the delivery time of the orders to market.

Many market participants usually use multiple co-location practices where servers used for algorithms work are located in different locations, each of which is near a different platform.

The proximity of your server, or that of your broker, to the stock exchange server on which you chose to do this, is a key competitive advantage to the profitability of a high frequency system. If you imagine the presence of other high-frequency traders on the same market, in such a way as to make the sector extremely competitive, it can be concluded that the lack of co-location requirement would result in the loss of profit opportunities that would be exploited by others faster operators.

1.3 Identification methods

In light of the operational features presented earlier, economic literature has adopted three main approaches to the identification of high frequency traders.

The first methodology is to identify HFTr directly on the basis of the information given by the same market platforms on the traders who carry out high-speed trading.

The main advantage of the direct method is certainly its simplicity.

However, this method leads to the exclusion of all subjects who do not perform HFT on a primary basis, thus providing a partial view of the phenomenon.

The indirect method is to identify HFTrs based on their operational characteristics. For example, they may consider those traders who conduct proprietary transactions, have a flat position at the end of the session, carry a large number of transactions.

The main limit of this mode is implicit in the possible inequality of the basic criteria used.

Lastly, a last resort, even this indirect approach, is based on the analysis of the strategies used. This is a very expensive method, as it is necessary to analyze large amounts of data in order to identify the underlying strategies for entering, modifying and deleting orders.

The main limit is that using this method runs the risk of incorrectly including operators in the HFTr category.

Moreover, since the strategies implemented by the HFTr are very different from one another, the difficulty of analysis is remarkable, as will be highlighted in the second chapter.

For the purpose of generic identification of high-frequency trading players, it is possible to obtain an overview by considering "pure" operators (ie those that can be identified directly through public information) and some of the major investment banks. Among these, since it is not possible to determine with certainty what these have high frequency technologies, the major banks operating on the market as a market maker are selected.

This is of course an approximation, but it can provide a general framework for empirical analysis of the phenomenon.

The following figures[31] 2 and 3 provide an indicative list of the major global investment banks which, although not performing HFT as their primary activity, possess high-frequency technologies and is therefore logical to consider for the purposes of an empirical analysis of the diffusion of high frequency trading.

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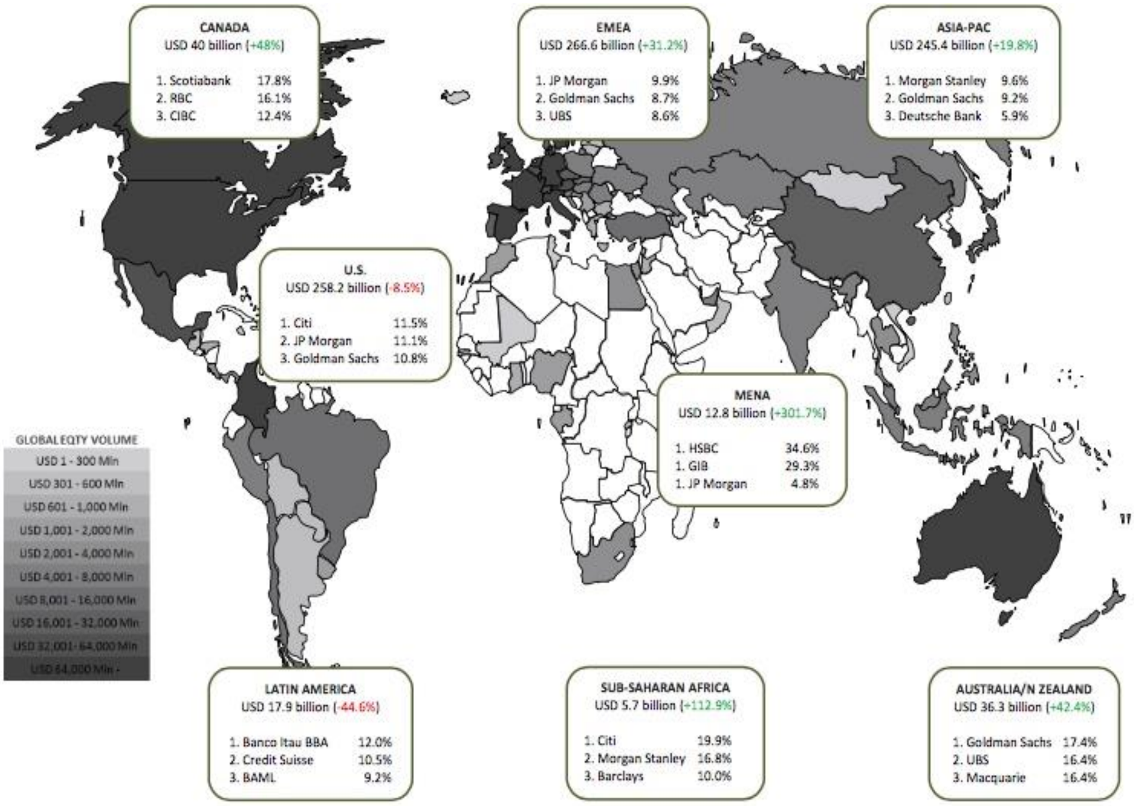
[31] Source: *Bloomberg, Emea league table*, http://www.bloomberg.com/professional/content/uploads/sites/2/2015/01/2014_League-Tables_Global-Equity-Capital-Market.pdf.

Figure 2 – Global Equity & Equity linked

FIRM	2014 RANK	2014 MKT SHARE	2014 VOLUME USD (Mln)	2014 DEAL COUNT	2013 RANK	2013 MKT SHARE	MKT SHARE CHG (%)
Goldman Sachs & Co	1	9.2	74,861	385	1	11.7	-2.5
Morgan Stanley	2	8.8	71,757	434	3	8.2	0.6
JP Morgan	3	8.3	67,807	470	2	8.8	-0.5
Bank of America Merrill Lynch	4	7.5	61,443	413	4	7.5	-
Citi	5	7.4	60,586	375	5	6.6	0.8
Deutsche Bank AG	6	6.4	52,397	326	7	5.9	0.5
UBS	7	5.5	44,831	303	6	6.3	-0.8
Credit Suisse	8	5.3	43,707	354	8	5.2	0.1
Barclays	9	4.4	35,641	295	9	4.9	-0.5
RBC Capital Markets	10	2.1	17,145	199	12	1.6	0.5
HSBC Bank PLC	11	2.1	16,956	73	13	1.2	0.9
Nomura Holdings Inc	12	2	15,979	128	11	1.8	0.2
Wells Fargo & Co	13	1.6	13,139	173	10	1.9	-0.3
Jefferies LLC	14	1	8,474	139	14	1.1	-0.1
Macquarie Group Ltd	15	0.9	7,762	69	18	0.8	0.1
BNP Paribas SA	16	0.9	7,331	63	17	0.9	-
Societe Generale	17	0.9	7,017	47	21	0.7	0.2
BMO Capital Markets	18	0.8	6,563	90	19	0.8	-
Sumitomo Mitsui Financial Group Inc	19	0.7	6,089	59	16	0.9	-0.2
Mediobanca	20	0.7	5,534	24	37	0.3	0.4
TOTAL	100%		817,387	4,155	753,647	100%	

Figure 3 - Global Equity, Equity linked & Rights Snapshot



1.4 The flash crash of May 6, 2010

On May 6, 2010, the DJIA[32] index lost about 8% within a few minutes, dropping from 10,650 points to less than 10,000, then going back to to 10,520 points in the next 10 minutes.

Figure 4 – Dow Jones intraday - 6 May, 2010[33].

DJIA was not the only actor on the stage. In fact, at 14:42 pm, even the *S&P 500*[34] and *Nasdaq* indexes began to quickly lose points, reaching a decline of 9% and then close the session with losses of around 3%, still very far from the lows touched In the previous minutes.

It emerged the image of an extremely fragile market, where a single large transaction

[32] *Dow Jones Industrial Average* is the It is the best known stock index of the New York Stock Exchange.

[33] Sorce: *Bloomberg* data.

[34] *S&P 500* index has been created by *Standard & Poor's* in 1957 and follows the trend of a stock basket formed by the 500 US companies with greater capitalization.

transmitted from the high frequency trading software of *Waddell & Reed Financial*, generated, through a domino effect, a strong variation of the share price.

The order involved a large amount of E-mini S&P 500[35] futures contracts, and the massive presence of high-frequency algorithms in the the sale transaction operated on the entire stock price, causing a noticeable and rapid loss of the the stock market value.

After almost five months of investigations, SEC and the Commodity Futures Trading Commission presented the detailed report "*Findings Regarding the Market Events of May 6, 2010*". We will look more closely at the events of that fateful day according to that report.

In the United States was a trading day like others. The morning markets opened negatively, affected by the worring news coming from Europe in relation to the debt crisis, despite only four days earlier, on May 2, the countries of Eurozone and the International Monetary Fund had approved a rescue loan of 110 billion euro for Greece.

At 1 pm, US time, the Euro began a significant decline compared to Dollar and Yen. In addition, the feeling of a negative market increased immediately the volatility of some securities, as evidenced by the increase in Liquidity Replenishment Points (LRPs)[36] above average levels.

At 2.30 pm, the S&P 500 index's volatility (VIX) rose by about 22.5% compared to the opening level, while constant sales pressure pushed the DJIA below 2.5%. In addition, the liquidity[37] of the E-Mini S&P 500 futures contract fluctuated from $6 billion to $2.65 billion in the morning (a decline of about 55%), while ETF S&P 500 SPDR (SPY) liquidity drops from $275 to $ 20 million (about 20%).

In this context of thinning liquidity and high volatility, a "player" began a major sales program of 75,000 E-Mini contracts (valued at approximately $4.1 billion) as a hedge of a position of really existing actions.

Basically, there are several ways to perform a "trade" of significant size:

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[35] The Future on the S & P 500, introduced in 1982, is the main tool used by managers to track the index or to hedge on the US market. It is contracted to CME.

[36] The LRPs is also an indicator that measures volatility on individual listed securities.

[37] The term liquidity refers to the depth of the market both at purchase and sale, which is formed by the orders placed by market participants, namely the desire to buy or sell, above, below or at current market levels.

In the first place, it may entrust the task to an intermediary can handle the position, selling block of assets.

Second, orders can be entered manually.

Finally, the operation can be performed through a self-running executable algorithm that takes into account the preferences of the subject, taking into consideration some basic variables such as price, time and volume.

In a large-scale bargaining it is then possible to choose how and if to involve human ability rather than a machine.

In this case, it was decided to sell through a "*sell algorithm*" programmed to execute E-Mini orders with an *execution rat*[38] of 9% in relation to the trading volume calculated every minute, without taking into account the two other fundamental variables (price and time)[39].

In any case, the algorithm executed the sales program in just 20 minutes and this important quantity sold was mainly absorbed by HFTr and brokers, as well as generic buyers in futures and arbitrage market. Specifically, high-frequency operators accumulated a considerable net position of around 3,300 contracts, and between 2:41 pm and 2:44 pm they aggressively sold about 2,000 E-mini contracts to temporarily reduce their long position. At the same time, bargained 140,000 contracts, that means to more than 33% of the total volume as required by the operational practice of HFTr: namely to accomplish a high number of trades, but without accumulating more than 4000 for sale or purchase. The sales algorithm described above reacted to the increase in volumes by increasing the number of executed orders, but the orders already on the market were not completely absorbed by generic buyers or arbitraggists.

It was therefore confirmed that in case of high volatility situations, high volumes do not necessarily imply a satisfactory liquidity in the market.

Liquidity crises in the E-Mini and individual actions, generated a very sharp decline in short term.

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[38] By simplifying the operation of the algorithm, it is meant that the main input was trading in a way directly proportional to the volumes of exchange.

[39] This program has been used in most trade the E-Mini contracts in the current year, but never without the time and price variables.

On this day over 15,000 operators, 16 of them classified as HFT, exchanged more than 1,455,000 contracts: about 1/3 of the total daily volume.
Between 2:41 pm and 2:44 pm, the E-Mini lost about 3% in just 4 minutes, and then the arbitrages who had the future portfolio, sold at the same time an equivalent amount in the stock market, generating a downturn of the SPY price.
Between 2:45:13 pm and 2:45:27 pm, HFTr traded over 27,000 contracts: about 49% of the total.
From 2:41 pm to 2:45:27 pm the price of the E-Mini dropped by 5% while the price of the SPY[40] by 6%.
At 2:45 pm the sales algorithm had already concluded 35,000 of the 75,000 E-Mini contracts (estimated at approximately 1.9 billion) and about 28 seconds later, at 2:45:28 pm, the E-mini bargaining was interrupted for 5 seconds so as to prevent an excessive price decline and a consequent domino effect.
In this very short time span, the downward pressure diminished and the buyers' interest increased; in other words, it came a large amount of purchase orders from investors, which caused a rise in prices.
When at 2:45:33 pm the activity was resumes, prices stabilized slowly and the E-Mini started to give recovery signs followed by the SPY. The sales algorithm continued its program until 2:51 pm, during the rise in prices, exchanging the remaining 40,000 contracts (worth about 2.2 billion dollars).
Finally, at 3:08 pm, the continuing increase in demand due to the placing of orders by "*opportunistic buyers*"[41], reported E-Mini and SPY prices at *pre-crash* levels.

[40] ETF S&P 500.
[41] Operators that exploit the temporary inefficiencies of the markets.

Figure 5 – E-Mini Market Depth All Quotes[42]

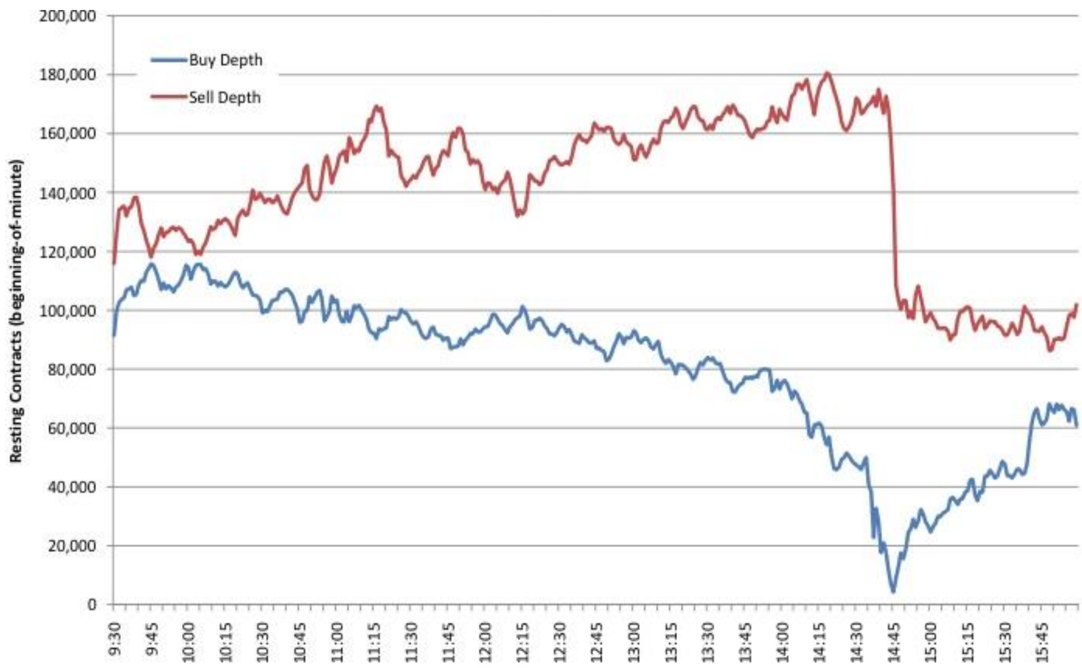
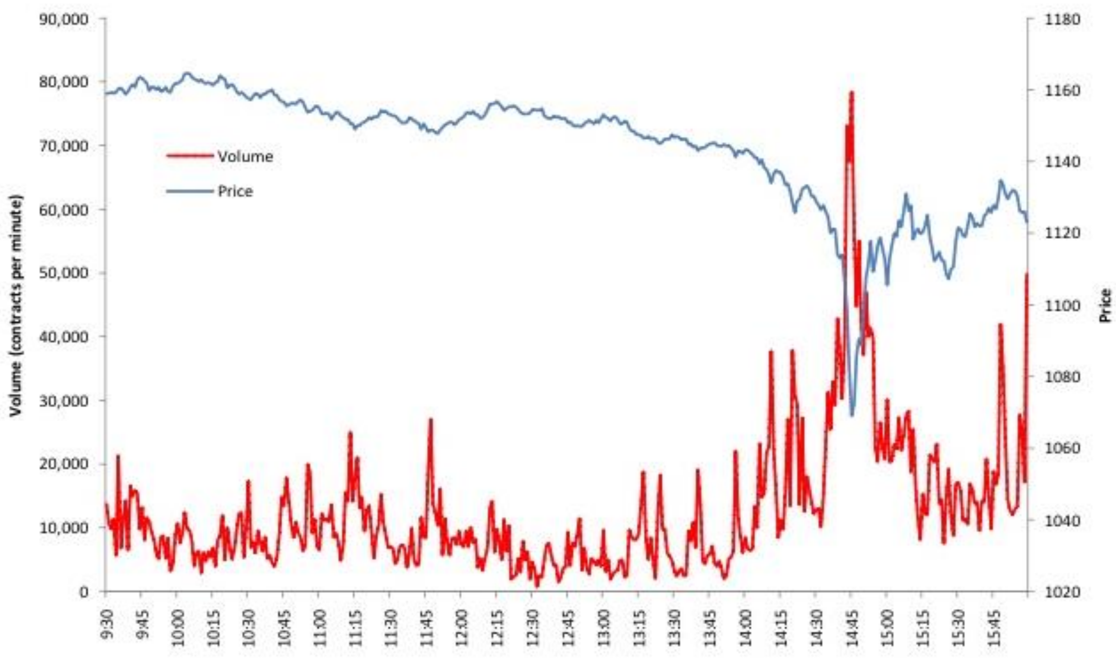


Figure 6 – E-mini Volume and Price



[42] Source figures 3,4,5,6: SEC, *Finding regarding the market event of may 6, 2010*.

Figure 7 – E-Mini Buyer Initiated Volume

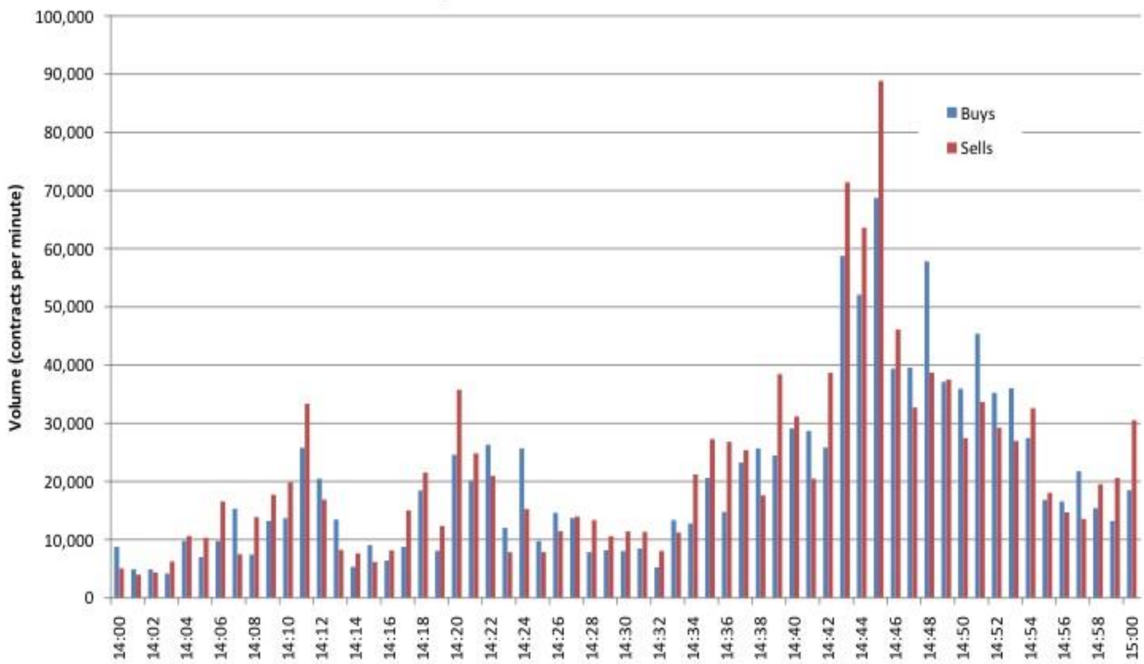


Figure 8 – Trader Type May 3-6

Panel A: May 3-5

Trader Type	% Volume	% of Trades	# Traders	Avg Trade Size	Limit Orders % Volume	Limit Orders % Trades
High Frequency Trader	34.22%	32.56%	15	5.69	100.000%	100.000%
Intermediary	10.49%	11.63%	189	4.88	99.614%	98.939%
Buyer	11.89%	10.15%	1,013	6.34	91.258%	91.273%
Seller	12.11%	10.10%	1,088	6.50	92.176%	91.360%
Opportunistic Trader	30.79%	33.34%	3,504	4.98	92.137%	90.549%
Noise Trader	0.50%	2.22%	6,065	1.22	70.092%	71.205%
All	2,397,639	446,340	11,875	5.41	95.45%	94.36%

Panel B: May 6

Trader Type	% Volume	% of Trades	# Traders	Avg Trade Size	Limit Orders % Volume	Limit Orders % Trades
High Frequency Trader	28.57%	29.35%	16	4.85	99.997%	99.997%
Intermediary	9.00%	11.48%	179	3.89	99.639%	99.237%
Buyer	12.01%	11.54%	1,263	5.15	88.841%	89.589%
Seller	10.04%	6.95%	1,276	7.19	89.985%	88.966%
Opportunistic Trader	40.13%	39.64%	5,808	5.05	87.385%	85.352%
Noise Trader	0.25%	1.04%	6,880	1.20	63.609%	64.879%
All	5,094,703	1,030,204	15,422	4.99	92.443%	91.750%

A second liquidity crisis was recorded on the stock market around 2:45 pm, caused by the shutdown of many automated trading systems that consistently provided liquidity to the market.

System breaks are generally designed to prevent potential situations of risk, in case prices change beyond predetermined thresholds. That will give the opportunity to evaluate the conditions of risk in case the program continues.

On that occasion some market makers and other liquidity providers, based on their respective risk assessments, significantly increased the bid/ask spread, while others (in significant number) withdrew from the market.

On the other hands, while volumes were increasing, HFTrs continued to exchange more and more securities.

At about 2:45 pm, just as E-Mini and SPY's prices had begun to recover, sales orders on stocks and ETFs began to meet ever smaller purchasing interests, causing a rapid decline in most of the titles and consequently market indexes.

Between 2:40 pm and 3:00 pm, about 2 billion bonds were traded for a total value of $56 billion, and 98% of them were traded at less than 10% compared to their value at 2:40 pm. Liquidity vanished completely for some stocks and ETFs.

Sellers did not find matching purchase orders and vice versa, resulting in irrational pricing (from $1 to $100,000) as a result of the so-called "stub quotes", ie bid and ask that market makers settled at prices very far from their actual value, in order to fulfill their obligation to continue listing (obligation also provided in case of withdrawal).

Only around three o'clock the stock returned to be traded at prices that more or less reflected their real value.

According to the events just described, it follows that in stressed market conditions, the automatic execution of orders of significant magnitude can trigger extreme price movements.

This is especially true if the sales algorithm does not take into account the fundamental variable price, plus the fact that the interaction between programs that run automatically orders and HFT strategies, can sometimes erode the liquidity and create disorder in markets.

As demonstrated by the events of May 6, in situations of significant volatility, a high volume of trade does not necessarily imply a high liquidity in the market. In addition, the simultaneous withdrawal of many participants may trigger a liquidity crisis and lead to the breakdown of price formation processes with the consequent application of "*stub quotes*"[43].

Another factor that deserves consideration is the application of pauses to the CME.

This mechanism was fundamental in E-Mini's trading since it allowed operators to reconsider strategies and HFTrs to vary the parameters of the algorithms in order to adapt them to the situation.

Finally, the main need, highlighted by the events of this particular day of trading, is to consider more closely the interconnection between the derivatives markets and the securities markets.

1.5 High frequency extent

The high frequency trading phenomenon began to develop in parallel with technological development, financial innovation and regulatory environment changes that made possible the expansion of this industry.

In particular, the issuance of the NMS[44] Regulation in the US and later MiFID[45] in Europe (similar to the SEC's NMS Regulation) modified the institutional environment by encouraging the incredible expansion of the high-frequency industry.

Since 2005, this industry has assumed such proportions as to affect the functioning of markets, as the profitability of these depends to a significant extent on the ability to attract and retain volumes of high frequency.

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[43] For applications, we mean trading in both bid and ask pricing at market-makers at very distant market rates (stub quotes).

[44] The "Regulation National Market System" is a financial regulation promulgated by the SEC, described as a series of initiatives designed to modernize and strengthen the national market for equity titles. This regulation is intended to ensure that investors receive the best execution price for their orders by encouraging competition in markets.

[45] "Markets in Financial Instruments Directive" Directive 2004/39 / EC of the European Parliament and of the Council April 21, 2004, adopted in Italy in 2007 by Legislative Decree No. 164/2007.

In fact, the high turnover made daily by HFTr generates a corresponding volume of commissions that represents a significant part of the revenues and, consequently, of the profits. For these reasons, in order to attract the volumes of exchanges of HFTs, there have been numerous mergers[46] and acquisitions among large stock exchanges, so as to ensure better services and in order to cope with the significant investment in technology and infrastructure required to meet the needs of high frequency industry.

Such mergers, thanks to economies of scale and increased volumes, have allowed the markets to survive and succeed in generating profits in competitive contexts, although the dependence on these operators has increased considerably.

If a market does not succeed in providing the appropriate technological infrastructure, it would be destined to suffer a sharp decline in trading volumes and the consequent significant reduction in revenues for the benefit of markets able to offer the level of technology required.

HFT trades on total market trades[47]

United States	55%
Europe	35%
Japan	28%
Australia	20%
Canada	18%
Asia	12%
Brazil	6%

The most advanced countries of the world have a different degree of participation of HFTs; the gap between the delay in the high-frequency industry in Europe and the United

[46] Merges: CME and CBOT, NYSE and Euronext, LSE and Milan Stock Exchange, Bovespa and BM & F, Bats and ChiX Europe, Nasdaq Omx and Intercontinental Exchange.
[47] Source: *Tabb Group* data (2012).

States is mainly due to the fact that the MiFID (similar to the NMS Regulation) started to be effective only at the end of 2007.

After Europe, there are Japan, Australia, Canada, Asia and Brazil with slower trade exchanges attributable to HFTr on total stock exchanges.

The *Tabb Group* research also shows that stock markets are dominated by three different types of high-frequency investors:

I. *Independent Proprietary Firm (48%)*
II. *Broker/Dealer Proprietary Desk (46%)*
III. *Hedge Funds (6%)*

The first type of investor trade financial instruments with resources belonging to his own company, on the contrary, the other two categories commit the resources of depositors/investors.

The main players in the high-frequency market have been identified by Tradeworx in a research conducted in 2009, and given the high entry barriers in the industry, it can be assumed that the following players are still the protagonists of the high-tech industry frequency: *Getco, TradeBot, Citadel, Knight Capital, UBS, ATD, Goldman Sachs, Morgan Stanley, Renaissance Tech, Millenium, SAC, Tower* and *Hudson River.*

Each operation conducted by these companies is characterized by an extremely low expected profit, and their overall profits depend on the size of the market in which they operate, the volume of daily trading and the bid/ask spread.

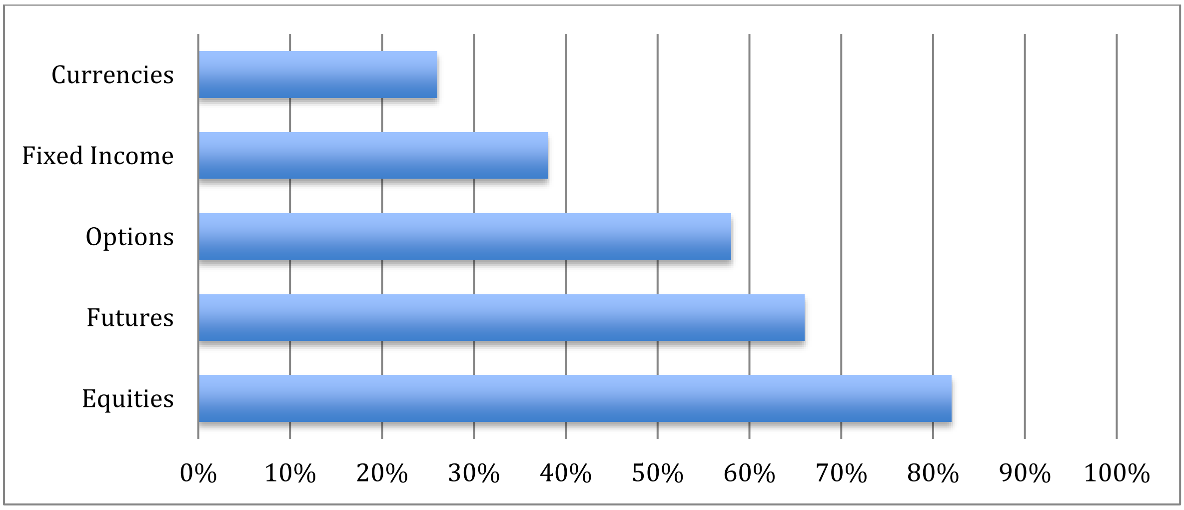
The business model of companies specializing in high-frequency trading appears quite simple in its sophistication:

The companies have very low profit margins, continually consumed by fierce competition, gains deriving directly from revenues.

It is therefore of fundamental importance for these companies to always seek new business opportunities on other markets or on different asset classes in order to increase their turnover.

The following chart clearly shows this trend[48].

Figure 9 – Asset Class traded by HFTr (USA 2009)



HFTrs, born on US stock markets and continually appropriating shares of trade, have now become the protagonists. Subsequently, they began exploring other equity markets and have spread widely in Europe and Asia and then progressively move on other asset classes such as futures, options, exchange rates and fixed incomes.

Operations on these types of financial instruments are now significant and, above all, growing so much so that we often talk about the "colonization" of the high-frequency industry compared to those asset classes.

[48] Source: *Advancetrading.com* data.

1.5.1 Order to Trade Ratio

As pointed out in the previous chapters, detect the presence of high-frequency trader it appears to be a particularly complex task, since the heterogeneity and the opacity of the strategies implemented by this type of trader make it difficult to identify.

Order to Trade Ratio (OTR)[49] is a particularly effective indicator in verifying the presence and level of diffusion of HFTs in a given market.

This indicator measures the number of trade actually made with respect to the number of orders, identifying those types of operators that perform a few trades, compared with a high number of orders placed.

OTR is generally defined by the following relation:

$$OTR = \frac{Total\ orders}{Total\ operations\ performed}$$

For the total orders have to be counted all messages relating to the insertion, modification and deletion of the data.

As expected by MiFID[50], while the European Securities and Markets Authority (ESMA) is preparing regulatory technical standards (RTS), which specifies the report on time, this indicator has attracted considerable interest and is often considered to be very useful.

The utility is not only for the purpose of identifying high-frequency operators, but it is also a mode at the regulatory level to suppress the possible negative effects attributable to HFTr.

If a maximum OTR would be imposed, with heavy penalties in case of overrun of it, high-frequency operators would be forced to enter a surplus amount of orders and/or to enter orders with a higher probability of execution, ie with prices closer to those of the market.

In this direction, the order to trade ratio would therefore limit orders placed in "bad faith", ie those orders far from market prices, used for the implementation of the various aggressive strategies described in the second chapter. The only negative aspect resulting

[49] Consob *"Order to Trade Ratio"*, www.consob.it/documenti/novità/otr.pdf.
[50] Directive 2014/65 / EU of the European Parliament and of the Council, Article 63.

from the application of an OTR regime, would be represented by a significant erosion of liquidity in the market.

However, regulators seem to prefer OTR schemes to all other levers that can be used to limit the high-frequency trader's operation, such as transaction fees, minimum rest times between orders, different commission structures, imposition of continuous market-making obligations and increase in "*tick sizes*".

The motivation is that these measures would not be very useful, since it only would be able to slow down the operation of the player to another frequency, presenting at the same time considerable drawbacks[51].

From 2005 to date, the average OTR has grown steadily in the major stock markets, futures, options, exchange rates and fixed income securities, thus witnessing a general increase in high-frequency trading.

1.6 Deployment in Europe

Once saturated the US financial markets, high-frequency traders have begun to explore other markets, especially the European one, where the spread of the phenomenon is significant and at the same time characterized by considerable heterogeneity between different trading platforms.

The following table presents the odds of exchanges attributable to high-frequency traders resulting from the survey conducted in 2010 by ESMA on the European market microstructure[52].

[51] Transaction fees could be transferred to investors by increasing the spread. The introduction of minimum rest periods would result in a reduction in liquidity as well as difficulties in operational identification. Formal and continuous market-making commitments could lead some operators to exit the market with a consequent reduction in liquidity

[52] *Call for Evidence CESR (ESMA), Micro-structural issues of the European equity markets,* April 2010.

Trading platform	Estimated market share
Borsa Italiana (LSE)	20% (equities)
Borsa Italiana (LSE)	30% (futures)
Chi-X	40%
Deutsche Boerse	35-40%
London Stock Exchange	33%
Nasdaq OMX	13%
NYSE Eronext	23%
Turquoise (LSE)	21%

In early 2010, the platform most affected by high frequency trading were BATS Chi-X Europe and Deutsche Boerse with estimated market shares of between 35 and 40%, while the platforms and the countries least affected by the phenomenon were the Nordic countries, as witnessed by the shy 13% of Nasdaq OMX Nordic.

However, estimates of the extent of high-frequency trading in Europe are at the same time significant and characterized by uncertainty.

In fact, it should be emphasized that there is no general consensus on the exact scope of the HFT.

This lack of clarity and precision is due to various and varied reasons: firstly, it is not possible to obtain timely estimates due to the difficulty of identifying HFT operators,

which are often assimilated to the simplest algorithm traders, thus making estimates very much overestimated.

In addition, only proprietary trading companies whose core business consists of high-frequency trading is taken into consideration. Aside from the analysis all other operators (such as investment banks) that carry out this activity as secondary and ancillary, provide an incomplete view of the phenomenon.

Second, the identification activities by trading platforms are complicated by the heterogeneity of the strategies implemented by high-frequency traders and the resulting wealth of information to analyze.

The current lack of clarity contributes to fueling the secrecy surrounding the high-frequency trading world and this uncertainty is unacceptable given the influence this phenomenon generates on the financial markets.

Pending further investigation by the supervisors, the only certainty currently available is that the extraordinary growth of the phenomenon will continue[53].

1.7 The rise in the United States

The American market has been for these players the main "*playground*".

The following charts[54] show the growth of trading orders[55] respectively in some markets (NYSE, AMEX, NYSE-Arca) and the (lack of) growth of actual negotiations, between January 2008 and August 2012.

The method of representation of temporal evolution is based on colors.

Each trading day is in fact represented by different colors, the most recent data are associated with the hottest shades of the spectrum (red, orange, yellow and green), while older ones are represented by cold colors (blue, blue, violet and purple).

By linking these data, you get a considerably increasing[56] OTR over the period considered, in other words an increase in transactions attributable to HFTs.

It has already been stressed in section 3.1 that this indicator, although relatively ineffective in identifying individual operators, is particularly useful in presenting the aggregate phenomenon.

Growth in trading orders is instantaneous, and it is equally easy to note that trading frequency has not increased significantly, and in fact is lower in 2012 than in previou

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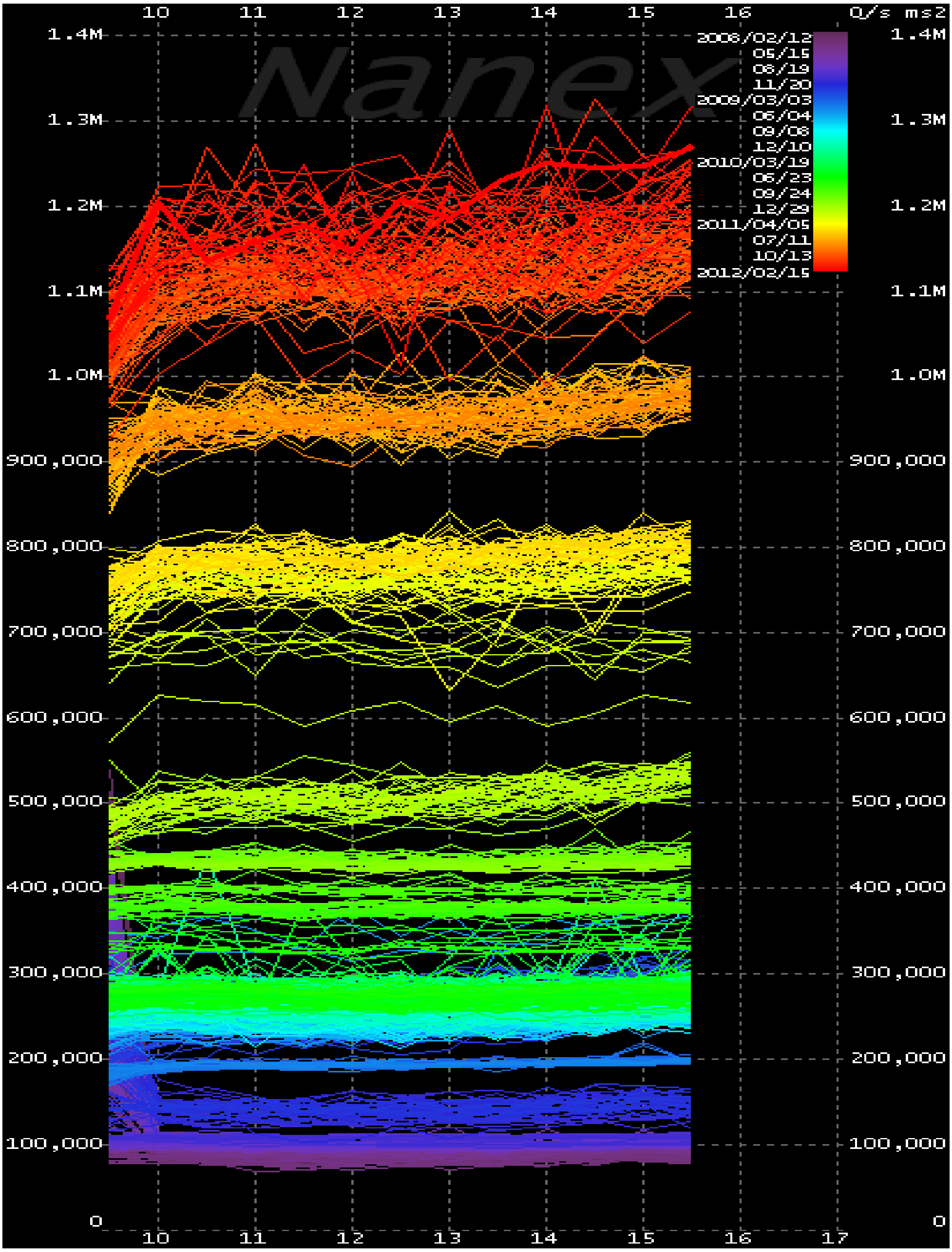
[53] Thoughts shared by manu scholars, see *Broogaard (2010) Methodologies and market impact e risposte a Call for evidence ESMA, Micro-stuctural issues of the European equity markets,* April 2010.

[54] Source : *Nanex – The rise of HFT machines*

[55] Data obtained by *CQS (Consolidated Quotation System)*, an electronic service that provides information on trading orders on some markets

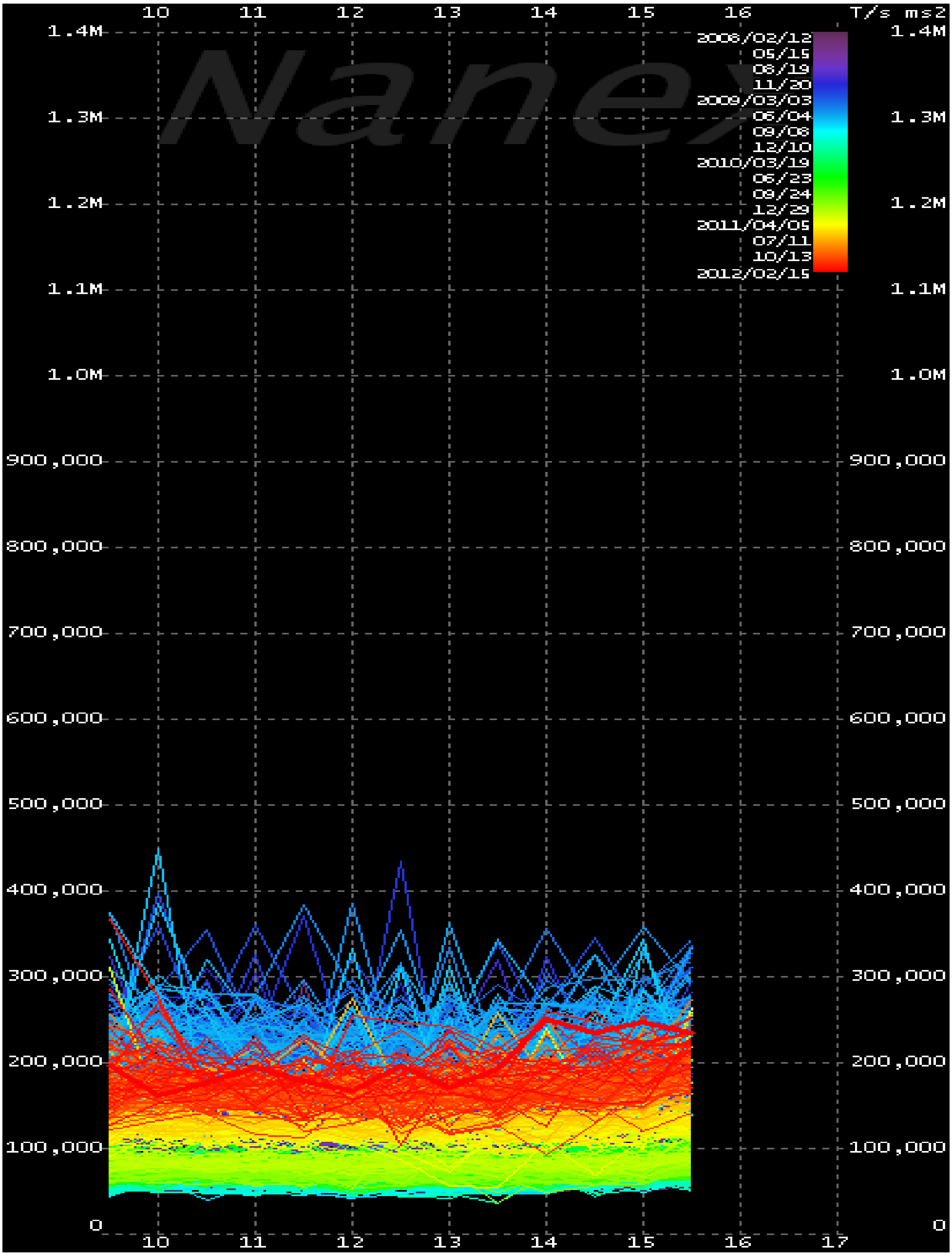
[56] By increasing the numerator (total trading orders) proportionally more than the denominator (negotiated transactions), the OTR result that is obtained for each trading day is generally increasing, moving from an average value of 6 in 2007 to a maximum value 70 detected in 2012.

Figure 10 – Quote message Growth[57]



[57] Source: Nanex Research, "The rise of HFT machine" (2013).

Figure 11 – Trade message growth[58]



[58] Source: Nanex Research, "The rise of HFT machine" (2013).

Reworking the data are obtained on the same graph the daily trading and the quantity of orders placed daily from January 2006 to August 2012[59].

The red line shows the number of orders placed on each trading day while the blue line is the actual number of trades.

In the graph (next page), you can easily identify three maximum points relating to orders placed, simply summarized as follows:

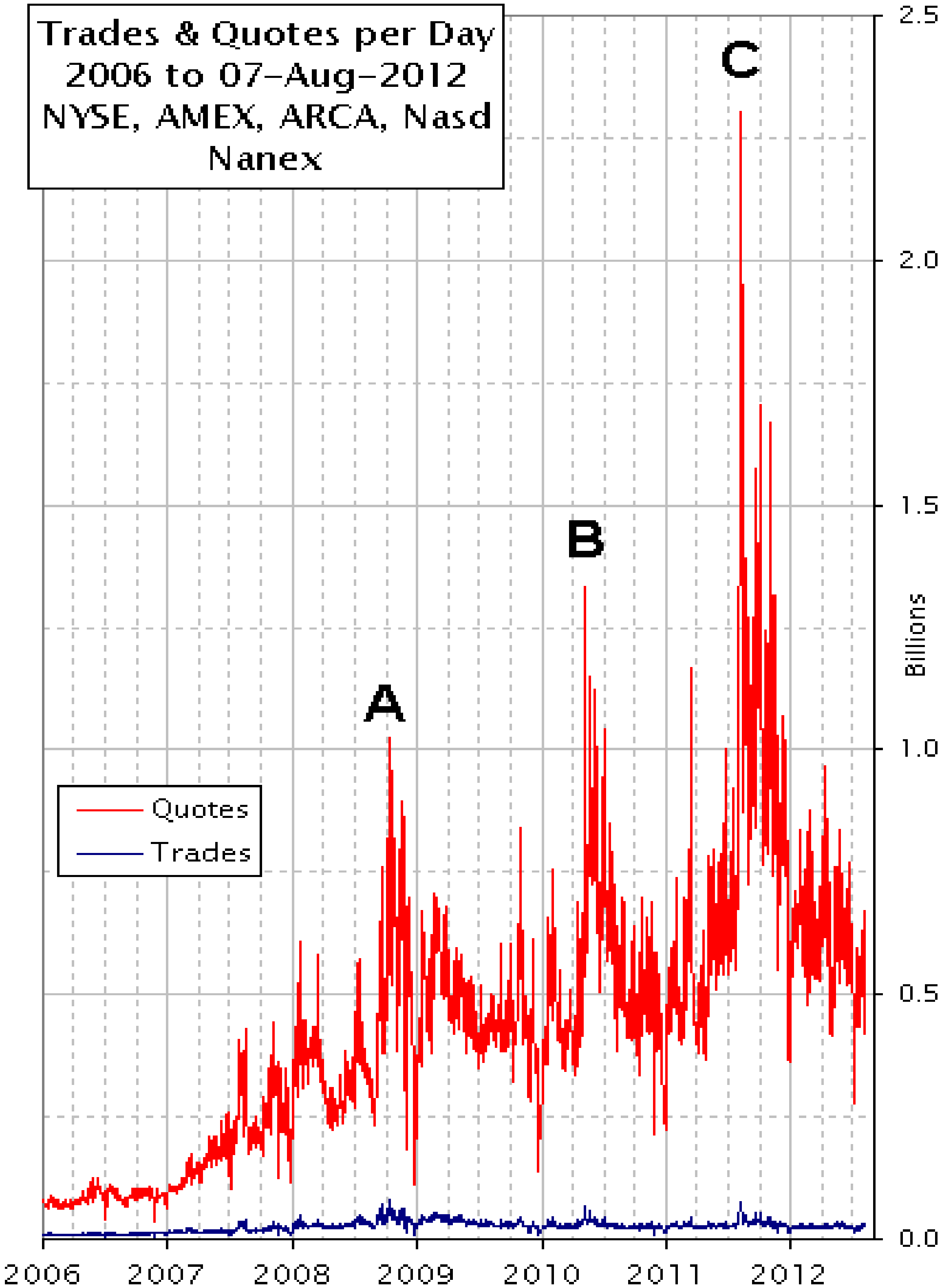
DATE	**EVENT**	**ORDERS (millions)**	**TRADES (millions)**	**OTR**
2000	Bull Market	5	3	1,67
October, 10, 2008	Financial Crisis **(A)**	1.018	83	12,26
May, 6, 2010	Flash Crash **(B)**	1.112	65	17,11
August, 8, 2011	Downgrade USA **(C)**	2.297	75	30,63

Comparing the events identified by the letters A, B, and C, with the situation on the "bull" market of the 2000s (not in the graph) it can be seen how the exponential growth in entering orders is more than proportional to the growth of the actual trading.

The resulting OTR, varies between 2000 and 2011 by the absolute value of 1.67 to 30.63 percent, an increase of 1.734%.

[59] Source: *Nanex Research*, graph in the next page.

Figure 12 – Trade & Quotes per Day 2006 to 2012[60]



[60] Source: Nanex Research, "The rise of HFT machine" (2013).

Letters A, B and C identify respectively:

A) The financial crisis of 2008, already characterized by a significant increase in OTR, linked to an ever-increasing increase in the phenomenon following the adoption of the NMS Regulation in 2005, which has already been mentioned above.

B) The events of May 6, 2010, better known with the term "Flash Crash", which marked a new maximum in relation to the quantity of orders placed and a consequent significant increase in OTR (for a detailed description see paragraph 1.4).

C) US downgrading at that time numerous rating agencies around the world, including Standard&Poor (S&P), reduced the US government's rating from AAA to AA + for the first time in history, provoking a serie of turbulences on the financial markets.

The growth of high-frequency trading phenomenon in the US market, as witnessed by the increase of the Order to Trade Ratio appears remarkable. Many scholars, organizations and institutions, both European and American, have been questioned about the effects resulting from this exceptional increase in the number of orders not followed by an equally important increase in actual trading, and more generally on the effects of the high-frequency trading phenomenon.

The following chapter will analyze the impact these systems have on the quality of the market (in terms of informational efficiency, liquidity and volatility), market integrity and systemic risk associated with the shock contagion between markets.

Chapter 2

EFFECTS AND HIGH FREQUENCY TRADING REGULATION

The significant diffusion, discussed in the previous chapter, of High Frequency Trading in recent years (more accentuated in American markets than in European financial markets) has attracted an increasing attention and interest from supervisory authorities in relation to its possible effects.

Research has also produced several theoretical and (more often) empirical contributions, in which it is attempted to determine the possible repercussions of the market participants' significant speed increase in operating[61] on:

I. the systemic risk of shock contagion on a single market.
II. the quality of the market in terms of price information, volatility and liquidity.
III. the implications for market integrity.

These studies are often conflicting and the results that come depend on what is considered for the analysis, thus providing no unequivocal, and often antithetical, conclusions.

In fact, in some cases, studies led to the conclusion that the operation of high frequency traders has positive effects in terms of liquidity, volatility and price information efficiency. In other cases, the result of the research was the opposite, showing a deterioration in the quality of the market (again in terms of price discovery efficiency, liquidity and volatility) and a significant systemic risk. The complexity of the effects of high-frequency trading and the antithetic of results of both theoretical and empirical researches, justify the regulation delay. Authorities in fact just recognized the phenomenon without coming to a

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[61] In terms of timing, modification and cancellation of trading orders.

proper regulation. Now this is necessary due to the impressive growth of the presence of high-frequency traders in the main financial markets.

The debate about HFT's regulatory issues has also led to the identification of policy measures, in order to mitigate the potential negative effects of high-frequency trading.These interventions involve, on the one hand, the increase of the information to be provided to the authority in regards to the operation on the markets, and on the other hand, some of the market microstructure features.

The obligation to notify algorithms, *circuit breakers*[62], the limits to the minimum *tick size* and the commission regimes differentiated by these entities, are just some of the main policy analyzed.

In general, in today's context of high financial market integration, the usefulness and effectiveness of such policy instruments depends directly on the creation of a coordination between different trading venues, to prevent arbitrage between the different jurisdictions.

2.1 Systemic risk

There is no generally recognized definition for "sistemic risk".

In corporate finance, it is opposed to specific risk and is defined as "the factor-dependent risk that affects the overall market trend and can not be reduced by diversifying the portfolio".

The Bank of International Settlements (BIS) has defined it, from a more general perspective, as "the risk that the failure of a participant to meet its contractual obligations may cause the failure of other participants"[63].

[62] Mechanisms used to limit or stop the negotiations on the occurrence of certain conditions.

[63] *Brealey, Myers, Allen – Principles of Corporate Finance (2014).*

For the purpose of analyzing the effects of high-frequency trading, a systemic risk is the risk deriving from an initial shock on a market, which can rapidly propagate to other markets, creating a general instability situation for the contagion due to the operation of high-frequency traders. The causes leading to systemic events lie mainly in the influence that the various high-frequency subjects have on each other and on the market in general.

It means that systemic shock propagation does not depend by the size of the subjects and the extent of the operations, but by the correlation between high-frequency operators.

Il rischio sistemico è quindi inteso come il rischio legato al contagio tra i mercati di *shock* che intervengono su un unico mercato.

The systemic impact is due to the fact that very often HFT operators and algorithmic trading systems (AT) use highly-related strategies. In fact, can be experienced deep and sudden destabilizations of one or more markets caused by a shock affecting a single AT or HFT operator. This is the case of Knight Capital[64] that on August 1, 2012, due to an error in the algorithm used, in just 45 minutes of trading lost about 440 million dollars (equal to 4 times the net profit of 2011).

On that occasion it influenced the strategies of the other high-frequency traders, causing a real shock in the market that was soon to affect also other trading venues given the intense cross-market operations of the operators involved.

In addition to the shock risk of individual AT or HFT operators, there may be extremely uncertain market situations.

In such contexts, the operation of high-frequency trading systems can amplify downward or upward pressure generating extreme disorder in the markets.

An extremely impressive example is the *flash crash* of May 6, 2010, as described in the first chapter.

That day HFTrs have played a key role in amplifying the market movement, while not having represented the cause (which is identified rather in placing of a large sell order).

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[64] It is one of the largest high-frequency traders in the US market.

In that situation the orders placed by HFT traders, triggered sell orders of other traders in the futures market, creating a chain effect that moved simultaneously on the stock market, where major indexes lost about 10% in a few minutes and then recovered quickly.

SEC's report[65] shows how in that situation the HFTrs have at first provided liquidity to the market, absorbing a considerable amount of orders, then later followed the market subtracting liquidity and emphasizing the drop in prices.

Many empirical studies have analyzed the impact and effects of HFTr's operations based on *flash crash* events.

Krilenko et al.[66] after identifying the HFT operators have observed the operation, and noted the great differences with respect to that market makers. They have shown that these operators did not provide liquidity to the market and they also boosted the price movement and offset the effects on other markets.

According with the SEC report's results, HFTrs have triggered flash crashes and also, in certain stressed moments, HFTrs caused a subtraction of liquidity and increased volatility in the market, since they were not willing to accumulate long or short positions but attempted to balance their position.

This situation is found perfectly during the *flash crash.*

While at first HFT traders have actually provided liquidity, absorbing the sales orders of the *foundamental sellers*, after a short time they reversed the trend, with the aim of closing the trading day, thus amplifying the drop in prices.

This trend finally stopped with the intervention of the foundamental buyers who reversed the trend by entering large purchase orders.

[65] *SEC, "Findings Regarding the Market Events of May 6, 2010".*

[66] *Krilenko et al. "The Flash Crash: The Impact of High Frequency Trading on an Electronic Market" (2011).*

2.2 Market quality

The most important question about high-frequency *trading*, that scholars and literature try to answer at is:

Is HFT beneficial or harmful to the economy in general?

The answers mainly concern the evaluation of market quality parameters.

In fact, the effect of high-frequency traders on market quality is able to give a unambiguous answer to the previous question and, therefore, a positive or negative opinion regarding the spread of these players on the financial markets.

The first theoretical model that analyzes the impact of high frequency trading on market quality is due to *Cvitanic and Krylenko*[67]. They hypothesized an electronic market initially composed of low frequency traders (humans), then to add high frequency traders (machines) and analyze the effects of their presence.

They considered that high frequency traders are very similar to *market makers*, ie operators who do not have an informational advantage over other market participants, but who have a single advantage: the faster input in speed, modification and deletion of trading orders.

Cvitanic and Krilenko conclude that the presence of high-frequency traders affects the average price of trading and the distribution of prices.

After the introduction of high-frequency traders in the electronic market there is a concentration of transaction prices around the average, ie a lower volatility, and an increase in trading volumes, ie an increase in liquidity in the market.

Most of the academic literature and empirical studies confirm these results[68], however, in some studies the different assumptions underlying the basis of theoretical models, may affect the results obtained.

For example *Jovanovic and Menkveld*[69] are convinced of the presence of a constant information asymmetry between the high-frequency players and other participants in the market.

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[67] *Cvitanic e Kirilenko, "High Frequency Traders and Asset Prices" (2010).*

[68] See: *Jarnecic and Snape, "Handbook of high frequency trading" (2010).*

The empirical analysis results and the theoretical model presented by them depart significantly from previous conclusions, stating that HFT can create or amplify adverse selection phenomena[70], cause an increase in the bid/ask spread, and even cause a decrease in trade (Ie less liquidity).
However, most studies examining the effects of algorithmic trading and high-frequency trading on market quality, get positive results on the parameters taken into account.
In detail, in considering the quality of a financial market, the following key parameters must be considered:

I. Information Efficiency;
II. Volatility;
III. Liquidity.

2.2.1 Market efficiency

Information efficiency indicates the ability of markets to adjust stock prices to information available to traders.
When an event occurs in the capital market - for example an unexpected modify of interest rates or a feature of the company that issued a security - the current market stock value may diverge from the corresponding real equilibrium value.
The information efficiency of the market is the degree to which the prices of financial assets are adapted to news, and the degree with which the stock prices reflect the informations relevant to the issuing company.
The measures commonly used to define the degree of efficiency of the market are three[71]: weak form, semi-strong form and strong form.

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[69] *Jovanovic and Menkveld "Middleman in Limit Order Markets" (2010).*
[70] Intended as a possible consequence of the information asymmetry between market participants, see: *George Akerloff, "The market for lemons" (1970).*
[71] *Saunders and Cornett "Financial Markets and Institution" (2009).*

According to market efficiency in weak form, market information is already included in stock rates, so all historical information and rates are not useful in predicting future stock rates.

A market efficiency in semi-strong form instead focuses on the speed of informations reflecting in stock rates, whereas the markets immediately reflect the information become of public knowledge.

Lastly, market efficiency in strong form stipulates that stock rates incorporate all the information on the market, whether public or private.

As a result, even knowing about confidential information is not possible to achieve extra returns.

According to the information efficiency of the markets described above, high-frequency trading systems are likely to compromise the correct price formation process, since orders generated automatically by input-output algorithms are based on rate and volume observations of the market at a given moment. Therefore they do not provide any informative contribution to the economic fundamentals of the negotiated title.

The significant diffusion of the phenomenon could therefore lead to a shift away from the levels identified by the fundamental analysis, thus reducing the signaling value.

Many studies on the price formation process detect a negative impact by high-frequency trading on price information efficiency[72].

In particular, Zhang[73] argues that HFTrs, in addition to lowering the price signaling value, could divert informed investors from transparent platforms by targeting them on alternative platforms that do not provide *pre-trade* transparency, compromising the proper *price discovery*[74] process.

On the contrary, it is also considered that the higher operating speed of high frequency operators allows the information that arrives on the market to be incorporated as quickly as possible into prices, thereby facilitating the price discovery process.

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[72] See: *Jarrow and Protter "A Dysfunctional role of High Frequency Trading in Electronic Markets" (2011).*

[73] *Zhang "High-Frequency Trading, Stock Volatility, and Price Discovery" (2010).*

[74] *Broogard "High frequency trading and price discovery" (2010)* e *Hendershott e Moulton, "Automation, Speed and Stock Market Quality" (2011).*

According to this consideration, HFTrs would certainly contribute to the creation of a semi-strong market efficiency, by adjusting the prices to the new information in seconds ahead of what would have happened in their absence.
However, it can not be concluded that more immediacy in the transfer of price information is categorically positive, as that speed could amplify the adverse selection of market participants and thereby reduce the overall efficiency.
Generally speaking, the risk of adverse selection can be considered as the risk of having transactions with counterparties having an informative advantage.
In the event that the spread of high-frequency systems in a market is very high, an individual may be exposed to the risk of adverse selection, in this case understood as the risk of trading with counterparties having a high technological advantage.
HFTrs, due to the complex strategies analyzed in the second chapter and to the fastest speed, may in fact affect the market and disprove the operations of *slow traders*[75], increasing their risk of substantial losses and discouraging them from participating in the market.
This happen with small investors who tend to leave the market when the situation becomes tense and uncertain.
The output from the market of numerous operators would also lead to a decrease of liquidity.
To sum up, in assessing the effects of faster speed in the rates information transmission, some consequences should certainly to be considered, such as adverse selection and the decrease in market liquidity.

[75] Generic operators who do not have advanced technologies.

2.2.2 Volatility

In finance, volatility is an indicator that measures the uncertainty or variability of the performance of a financial asset over time.

The variability is statistically measured by the variance, which represents the average of the squared deviations from the expected value and is calculated by the following formula:

$$Var(x) = \frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^2$$

where X_i indicates the performance in the period and $\overline{x}$ indicates the average of the observed yields. Another measure of variability is the mean square deviation (or standard deviation), which is obtained from the square root of the variance and is often used to indicate volatility:

$$\sigma = \sqrt[2]{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^2}$$

Volatility is a measure of uncertainty about future price movements of a good or a financial asset. Increasing volatility increases the likelihood that performance is very high or very low, ie the likelihood that price movements will be very wide will be increased or decreasing.

A high variation in the price of financial instruments is not necessarily a negative factor for the title or for the market in which it is traded.

High volatility is a feature that makes the market particularly attractive for some types of investors, such as high frequency traders, who are usually open and close positions in the shortest time.

Some theoretical studies and many empirical studies have analyzed the impact of HFT on market volatility, often reaching conflicting results.

One of the most important contributions is Broogard's analysis[76]. It is focused on the link between HFT and volatility and concludes that, on the one hand, *intraday* volatility generates an increase in the spread of HFT in the short term, and moreover, the increase in the market penetration of high-frequency systems causes a reduction in *intraday* volatility.

The bond between HFT and volatility therefore acts substantially in both directions.

The more volatile markets are preferred by high-frequency trader for the possibility to obtain larger profits, but at the same time a high diffusion of such players significantly reduces the volatility. The overall effect is however positive.

It is generally acknowledged that from the beginning of the new century to the present, the intensification of high frequency trading and of the simplest algorithmic trading, as Boehmer et al. demonstrated[77], has on average resulted in a significant increase in the volatility of share prices.

This evidence has recently been confirmed with regard to the Italian stock market, by a Consob study[78].

The analysis shows that an exogenous increase in the level of HFT activity results in a significant increase in the volatility of daily returns. In fact, depending on the specification used, an increase of 10 percentage points of the weight of "pure" HFT on the total of exchanges results in an increase in intraday volatility ranging from 4 to 6 percentage points[79].

2.2.3 Liquidity

Liquidity is by definition the ability of an investment in real or financial assets[80] to turn easily and quickly into the currency on favorable economic conditions, ie without significant price offerings from the current value.

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[76] *Brogaard, "High Frequency Trading and Volatility", (2012)*

[77] *Boehmer et al. "International Evidence on Algorithmic Trading",*

[78] Consob *"The impact of HFT on volatility, evidence from Italian market. " (2015).*

[79] The results vary slightly (the effect is between 3% and 5%) if we consider a larger dimension of HFTr, ie, besides the presence of "pure" operators, the operation of investment banks.

[80] Money is the most liquid asset. Other assets (real estate, financial instruments, bank deposits) each have a different degree of liquidity.

The more liquid is an activity, the less the transaction costs, the loss of capital that may result in the conversion and the time needed for the conversion itself.

Factors that may affect the liquidity of a financial instrument are different. First of all, the requirement for liquidity of a financial instrument is its marketability, in turn influenced by the transferability of the same and then from its circulation in the secondary market after the issuance in the primary market.

Another factor is the standardization of the title, which serves to ensure maximum access by investors: a market is in fact much more liquid the greater is the volume of trading.

Liquidity also depends by the residual life of the financial instrument (a stock is more liquid as close to its expiry date), by the credibility of the issuer and whether the stock in question is quoted or not.

Breadth, thickness and elasticity of the relevat market also contribute to the liquidity of an instrument.

With reference to HFT's impact on liquidity, this is measured immediately with the effective bid/ask spread, given by the difference between the transaction price and the average between bid and ask (mid price)[81].

$$effective\ bid/ask\ spread\ =\ price_t - \frac{(ask_t + bid_t)}{2}$$

Most of the empirical analyzes[82] agree that the high participation in the market by high-frequency trader produces a narrowing of the bid/ask spread, with consequent positive impacts on liquidity.

Despite all these studies show a very positive effect on the quality of the markets in terms of liquidity, in particularly turbulent market conditions high-frequency traders can generate a substantial absorption of liquidity, causing very destabilizing effects for the financial markets.

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[81] However, there are several much more complex formulations for the measurement

[82] *Jovanovic, Menkveld "Middleman in limit order markets"* (2011), *Riordan e Storkenmaier "latency, liquidity and price discovery", Journal of financial markets (2011).*

In the analysis of the "ghost" strategies (chapter 3), it has been stressed that through pinging, smoking, layering and spoofing strategies, HFTr floods the trading book of orders, modifying and deleting them continuously, thus creating a kind of illusionary liquidity.
In practice, we can refer to this phenomenon with the expression "*ghost liquidity*", in order to indicate an apparent liquidity that often tends to disappear in turbulent market conditions in a very short time.
Van Kervel[83] fact shows how the actual liquidity in the markets is overestimated in the presence of high-frequency traders.
The massive presence of orders on negotiation book's different levels makes in fact perceive a significant interest in that particular financial instrument, and that misperception leads the slow trader to wrong decisions.
Very often, too, in order to increase the probability of execution, HFTrs simultaneously place orders on different trading platforms. Once the order is placed in any of these, the implemented algorithm sends cancellation signals for similar orders sent to the other *trading venue*, thus generating a significant and immediate reduction in liquidity.
Ultimately, the perception of the overall HFT effect on liquidity appears to be ambivalent: when it is all right and there are no particularly turbulent conditions, HFTrs' operations generate a substantial reduction in the bid/ask spread and a consequent increase in liquidity.
In case of troubles in the financial markets, when the need for liquidity is most needed, HFTrs exit from the market, generating a sharp reduction in liquidity with all the consequences.

To conclude the analysis of the effects of HFTrs on market quality, it can be stated that most empirical and theoretical studies conclude that there is no particular evidence of adverse effects.
The *trade-off* between volatility and liquidity seems perfectly balanced.
The risk of a general increase in volatility seems to be canceled by the stability associated with increased liquidity in the financial markets.

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[83] *Van Kervel, "Liquidity: What you see is what you get?"* (2012).

However, this balance disappears in particularly turbulent market situations, and the high risk associated with sudden liquidity reductions in particular contexts may be attributed to the lack of legislation to regulate this phenomenon.
Brogaard, in one of his researches[84], argues that "overall, the activities of high frequency traders are not harmful to other operators and HFT tends to improve market quality".
To conclude, it can certainly be said that the spreading of High-Frequency Trading in financial markets is undisputed, especially in the United States (as shown by *Nanex*'s research) where the HFT systems are responsible, in some circumstances, of about 2/3 of the total volume of trade.
It does not appear pretentious to say that *High-Frequency Trading* has become a major (if not fundamental) source of liquidity.

2.3 Market integrity

In order to protect the integrity of financial markets it is necessary to protect investors from market abuses, or by manipulative behaviors can alter the regular formation of prices of financial instruments.
The aim is to ensure the market that transparency and efficiency indispensable for its proper functioning.
Despite the positive impact generally recognized by the academic theory on market quality, some strategies put in place by HFTrs tend to generate a distorted representation of the trading book and can be considered manipulative.
These are *smoking*, *spoofing*, *layering* and *front running* strategies, already mentioned in the second chapter, and which need to be discussed also here, as they may set up *trading abuse* situations and manipulation of financial markets.
The practice of "*smoking*" is to enter very appealing orders, often called "fake orders", in order to attract a considerable number of slow trader, and then modify them quickly

[84] *Brogaard, "High Frequency Trading and its impact on market quality" (2010).*

through the insertion of less favorable conditions, even before the counterparties, attracted by the initial conditions, may realize the changes.

"*Spoofing*" is instead to obtain better terms of purchase for a title considered interesting by HFTrs; the aim is to manipulate the market by entering a series of sell orders (usually with bid price higher than the ask price on the market), in order to convince other investors to be in a bearish phase, and then delete them before they are executed taking advantage of the very high operating speed.

The "*layering*" is a practice similar to *spoofing* and consists in introducing simultaneously one order not visible in the book trading from one side of the market (ie purchase) and another order, visible in the book, on the other side (ie sale), so as the other participants in the market believe (erroneously) the beginning of an impending bearish phase, and then again take advantage of the operating speed by deleting the sales order before it is executed and run so the hidden purchase order at a more advantageous price.

Finally, "*front running*" is a particular strategy put in place by financial intermediaries who carry out their own and third party transactions. It consists of taking advantage of operational speed by entering orders (on their own) a few moments before the customer orders are entered. In this case using information not available to other operators, you can get profits enduring minimal risks.

The high speed of entry, modification and cancellation of orders, enables the realization of some manipulative strategies of prices that damage the integrity of the markets. Moreover, the spread of high-frequency trading may affects fair market access.

The technological and temporal advantage of HFT operators is a competitive advantage and at the same time an element of disparity among market participants, so informed investors would be encouraged to turn their investments elsewhere or to use less transparent platforms, altering the training process of prices.

2.4 Positive and negative aspects

The following chart summarizes the main advantages and disadvantages, identified by the majority of theoretical and empirical research and resulting from the presence of high-frequency trading systems:

MAIN BENEFITS	MAIN NEGATIVE ASPECTS
Increased liquidity in the financial markets	Informations are asymmetric
Decrease of the average *bid-ask spread*	Adverse selection
Decrease in transaction costs	*Ghost liquidity*
Increased price information efficiency	*Flash crashes*
Increased links between markets	Manipulating price strategies

2.5 Regulation

The regulation of High-Frequency Trading seems increasingly necessary and the legislative/political debate aimed at limiting the use of these trading systems is particularly acute in America, Europe and Asia.

As already discussed, some experts believe that these technologies will help the market because they increase liquidity and decrease the *bid/ask spread*. However, *authorities* generally believe that with these methods the market is manipulated to the disadvantage of normal operators and HFT should be regulated, or indeed excluded.

The regulation could identify and impose predetermined relationships between orders placed and actually executed orders (OTR), beyond which are triggered in a penalty (for example, a fine if it does not occur at least the execution of 1 order every 100 placed on the market) with the aim to reduce distortions on trading books.

In the United States, after sudden crashes[85] and after experiencing several anomalies, a counter-offensive began with heavy penalties and more stringent rules.

Europe, however, is not yet running for cover and the phenomenon is growing, contrary to what happens in the US.

Starting precisely from Italy where, as certify the figures released in February 2015 by Consob[86], the Milan Stock Exchange has become a land of conquest with more than 30% of trade attributable to HFT.

A major responsibility for the huge diffusion of HFT systems should be attributed to trading platforms. These, without impartiality, "rent" (for a very expensive fee) access points by the headquarters of electronic platforms that manage bargaining, in addition to the *co-location* of HFT servers. This is now a practice that seems to be quietly admissible and more than about transparency the defect seems to be about competition, as inevitably are genarated categories of privileged users.

2.5.1 IOSCO's recommendation

At international level, IOSCO[87] published a report[88] in October 2011, which represents an important starting point for the examination and analysis of high-frequency trading and AT.

The report examines and analyzes the role of HFT in relation to the impact of technology on the integrity and market efficiency.

Are entitled to the benefits of technological progress (innovation, efficiency and liquidity

[85] The most famous is the *flash crash* of May, 6, 2010 but in the last years occurred many similar events.
[86] Consob, *"the impact of High Frequency Trading on volatility, Evidence from the Italian market"* (2015).

[87] International Organization of Securities Commissions.
[88] IOSCO, "Regulatory issues raised by the impact of technological changes on market integrity and efficiency" (2011).

of the market), but also focuses on its potential adverse effects (eg, increased likelihood of flash crash and the increased volatility).

The Report states some regulatory principles, through the dictation of recommendations aimed at market surveillance, through the knowledge of the concrete impact that technological developments may have on market quality and through the identification of measures to reduce the risk that technological change may pose to the integrity and efficiency of markets.

In particular it is established that[89]:

I. *Regulators* shall require trading house managers to ensure impartial, transparent and non-discriminatory access to their markets, products and services associated;

II. *Regulators* shall ensure that trading venues, in order to deal with volatile market conditions, provide adequate trading control mechanisms (eg *trading halt*, *volatility interruptions, limit-up/limit-down controls*);

III. *Regulators* identifies the risks from the currently non-regulated participants, and once identified, take concrete measures to address them;

IV. Trading systems and algorithms are able to handle changing market conditions by adapting to them, while maintaining the stability needed to minimize operational risk;

V. Trading systems are able to adjust to changes in operational message flows (including sudden increases);

VI. The total order flow of trading participants is subject to appropriate controls, based on regulatory requirements set by a dedicated Financial Market Supervisory Authority;

[89] IOSCO "Objectives and Principles of Securities Regulation" (2011).

VII. *Regulators* should:

a) continue to analyze the impact of technological development and changes in market structures (including HFT) on the integrity and efficiency of the markets themselves;
b) seek to ensure that appropriate measures are taken to reduce the risks posed by such developments (including price formation risks and market stability);
c) monitor technological developments in order to determine whether these can lead to the development of new forms of market abuse or the change of existing ones and to provide the necessary reactions;
d) update their devices and expertise in ongoing trading monitoring to ensure their consistent efficiency (including orders and placements and canceled orders)

Principles contained in "*Objectives and Principles of Securities Regulation*" are the following:

Principle n°33

"The establishment of trading systems, including securities trading, shall be subject to authorization and supervision by the Authorities."

Principle n°34

"There is a need for constant oversight of trades and commerce by the Authorities, aimed at ensuring that the integrity of the negotiations is maintained through fair and equitable rules that can determine the right balance between the needs of different market players."

Principle n°36

"Regilations must be designed to detect and prevent manipulations and other incorrect practices"

2.5.2 American experience

In the United States has been developed a system that allows participants to negotiate the best available price on the market.

The NMS Regulation has in fact defined the National Best Bid or Offer (NBBO) mechanism, which guarantees the execution of the lowest-priced purchase orders on national markets and the highest-price sell orders on the markets at that time.

To locate the NBBO markets are therefore obliged to inform a *Securities Information Processor (SIP)* about price and quantity of the best ask and best bid relating to listed securities, in order to ensure that the negotiations are always executed at the best available price.

To protect participants and ensure implementation at the national best price, "National Market System" Regulation also introduced the so-called "order protection rule" that prevents the market to bargain at different prices from NBBO.

So if a market is not able to make an order to the NBBO, it is obliged to forward the order to who at that time offers the best price or must, otherwise, cancel the order.

The HFT phenomenon has not yet received specific regulatory discipline, but *SEC (Securities and Exchange Commission)*, considering the importance of such instruments for global market stability, has, however, started to show a major interest in the phenomenon since January 2010, when published a *Concept Release*[90] requesting information about mode and operation of HFTr, as well as analyzing costs and benefits of high-frequency traders.

Following the flash crash of May 6, 2010 on the US market, SEC and CFTC (*Commodity Futures Trading Commission*) presented a joint report entitled "*Findings Regarding the Market Events of May 6, 2010*", which describes the sequence of events that would have led to the collapse of the Dow Jones Index in just a few minutes, highlighting the ability of

[90] *Securities and Exchange Commission* , 14 gen 2010.

HFTs to boost market volatility under particularly turbulent conditions.

Considering these events and considering the supervisory authority's need to acquire useful data for control and suppression of illicit activities, the US authorities adopted a regulatory approach aimed essentially on tracking the activities of "*large traders*": subjects who trade in large quantities and able to influence prices.

HFTrs are considered as a subset of large traders, and their activity is then regulated by the rules provided for large traders.

The new rules require a stronger information regime for certain subjects (*large traders* and *broker-dealers*) by imposing on them obligations that are aimed at ensuring the transparency of their subjective status and the operations they perform.

SEC has thus adopted *Rule 13h-1* and *Form 13h* where:

I. It is defined which subject assumes the quality of *large trader*; They are in fact defined large traders *(Rule 13h-1)*:

II. Those whose securities transactions amount to or above a certain level of identification (2 million shares or $ 20 million over a trading day);

III. Those who directly or indirectly carry out purchases or sales for a total amount equal to or greater than the predicted level of identification;

IV. Those who voluntarily registered as a large trader by the supervisory authority.

V. These subjects are required to be identified by SEC using the *Form 13H* in order to obtain the Large Trader Identification Number (LTID)*;*

VI. Large traders are required to provide their own LTDI to each *broker-dealer* through which they carry securities transactions on the market.

VII. *brokers-dealers* are required to provide the SEC, upon request, data on transactions made by large traders by the morning following the day on which the transactions have been executed;

VIII. *broker-dealers* are required to hold accounting books related to such transactions.

The obligations therefore articulate essentially on two levels;

I. the registration of large traders with the supervisory authority;
II. the registration of transactions and the obligations of information and monitoring of large traders imposed on *broker-dealers.*

In addition to the regulatory effort just described, numerous investigations have been carried out to define correctly the HFT phenomenon.
For example, in September 2012, the US Senate Banking Commission heard witness David Lauer, a Chicago-based HFT trader, who in his written testimony stated that "US stock markets are in troubled waters".
On May 6, 2010, Lauer, in his view, realized that fast-trading programs could be a potential risk for the market, and suggested a decisive step in the regulation by fixing to 50,000ths the minimum sealing time of the position.
Such an initiative should be combined with the imposition of pre-established ratios between orders placed and orders actually executed beyond which a sanction would be dispelled.
The US authorities are far ahead compared to the European ones, and not only SEC is investigating (SEC has already sanctioned Athena Capital Research, UBS and Latour Trading) but also the federal police and the judiciary.
In April 2014 the FBI announced an investigation launched in 2013 that employes hundreds of agents and computer experts, in order to gauge IT systems and operations of companies using HFT systems. The aim is to detect potential crimes in orders placed, modified and deleted.
The widespread fear is that high frequency traders take advantage of early information on all other investors.
The most hardened hunt for market manipulators is, however, conducted by New York Attorney General, firmly convinced of the fundamental role and responsibility of the

authorities in rebuilding investor confidence. *Barclays, Ubs, Credit Suisse* and *Deutsche Bank* are on charge of having exchanged exchanges thanks to high-frequency technologies and taking advantage of privileged information at the expense of less agile workers such as pension funds and insurances.

To avoid a collapse of credibility banks expressed their readiness to cooperate by signing an agreement with the *Department of Financial Services (DFS)* in New York, for the installation, inside their offices, of monitors managed by independent bodies, to control possible manipulation of orders during the trading sessions. This is to gather evidence on the alleged practices to the benefit of HFTrs.

Banks declare they are tired of controversy, inspections, investigations, fines, and they prefer to start doing something, especially because sometimes predators have become victims of their own systems: in August 2013 *Goldman Sachs* lost $ 100 million due to an "accident" due to a technical failure; *Knight Capital* has ended up on the brink of bankruptcy also for a technical problem, in China the authorities are investigating the broker "*Everbright Securities*" after a purchase order wrong for $ 3.8 billion that had resulted to pick up the Shanghai Composite Index by 6% in a few minutes.

So in the absence of specific legislation, with fines and accidents along the way, in the USA the practice of *High Frequency Trading* is slowing down.

Some unofficial sources, in fact, estimate that the 70% of trading attributable to HFTrs in 2012, today has gone to 50-60%: a clear signal that the regulation, although general and non-specific, can give results.

At the same time, however, high frequency is colonizing other asset classes and other equity markets. In particular, HFT operations shifted to currency markets where exchanges attributable to high frequency trading systems went from 9 to 35% total trade. The main reason is that currency exchanges are active uninterruptedly, with an ever-increasing liquid that moves within 24 hours from Asia to Europe and finally to America.

The equity speculation instead focuses on Europe, caused by limited awareness of the problem and the inadequate actions of the controllers.

2.5.3 European experience

While in the US the percentage of exchanges with high-frequency automatic trading systems decreases, in Europe this percentage rises to 50% in regulated markets.

In Europe, the *MiFID (Markets in financial instruments directive)* Directive introduced a principle based on the "*best execution*". Instead of ensuring the best price order (NBBO), as is the case in the United States, the directive requires investment companies to "consider the most reasonable solutions for obtaining the best possible result for their order customers, taking into account price, costs, speed, scope for execution, size, nature and / or any relevant consideration for the execution of such order "- *European Commission* 2004.

Concerning the HFT in Europe, the debate is still particularly fierce.

While England has had and continues to have a friendlier attitude towards the high-frequency traders, Eurozone politicians seemed to have a different view[91] and had created a lot of waiting for the close of trading in place, both at the European and Member States Parliament, as regards the final changes to the final text of *MiFID2* after the European Commission had published the contents in October 2011.

The regulation of high-frequency trading has become more concrete with the adoption of the *MiFID2*[92] Directive and the European Regulation No. 600/2014, both aimed at greater transparency and market efficiency and better investor protection. Together, these two instruments should be the legal reference for each member country.

It is also assumed that high-frequency transactions, starting from the moment the regulations will be applied (2017), will be made more difficult since the new rules will provide *regulators* with the opportunity to test the programs before authorizing them, to impose on trading companies registration and storage of trade information, in addition to the possibility of introducing "speed limits" that would guarantee a minimum half-second interval between individual orders (sale or purchase).

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[91] Austrian ECB member Ewald Nowotny had urged in September 2012 to ban the HFT

[92] [92]Directive 2004/39/EC

At EU level, *ESMA* considered it necessary to publish in December 2011 - on the basis of Article 16 of Regulation 1095/2010/EU ("to establish uniform, efficient and effective supervisory practices ... and to ensure the common application, uniform and consistent EU law ") - the document *ESMA*/2011/456 containing the "Guidelines on systems and controls in an automated environment for trading platforms, investment firms and competent authorities". The main objectives of the Guidelines are to maintain orderly conduct of the negotiations in order to ensure an efficient price formation process and equal treatment of market entry entities as well as market integrity by means of prevention, detection and sanctioning harmless behaviors.

Negotiation platforms and investment firms had to adapt to ESMA guidelines starting from May 2012.

Focus and the very reason for their emanation reside in an attempt to set up the necessary tools to minimize potential perverse effects on the market.

It is intended to regulate:

1) the management of an electronic trading system by trading platforms (regulated markets and multilateral trading systems);
2) market access in *direct market access (ADM)* and *sponsored access (AS)*

In particular, the electronic trading systems of a regulated market or a multilateral trading system must ensure, even considering innovations and trends that occur in the use of technology, compliance with the obligations imposed by *MiFID* and other EU and national norms. In addition, systems must be tailored to their business, they must ensure continuity and regularity in the automated market managed by trading platform managers.

Therefore, trading platforms must take into account at least the following elements:

I. *Governance*: appropriate governance processes need to be in place to verify the compliance of electronic trading systems with existing legislation and to supervise their development and use. Processes must include principles of compliance and risk management and a clear identification of responsibilities within the structure for the different phases leading to conformity assessment. In particular, compliance officers must clarify the regulatory obligations of the trading platform manager and, accordingly, the policies and procedures that ensure compliance with these obligations and ensure that any default is detected. Therefore, such personnel must understand the operation of trading systems without knowing the technical properties.

II. Capacity and Resistance: Electronic trading systems must have sufficient capacity to support unusual message volumes, allow any capacity increases to meet a rapid growth in demand, face unexpected emergency.

III. Operational continuity: electronic trading platforms must have adequate *business continuity* devices to handle the possible failures of electronic trading systems.

IV. Monitoring: Negotiation platforms must monitor their real-time electronic trading systems to respond promptly to problems (even through closing the market).

V. Development and Testing Methodologies: Before introducing an electronic trading system and before introducing its updates, trading platforms must adopt clearly defined development and verification methods. Such methodologies must ensure compliance with the rules and that the electronic trading system can continue to work efficiently even under *stressful* conditions in the markets.

VI. Security: they must have procedures and security mechanisms in order to protect their electronic trading systems from misuse or unauthorized access and guarantee the integrity of the data.

VII. Staff: the platforms should have procedures and mechanisms, recruitment and training, in order to determine its need for staff with the necessary skills and experience to manage electronic trading systems.

VIII. Registration / Co-operation: Platforms must keep for at least five years detailed records of their electronic trading systems regarding system properties, verification methodologies, audit results, and periodic reviews.

About 3 years later, in 2014, the EU Council adopted MiFID 2[93] that contains new rules for

[93] Directive 2014/65/UE

financial investment services in regulated markets, with which it tried to regulate the phenomenon of HFT.

The main new features of the high-frequency trading being mainly focused on 6 points of Article 17 of the law and in this case it is required that:

I. Investment companies performing algorithmic trading put in place systems and risk controls in order to guarantee their resistance;
II. provide an adequate level of liquidity and provide for measures to avoid sending erroneous orders or creating a "messy market";
III. provide at least once a year to the competent authority a description of the nature of their algorithmic trading strategies with details of trading parameters and limits, considering that the authority may always request further information about the companies themselves;
IV. the parameters and limits of the trading strategy should ensure that the same transmit firm quotes at competitive prices "with the result of providing liquidity to these trading venues on a regular and continuous basis, regardless of the prevailing market conditions";
V. investment companies should put in place controls and monitors to assess the suitability of persons who intend to use the company's direct electronic access points in order to use algorithmic trading systems; they should settle a written agreement between the company and the person, and the agreement should contain the essential rights and obligations arising from the provision of the service in question; nevertheless the responsibility for illegal acts committed by the person above, shall stand always with the policyholder company.
VI. The European Commission may take further steps to specify what is contained in the Directive.

Chapter 3

MAIN STRATEGIES

The common and distinctive element of the strategies implemented by high-frequency systems is the ability to insert, delete and modify thousands of orders at high-speed. Another feature of such systems is the continuous activity, which allows them to immediately adapt to the different market situations. Taking advantage of the extreme speed, they can suddenly change their positioning, adapting to market behavior and insert/delete orders of purchase/sale by the order book.

Systems are also able to constantly analyze the degree of liquidity on the market, adapting their positioning. The characteristics of these systems also allow to exploit or avoid increases and declines of liquidity through immediate reactions.

HFTrs can act actively (*price taker*) and passively (*liquidity provider*) in response to almost all contingent situations.

A "price taker" operator is a person willing to buy or sell at the best price the market offers at a given time[94], while for "liquidity provider" is an operator who, being not willing to buy or sell at the price on the market at the time of placing the order, intends to place the quantities held on the trading book, waiting for a price taker to meet the requirements[95].

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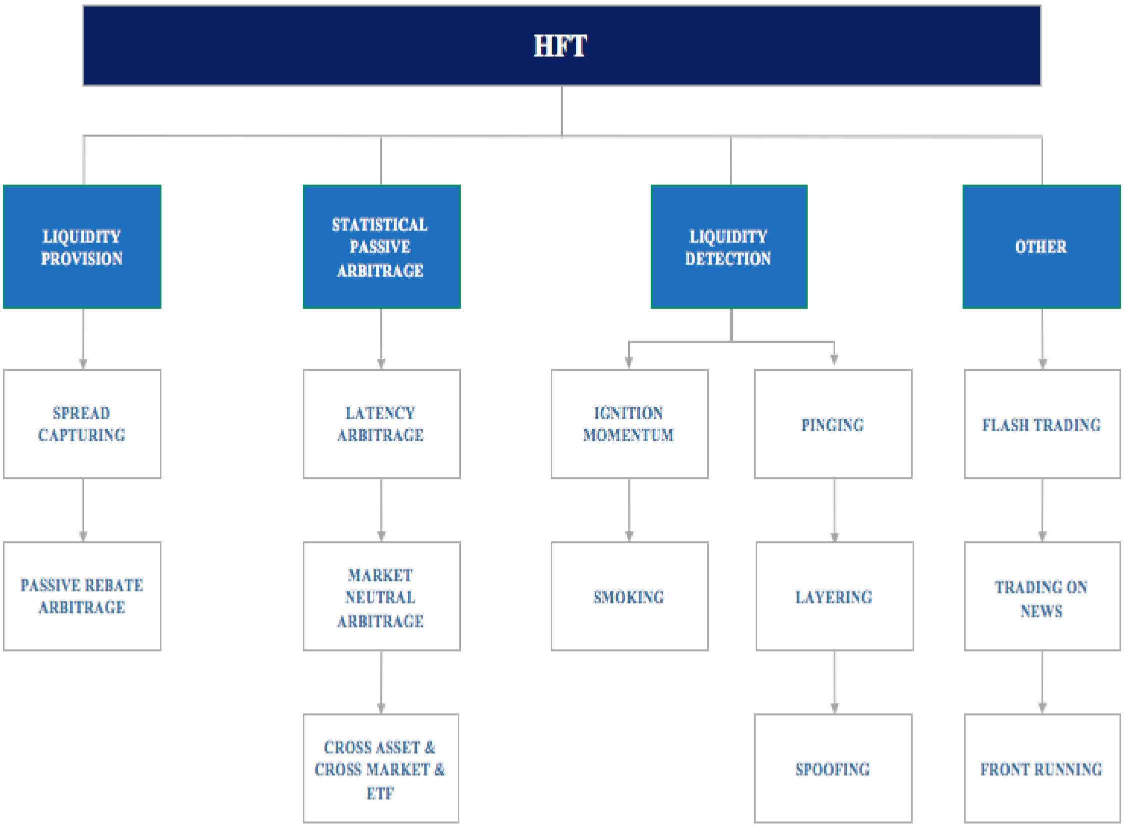
[94] The buyer price taker will accept, therefore, a purchase with the best bid price offered, vice versa the price taker seller will be satisfied with the best price in cash.

[95] The risk associated with liquidity providing is the possibility of never obtaining the execution of your purchase order because there are no price taker sellers or because these are met by other buyers willing to pay a higher price and therefore more convenient for sellers.

Figure 13 – High Frequency Traders main strategies



As just shown in the diagram, for simplicity and for better clarity, it is possible to break down the heterogeneity of the strategies used by high frequency operators.

Such heterogeneity is also one of the main elements that make it very difficult and complex to identify individuals performing high-frequency trading and so defined activities.

In literature and in operational practice have been identified different strategies through which high-frequency trading systems seek to maximize the economic return by exploiting temporal advantages and technical/computational advantages held by them compared to the rest of the market.

All strategies seek to exploit small market inefficiencies and some of these "spy" excess liquidity in order to identify new inefficiencies.

Below is a description of the following (main) strategies implemented by HFTrs:

I. *Latency arbitrage (Statistical Passive Arbitrage)*;
II. *Liquidity Providing;*
III. Arbitration of trading fees;
IV. Trading on news;
V. *Liquidity Detection;*
VI. Ignition Momentum;
VII. Flash Trading;
VIII. Ghost strategies (*Pinging/Smoking/Layering/Spoofing*).

3.1 Latency arbitrage

Arbitrage means price divergence between identical activities due to a temporary inefficiency in the functioning of the markets where they are traded.The technological advantage and the high computational capability compared to the rest of the market allow high frequency traders to take advantage of so-called *statistical passive arbitrage*.
These can be considered substantially non-risk gains, obtainable by the ability to carry out all the investment process operations in a low latency period[96].
Such opportunities, though considered a rare and exceptional event, are in fact very frequent and represent a natural field of application for high frequency instruments.
Indeed, a HFTr is able to identify the arbitrage opportunity when this occurs and, once identified, can fully exploit its amplitude thanks to the ability to beat all other market participants on time.
The disadvantage of the participants is twofold: they have both a lower speed at the time of identification and a lesser speed in the execution phase of the operation.
In recent years, the possibility and frequency of arbitrage has inevitably increased by the spread of several MTFs[97] on which the same financial instruments are listed.

[96] Co-location and low latency, combined with the computational advantage, are decisive in exploiting as many arbitrage as possible.
[97] Multilateral Trading Facilities are private bargaining systems that offer the option of negotiating quoted financial instruments on a stock exchange without regulatory admission and reporting duties.

3.2 Liquidity provision

One of the most common strategies used by HFT is to provide liquidity to the market and consists substantially in replicating the traditional activity of *market makers*, however, not having to undergo the stringent constraints which must be respected by those[98].

Additionally, HFT is not obviously required to act as a counterpart to all incoming orders; being able to choose whether and how to operate it has the potential to achieve an incredible profit opportunity.

Once the profitability and riskiness of the different market situations is assessed and if the risk/return profile is consistent, the high frequency system can start operating according to the schemes of a common *market maker*, ie trying to gain by the *bid-ask spread.*

The simple mechanism consists in placing bids and offers on the first levels in cash or letter of the trading book, or at the highest price at which at least one buyer is willing to purchase at least a single unit of a financial instrument and the lowest in at least a seller is willing to sell, and in waiting for participants (*price taker*) to the market the intersect with their respective buy or sell orders.

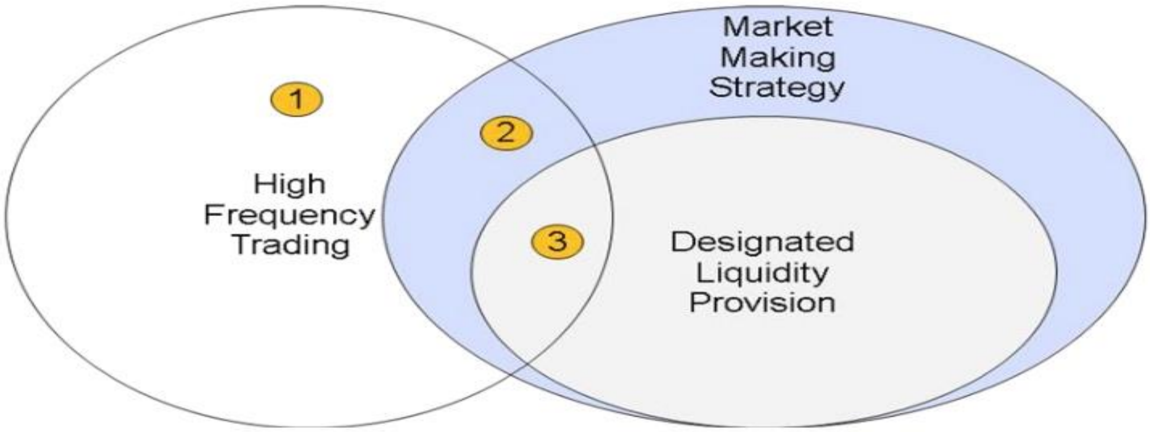
Tendentially, this strategy allows to have two main sources of income: the first is to profit from the gain offered by the bid/ask spread as the high-frequency systems are able to buy at a low price (bid) and sell at a higher price (ask). No less important, the second consists mainly of incentives offered by trading venues to entities that provide liquidity to increase the quality and attractiveness of the market, such as discounts and reductions in transaction fees.

Some trading venues also adopted asymmetric prices for different traders with the aim of attracting higher liquidity, higher trading costs for those who absorb liquidity from the market and lower costs for parties who instead offer liquidity. The main advantage offered by high frequency is once again a time advantage, while buying and selling proposals are systematically introduced beforehand and consequently performed before

[98] For example, timing obligations, minimum number of contracts, maximum allowed spread, and maximum reset time quotes.

those of traditional traders involved in similar strategies. In addition to this remarkable advantage, it adds the possibility of abandoning trading *books* in potentially dangerous situations, potentially diminishing considerably the risk associated with the implementation of this strategy.

Figure 14 – High Frequency Trading & Liquidity Provision



3.3 Passive rebate arbitrage

This strategy, mentioned in the previous paragraph (2.2), is a kind of compromise between latency arbitrage and liquidity offerings to the market and has as its main objective the exploitation of the profit opportunities offered by the new commission structures of ECNs[99].

In the industrial economy, given a sector of reference and a concentration level, the growth of companies operating in this sector that offer a homogeneous product increases the level of competition. Spectacularly, the presence of numerous trading systems parallel to the regulatory markets inevitably leads to a ruthless competition between ECN and regulated markets and between ECNs themselves.

[99] Eletronic Communication Networks are alternatives to regulated markets that enable institutional and private investors to trade securities listed on regulated markets with much lower transaction costs.

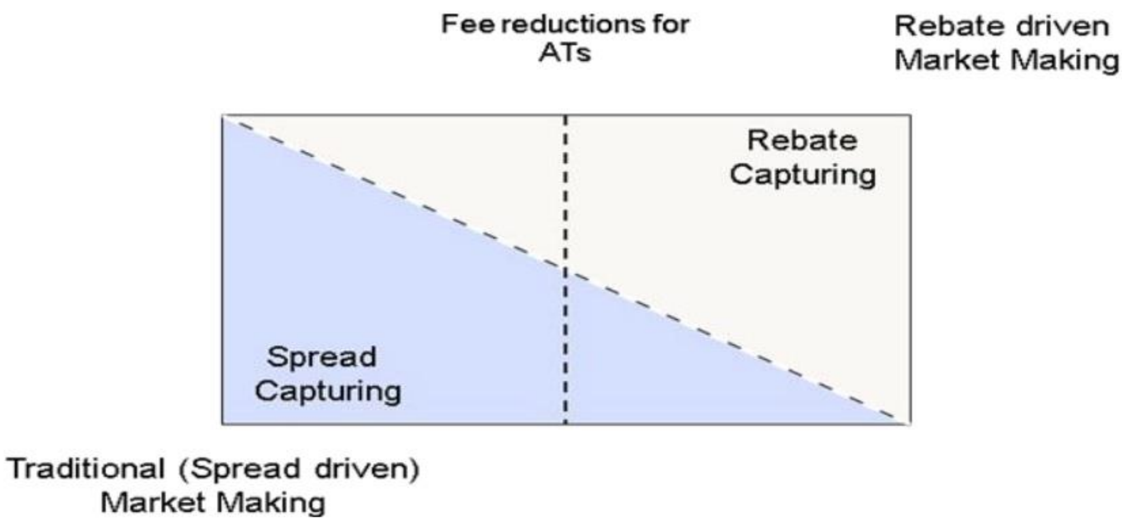
In addition to providing a decisive boost to the technological improvement of the exchange platforms offered, this competition was the underlying cause of the creation of new commission structures, offered by the ECN in order to attract the largest number of market participants. Attracting the largest possible volume of exchanges (and participants) is a "*conditio sine qua non*", ie a prerequisite if an ECN can be perceived better than others and compared to regulated markets. To offer, in fact, a trading book that presents the largest number of buying and selling proposals, with the ability to absorb sudden liquidity flows and large orders, is a key competitive advantage.

Consequently, ECNs began to offer downturns in commissions until they reached negative commissions for liquidity-providing operators, namely those liquidity providers, which give robustness and depth to trading books of financial instruments traded on ECNs.

HFTrs are thus encouraged to provide liquidity in order to obtain profits "capturing" the discounts on commissions (*rebate capturing*) offered by the multilateral trading system.

At the same time, they minimize the risks involved in implementing this strategy, thanks to the immediate ability to withdraw negotiation proposals from books, in potentially risky situations.

Figure 15 – Spread Capturing & Rebate Capturing[100]



[100] Source; *Deutsche Bank Research*, "*High Frequency Trading*" (2012).

3.4 Trading on news

Economic news often cause strong short-term market movements and can create interesting profit opportunities for traders.

News about profits and business results, changes in organization management, possible mergers, interest rates and central bank decisions: these are just a few examples of news that can cause wild price movements of shares and markets in general.

"*Trading on news*" is a strategy for gaining a profit by negotiating "*just in time*" financial instruments when events or news releases occur.

While this strategy is often considered one of the basic strategies of simple algorithmic trading, the joint use of that strategy with high frequency systems allows maximizing profits.

The speed of HFTs makes it possible to take advantage of the rapid movements that occur in the financial markets after the release of macroeconomic data or important news.

As far as the operation of HFTs is concerned, these systems have computer systems able to draw operational indications from the continuous flow of information from major information providers. By associating trading strategies with certain word *patterns*[101] in the news, or by a series of words that are statistically linked to a certain positive or negative impact on the financial markets, it is possible to minimize the time needed for the interpretation of the news and to send automatic trading orders to anticipate short-term market movements and thus achieve attractive profits.

3.5 Liquidity Detection

Liquidity detection refers to the activity through which HFTr "test" some key levels[102] by inserting small orders, this strategy aims to verify the presence of *stop loss* or take profits

[101] Sequences of words contained within a message.

[102] That is, particularly important levels based on technical analysis (supports and resistances) or prices at which numerous bargaining occurred.

from others market participants then make them take and accumulate the liquidity at these closing orders.

Stop Loss[103] is a conditional order used to minimize losses by immediately closing the position at the occurrence of a certain pre-determined price level, which corresponds to the maximum loss it intends to bear.

Take Profit is always a conditional order, however, having the purpose of automatically close in the profit position upon the occurrence of a predetermined absolute level of gain.

The *SL* and *TP* conditional orders have the considerable disadvantage of being trading orders whose positioning is easily predictable. In fact, HFT systems can, through the behavioral analysis of other traders, identify the behavior of operators based on technical or fundamental analysis. By inserting small *market orders*, HFTrs bring the price to the level considered to trigger the underlying conditions of *SL* or *TP*. Once the price set as a condition in the SL and TP orders is traded on the market, the latter are activated, releasing their liquidity mechanically on the market.

3.6 Ignition momentum

One of the finest liquidity detection strategies implemented by high frequency systems is the so-called *ignition momentum*[104]. This strategy consists of taking an aggressive position (*long or short*) that generates a strong movement in the price of the financial instrument in question and pushes other traders to react to the movement.

Finally, on this reaction, the *momentum trader* closes its position by gaining profits.

The *ignition momentum* is therefore characterized by: an initially stable price, a subsequent sudden increase in volumes, followed by a strong price movement and ultimately by achieving starting prices.

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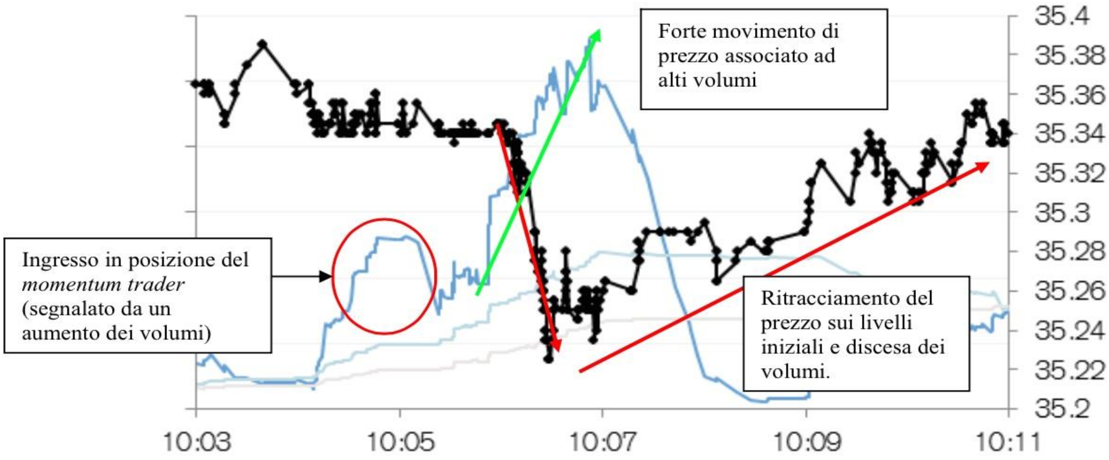
[103] A *stop loss* (SL) associated with a long position is a sales operation, whereas if associated with a short position is a purchase operation.

[104] Also called "*trade ignition*".

Figure 16 – Momentum Trading[105]



The graph[106] shows the main phases that characterize a *momentum ignition* strategy:

I. The price tends to be stable at € 35.35 between 10:03 and 10:06.

II. The first increase in volumes, coinciding with the entry into the position of the *momentum trader*, does not associate any significant price movement, but corresponds to a *short-term* accumulation phase.

III. At the end of the storage phase, the *momentum trader* strategically sends a significant order of magnitude at a time characterized by low volatility and low bargaining volumes.

IV. This order urges all other market participants to react to the sudden change in the scenario, usually with market orders aimed at closing their positions.

V. In this situation, the HFT system that had started a short strategy closed the profit strategy using the closing orders of other traders, which being sales orders can therefore be used to cover the short position previously accumulated by the momentum trader.

VI. Finally, as shown by the red line rising in graph 10, prices return to the starting levels within a few minutes.

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[105] Source: *Peter Gomber et al. "High-Frequency Trading" (2011)*

[106] Source: Elaboration data *Credit Suisse*, *Daimler* share based on *XETRA*.

3.7 Flash trading

Flash trading is one of the most aggressive and controversial strategies used by HFTs: this type of high-frequency trading has fueled the criticisms of the most important specialized newspapers and academic research.

According to *SEC* regulations, brokers are obliged to execute the transaction at the best price on the market, but if the transaction asset has more than one listing, the brokers are required to search the *NBBO*[107] and immediately transfer the order to market where this is present.

Flash trading is part of this regulatory mechanism. In fact, this expression means a service offered for a fee by some *ECN* to HFT clients, which represents a sort of first refusal on orders arriving on the market and that can not be performed because the price is different from *NBBO*.

The operation of this service is simple, the *ECN* before transferring the order (which should instead be immediately transmitted) offers it in visibility to the HFTs that have signed the *flash trading* agreement. The HFTs in turn have about 500 milliseconds[108] of visibility, enough time to process the data, analyze market liquidity, and embark on strategies that can profitably exploit the incoming order.

The advantages that *ECN*s have in offering the *flash trading* service are easy to understand because they can negotiate orders that would otherwise have to transfer to other platforms.

On the other hand, it is more complicated to understand the advantage and motivation that high frequency systems bring to decide to act as counterparts to these orders.

The variety of possible situations often contributes to fuel the complexity.

For example, there are some reasons why this decision can be justified:

[107] *"National Best Bid or Offer"* or they have to look for the best price on different markets.

[108] A.J. Sandler (2011) about *flash trading.*

- If the HFTs are in *long* position on Company X's shares, the *flash trading* service can offer the chance to see a purchase order and close the position at a price before it becomes available to the rest of the market.
- If HFTs are in *flat* position (ie its position is not long nor short on Company X's shares), flash trading can offer a risk-free arbitrage opportunity.
- If HFTs are *short*, flash trading is an informative advantage as it may signal a pressure on demand side that the high-frequency system can use to close short positions before other trading.

HFTs, exploiting in the manner just described such information advantage, are able to obtain a substantially risk-free gain (a true *free lunch*).

Even though these earnings are of a small size, high-end traders look for these opportunities on any financial instrument and on most markets. Multiplying the limited gain per single operation by the number (high) of these you get a certainly considerable final result.

3.8 “Ghost” strategies

With the unique nomenclature "*ghost strategies*" we indicate a set of strategies that differ from each other only for the minimum operational aspects, and in particular the *smoking, layering* and *spoofing* strategies.

The practice of "*smoking*" involves imposing very tempting “fake” orders, so as to attract a considerable number of slow traders, and then modify them rapidly by introducing less favorable conditions before the attracted counterparts from the initial conditions may realize the changes.

The "*spoofing*" method is getting better purchasing conditions for a title considered interesting by HFTr; the aim is to manipulate the market by entering a series of sales orders (normally the bid price is higher than the ask price on the market) so as to convince other investors of a bearish phase, and then delete them before they are executed taking advantage of the very high operating speed.

"*Layering*" is a practice similar to spoofing and involves simultaneously placing an unobservable order in the trading book on one side of the market (for example, in purchasing) and another order, this time visible in the book, on the other side (in this case for sale) so as to make (erroneously) believe to other market participants the start of an imminent bearish phase, then re-exploit the operating speed by deleting the sales order before it is executed and then execute the hidden order purchase at a lower price.

More generally, through these strategies, the HFTr flood the book of limit orders negotiation, modifying and deleting them constantly, artificially simulating market situations with the sole purpose of inducing the traditional algorithmic trader or trader to make the wrong operations in response to unreal situations, thus creating a sort of market illusion.

The high-frequency trading system is therefore a counterpart to these transactions, and having accumulated a certain amount of liquidity, it behaves with the same behavioral pattern in the opposite direction.

Operators are then pushed to close previously accumulated positions in loss.

HFTrs then create new market illusions in order to show an increase in trading orders, and then will be able to close the previously executed transactions.

The strategic objective is basically to take advantage of the predictability that distinguishes institutional traders such as mutual funds and pension funds, which often operate according to recurring patterns.

These strategies are ruthless and aggressive as they create market illusions, push to trading operators who otherwise would not enter the market and generate profits thanks to the loss of less evolved traditional trader or algorithmic trader.

Chapter 4

LIQUIDITY PROVISION & MARKET MAKING

Market makers are unique entities in a market environment. The U. S. Security and Exchange Commission defines a "Market Maker" as a firm ready to buy and sell a particular stock on a regular and continuous basis at a publicly quoted price[109]. Unlike other participants that have always exposure to potential future states of the world, market making (MM) players main objective is to ensure a risk free profit or to facilitate trade that otherwise might not occur.

In this chapter it will be presented a theoretical framework based on MM literature and a simple market making strategy.

An application of the suggested strategy will be presented in Chapter 5 with a step by step construction of a MM algorithm for the Rotman Interactive Trader Client (RIT); a proprietary market simulator whose features and functioning will be presented in the following chapter.

4.1 Market illiquidity, asset pricing and Bid Ask Spread

Whenever an investor would like to trade any asset, he always faces a trade-off between waiting in order to transact at a favorable price or immediately execute the trade at the current bid or ask price.

The bid and ask prices can be defined as the prices at which the market maker is willing to buy and sell respectively a given quantity of a given listed security. Consequently, the quoted bid price reflects a concession for execution immediacy, while the quoted ask price includes a premium for immediate buying.

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109 "Market Makers"

Illiquidity can be measured as the cost for the immediate execution and a natural measure is the spread between the bid and ask prices, which has been defined as the sum of the buying premium and the selling concession[110].

Empirical research has found that the relative spread on a stock is negative correlated with trading volume, number of shareholders, number of market makers trading the stock and stock price continuity[111], in general, higher is the spread between bid and ask prices and lower are the trading volume, the number of shareholders, active market makers and price continuity.

Moreover, Amihud, Y., & Mendelson, H. (1986) demonstrate the importance of market microstructure factors as determinants of stock return showing that asset returns are an increasing and concave function of the spread. Proving also that expected returns net of trading costs increase with target holding period and consequently assets with higher bid ask spread yield higher net returns. Hence, investors with long holding periods can obtain higher returns by holding high-spreads assets[112].

Financial researchers and practitioners are really interested in market microstructure factors such as transaction and liquidity costs because such factors influence the investments net gain and are clearly important in portfolio management decisions.

This reasons can largely explain the substantial interest in market microstructure models of the bid ask spread. Several statistical models empirically measure the components of the bid ask spread; in certain kind of models bid ask spread inference is made from covariance of observed transaction prices[113]. While, in others, spread inference is made through a trade indicator regression model[114].

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[110] Demsetz, H. (1968). The cost of transacting. *The quarterly journal of economics*, *82*(1), 33-53. Demsetz first related the spread to the cost of transacting but see also Ho, T., & Stoll, H. R. (1981). Optimal dealer pricing under transactions and return uncertainty. *Journal of Financial economics*, *9*(1), 47-73.

[111] Garbade, K. D. (1982). *Securities markets*. McGraw-Hill College and
Stoll, H. R. (1985). Alternative views of market making. *Market Making and the Changing Structure of the Securities Industry*, *67*, 67-68.

[112] Amihud, Y., & Mendelson, H. (1986). Asset pricing and the bid-ask spread. *Journal of financial Economics*, *17*(2), 223-249.

[113] See: Roll, R. (1984). A simple implicit measure of the effective bid-ask spread in an efficient market. *The Journal of Finance*, *39*(4), 1127-1139; Choi, J. Y., Salandro, D., & Shastri, K. (1988). On the estimation of bid-ask spreads: Theory and evidence. *Journal of Financial and Quantitative Analysis*, *23*(02), 219-230;
George, T. J., Kaul, G., & Nimalendran, M. (1991). Estimation of the bid–ask spread and its components: A new approach. *Review of Financial Studies*, *4*(4), 623-656;
Stoll, H. R. (1989). Inferring the components of the bid-ask spread: theory and empirical tests. *The Journal of Finance*, *44*(1), 115-134.

[114] See: Glosten, L. R., & Harris, L. E. (1988). Estimating the components of the bid/ask spread. *Journal of financial Economics*, *21*(1), 123-142;

In particular, Stoll (1992), suggested that transaction and liquidity costs (bid ask spread analysis) should be based on the investigation of MM activity and on costs it incurs[115].

The bid ask spread must, in fact, cover the order processing costs incurred by the providers of market liquidity (e.g. market makers) and all other costs. Thus, researchers have focused on additional costs that should be reflected in the spread;

Amihud and Mendelson (1980)[116], Demsetz (1968)[117] and Ho and Stoll (1981-1983)[118] concentrates on the inventory holding costs, while Easley and O'Hara (1987)[119], Copeland and Galai (1983)[120] and Glosten and Milgrom (1985)[121] focuses on adverse selection costs incurring when some traders are informed.

Most of the existing research at that time does not provide a model that reflects the above costs components simultaneously, finally, in late 1997, Huang and Stoll provides a model with a three way decomposition of the spread into order processing, inventory and adverse selections components[122]

4.2 Fundamental literature

The difference between the ask and the bid quotes and market making activity has long been of interest to regulators, traders and researchers. The researches belonging to this topic focuses on different market structure analyzing the differences with regard to;

- Transaction costs;
- Liquidity costs.

Huang, R. D., & Stoll, H. R. (1994). Market microstructure and stock return predictions. *Review of financial studies*, *7*(1), 179-213.

[115] Stoll, H. R. (1992). Principles of trading market structure. *Journal of financial services research*, *6*(1), 75-106.

[116] Amihud, Y., & Mendelson, H. (1980). Dealership market: Market-making with inventory. *Journal of Financial Economics*, *8*(1), 31-53.

[117] Demsetz, H. (1968). The cost of transacting. *The quarterly journal of economics*, *82*(1), 33-53.

[118] Ho, T. S., & Stoll, H. R. (1983). The dynamics of dealer markets under competition. *The Journal of finance*, *38*(4), 1053-1074.
Ho, T., & Stoll, H. R. (1981). Optimal dealer pricing under transactions and return uncertainty. *Journal of Financial economics*, *9*(1),.

[119] Easley, D., & O'hara, M. (1987). Price, trade size, and information in securities markets. *Journal of Financial economics*, *19*(1), 69-90.

[120] Copeland, T. E., & Galai, D. (1983). Information effects on the bid-ask spread. *the Journal of Finance*, *38*(5), 1457-1469.

[121] Glosten, L. R., & Milgrom, P. R. (1985). Bid, ask and transaction prices in a specialist market with heterogeneously informed traders. *Journal of financial economics*, *14*(1), 71-100.

[122] Huang, R. D., & Stoll, H. R. (1997). The components of the bid-ask spread: A general approach. *Review of Financial Studies*, *10*(4), 995-1034.

The former are all the expenses incurred when buying or selling an asset required for the transfer of ownership (e.g. broker commissions and spread). Transaction costs are themselves linked to liquidity costs, that are expenses directly linked to the risk that for a certain period of time a given financial asset cannot be traded quickly in the market.
The role of the market maker is to provide liquidity by trading when equal (in volume) and opposite (in sign; buy or sell) orders fail to arrive simultaneously in the market.
In order to perform its main function, it have to quote continuously bid and ask orders, standing ready to trade with anyone who comes in the market.
In particular, Bagehot (1971)[123] suggested that the market maker can trade with three different kind of "transactors":

- Informed traders;
- Liquidity traders;
- Traders not trusting the market.

The informed traders are people possessing special information (e.g. insider traders), they will usually buy when the target asset fair price is greater than the ask quote and sell when it is lower than the bid quote. The market maker will always suffer a loss in trading with Informed traders [It is evident that transactors with special information are playing a "heads I win, tails you lose" game with the market maker – Bageoth (1971)].
Liquidity traders are characterized by the need of trade immediately (they only need to convert securities into cash or cash into securities) and are prepared to handle a cost for trading immediacy provided by the market maker. The latter will always gain from his transactions with liquidity motivated traders.
Finally, traders not trusting the market are convinced that asset's prices are not considering some public information and represent a good investment opportunity. But, in semi-strong form efficiency, the current price reflects the information contained in all past prices (weak form efficiency) and all public information; hence, using public

123

information is not useful in finding undervalued assets. The market maker will always gain also in transacting with this type of traders.
In order to survive, market makers' gains from liquidity motivated traders and traders not trusting the market must exceed his losses with informed traders.
As outlined in the preceding paragraph, the market making as a liquidity provider incurs in three different kind of costs:

- Order processing costs
- Inventory costs
- Adverse selection costs

The former are the expenses of processing orders, these can be fixed or floating and are related to all kind of costs the market maker incurs such as communication system, software and hardware, servers, co-location services etc. This type of cost is less important because can be minimized through economies of scale and network externalities.
Inventory costs are all the expenses due to the MM activity that forces the market maker to carry a different portfolio composition from the optimal one. Spread capturing strategy usually has an optimal position equal to zero, hence the market maker is willing to buy or sell any financial security if and only if the counterparty is prepared to give a discount or a premium, respectively.
Finally, adverse selection costs are expenses linked to the possibility that the market maker generate losses transacting with informed traders (previously described) that have a special information set.
Given these distinctions, researchers have defined two different approaches: on one hand the inventory-based approach[124] suggest that market making activity should base on cost of carrying inventories minimization (or, in other words, the decisive point is the dependence of the bid ask spread on market marker's stock inventory position). On the

[124] Amihud and Mendelson (1980), Demsetz (1968) and Ho and Stoll (1981-1983) focuses on the inventory holding costs.

other hand, the information-based approach[125] focuses on adverse selection costs and different information sets between market maker and informed traders.

Stoll (1981)[126] suggested that under the inventory-based approach, bid ask spread driving factors can be analyzed from two different environments:

1. Single dealer environment[127]; In this context, the market is entirely dominated by a centralized market maker that has a monopoly on all transactions. It just has to quote bid and ask prices in order to maximize the profit by handling an important trade-off; usually on one hand, widening the spread can limit inventory costs, on the other hand, spread tightening can increase the number of transactions. The market maker has to find an equilibrium point between inventory costs minimization and number of executed transactions maximization. In this framework, buy and sell coming orders (stochastic demand and supply) are random variables that follows independent Poisson[128] distributions, introducing a gross and net limit position on inventories. The market maker maximizes his profit by maintaining a preferred inventory position (usually a flat position) and when his realized inventories deviates from it, he will adjust the spread (bid and ask quotes) to restore the optimal (preferred) position. So bid and ask prices set by the market maker are function of his inventory. In particular, Amihud and Mendelson (1980) showed that these are monotonically decreasing function of the inventory

[125] Easley and O'Hara (1987), Copeland and Galai (1983) and Glosten and Milgrom (1985) focuses on adverse selection costs incurring when some traders are informed.

[126] Ho, T., & Stoll, H. R. (1981). Optimal dealer pricing under transactions and return uncertainty. *Journal of Financial economics*, *9*(1), 47-73.

[127] In a pioneering study Garman proposed a rigorous stochastic model of the dealership market; an environment entirely dominated by a centralized market maker, who possesses a monopoly. His bid-ask quotes affect the stochastic mechanism which generate market sell and buy order, introducing a stochastic analogue of the classic supply and demand functions. The total activity in the market can be considered as a stochastic flow of market sell and buy orders depending on price. So, the discrepancy between market buy and sell orders and the continuous trading obligation, forces the market maker to carry positive (long position) or negative (short position) stock inventories. Garman studied the implication of carrying long or short position in inventories and suggested that "the specialist" must relate bid and ask quotes to its inventories position.
Garman, M. B. (1976). Market microstructure. *Journal of financial Economics*, *3*(3), 257-275.

[128] A Poisson distribution is a discrete probability distribution that expresses the probability of a given number of events occurring in a fixed interval of time.

position. Suppose the market maker think that a given security's fair price is X and by defining X_{bid} the bid quote (price at which he is willing to buy) and X_{ask} the ask quote (price at which he is willing to sell) with $X_{bid} < X < X_{ask}$ – if the market maker has a long (short) position on that asset, his portfolio value is exposed to downward (upward) price movements. Naturally follows that he should sell (buy) an amount equal $\max(0, |position|)$, so he will reduce X_{ask} and reduce sensibly X_{bid} (he will increase X_{bid} and increase sensibly X_{ask}).

2. Multi-dealer environment; Amihud and Mendelson (1983)[129]. suggested that in a multi-dealer context, the market maker understand that his profit depends on other specialists' behavior. The only difference with the previous setting is that the bid-ask spread depends also on asset's correlation.

Moving to the information-based approach, Coopeland and Galai (1983)[130] defines the market maker as a specialist that is assumed to set a bid ask spread in order to maximize the difference between expected revenues deriving from liquidity traders and expected losses derived from informed traders. They also analyze the bid ask spread structure using option theory and arguing that a limit order might be seen as an option. In particular, the bid ask spread can be considered as a straddle[131]. The market maker gives a call option to buy at the asking price and also a put option to sell at the bid price. The options are issued out of the money because the fair price lays between the bid quote and the ask one. Other market participant can exercise these out of the money options for two main reason; on one hand, liquidity traders are willing to suffer a certain loss because they are willing to pay for immediacy. On the other hand, the informed traders will trade for a gain by using special information.

[129] Amihud, Y., & Mendelson, H. (1983). Price smoothing and inventory. *The Review of Economic Studies*, *50*(1), 87-98.
[130] Copeland, T. E., & Galai, D. (1983). Information effects on the bid-ask spread. *the Journal of Finance*, *38*(5), 1457-1469.
[131] An american call option can be defined as the right to buy underlying asset at a predetermined price (the exercise price) during a certain period of time. The american put option is the right to sell the underlying asseta t a predetermine price during a certain time period. A straddle is a combination of a call and a put option on the same underlying asset.

4.3 A theoretical market making strategy

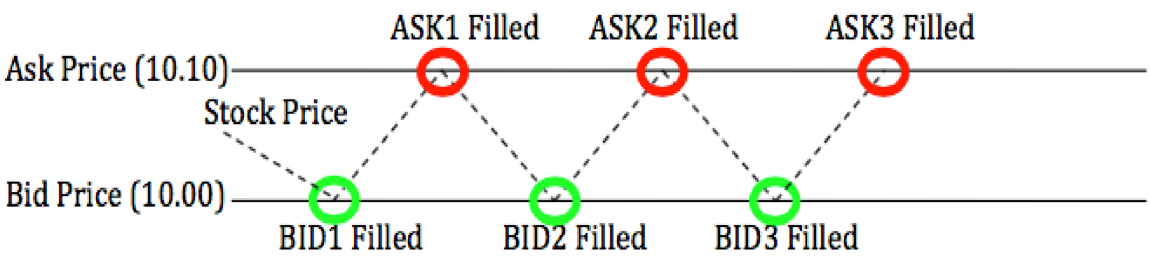
Market making strategies have played a really important role in the electronic stock market and with the development of algorithmic trading, the job of “making a market” for a stock is progressively transitioned to automated computer programs.

In this paragraph will be presented a theoretical event-driven strategy based on a mapping from the strategy current state to the strategy in the next step.

As explained in the previous paragraph, market makers fulfilling his tasks usually incur in two different kind of risk. The first one is the possibility to trade with informed traders possessing special information that will buy when the target asset fair price is greater than the ask quote and sell when it is lower than the bid quote. Since the market maker does not have a perfect and complete information set, this kind of risk became significant for very illiquid stocks, in that case a good strategy has to recognize the different kind of traders and set wider bid ask spreads in order to not incur in losses.

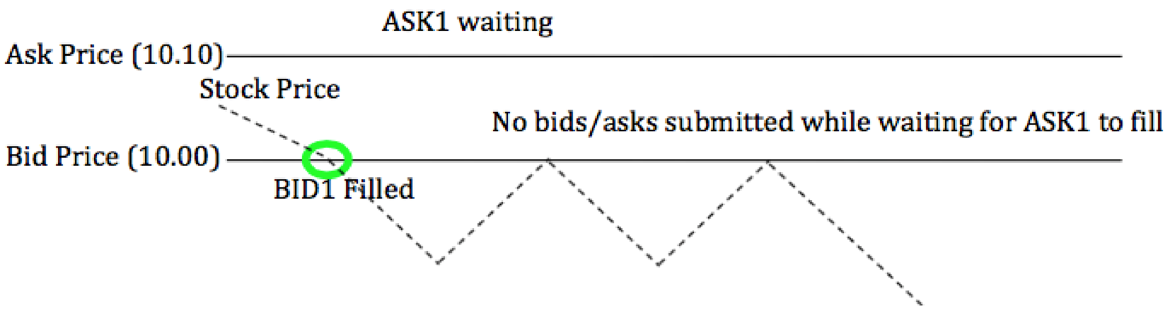
The second risk is the inventory one; more specifically, in a situation in which stock prices are bouncing or when there are small changes in prices in both directions, other traders’ orders should frequently hit market maker’s orders, which capture the bid ask spread and make profits. In order to give an example, a simple market making strategy in the case in which the market stay in a small trading range is to submit a couple of a bid and ask orders and waiting for the two orders to be filled in a reasonable waiting-time. This could be reasonable in a bouncing prices environment.

Figure 17 - Market Making strategy



The market maker submits three different couples of paired orders of equal size; once the first couple (BID1 and ASK1) is submitted, when the stock price trades down BID1 level (or up to ASK1 level), BID1 (ASK1) order is partially or completely filled. Once one order of the couple is filled, the market maker has an inventory of shares sensitive to price movements and is waiting for the order ASK1 (BID1) to be filled (notice that the risk became the waiting-time for the other coupled order to be filled). Then, If the prices trade up to ASK1 level (BID1 level) the market maker receive a partial or complete fill and can extinguish his inventory position and risk. In the case that the coupled orders fill for the same amount the market maker captured a 10 cent spread, have a flat position and can submit a new pair of coupled orders. While, in a situation in which the price is trending up or down, the market maker accumulates risky inventory that are sensitive to price movements and in the worst case could generate losses to the strategy.

Figure 18 - Market Making strategy



When the market stock price doesn't stay in the trading range (i.e. the market is trending down or up), only one of the coupled orders is filled and the waiting time for the other paired order to fill is potentially higher than in the previous case failing to capture the bid ask spread. In the example provided in the above picture, once BID1 order is filled, if the price continues its down-trend, the market maker has an inventory long position equal to the order volume.

When market is trending a MM strategy with no pre-trending action will accumulate inventory which can generate loss to the strategy, so it is really important to provide the strategy with forecasting signals and event driven signals caused by information's spread in the market.

Several MM strategies based on the mapping from the strategy current state to the strategy in the next step have been proposed[132] in the past, the main difference is that the proposed strategy will not make any particular assumption on whom the market maker is trading with; the strategy don't consider the first risk previously described in this paragraph (i.e. information asymmetry with informed traders), it does not differentiate between informed or liquidity traders.

Considering that it is virtually impossible to recognize in a fast and clear way different type of traders there is no possibility to differentiate between them, hence a MM strategy should be primarily based on the second risk previously described (i.e. inventory risk).

In order to minimize carrying inventory risk with trends its main feature is to provide trading signals from different information source in order to guide the market making strategy that places orders depending on its own trading logic.

Hence, intuitively, the proposed market making process is built up on two different components;

- Signal generator;
- Trading strategy.

4.3.1 Signal generator

The signal generator is built on three different information source; order book information, order book flow and news information.

For simplicity the first two sources can be grouped as order book signals (OBS) while the last one can be defined as a news signal (NS).

[132] Othman, A., & Sandholm, T. (2011, December). Liquidity-sensitive automated market makers via homogeneous risk measures. In *International Workshop on Internet and Network Economics* (pp. 314-325). Springer Berlin Heidelberg.
Othman, A., & Sandholm, T. (2010, June). Automated market-making in the large: the Gates Hillman prediction market. In Proceedings of the 11th ACM conference on Electronic commerce (pp. 367-376). ACM.
Chakraborty, T., & Kearns, M. (2011, June). Market making and mean reversion. In *Proceedings of the 12th ACM conference on Electronic commerce* (pp. 307-314). ACM.
Brahma, A., Chakraborty, M., Das, S., Lavoie, A., & Magdon-Ismail, M. (2012, June). A Bayesian market maker. In Proceedings of the 13th ACM Conference on Electronic Commerce (pp. 215-232). ACM.

The signal generators should be constructed separately and then combined with the trading strategy logic, this sub-paragraph will describe both signal generator starting from book order main features and OBS, moving then to NS providing only an intuition for a text analysis model.

OBS are obtained by the analysis of the information set included in the order book.

An order book is an electronic list of buy and sell orders for a specific financial instrument, organized by price level. It lists the number of shares being bid or offered at each price level dynamically and constantly updated in real time.

Order book information such as bid and ask prices and sizes may be very useful information able to provide insights on short run market movements.

An order book is usually constructed in the following way;

$BidSize_1$	$\boldsymbol{BID_1}$	$\boldsymbol{ASK_1}$	$AskSize_1$
$BidSize_2$	$\boldsymbol{BID_2}$	$\boldsymbol{ASK_2}$	$AskSize_2$
$\vdots$	$\vdots$	$\vdots$	$\vdots$
$BidSize_n$	$\boldsymbol{BID_n}$	$\boldsymbol{ASK_n}$	$AskSize_n$

Each raw from 1 to n is denoted as a different book level.

Prices decrease from BID_1 to BID_n and increase from ASK_1 to ASK_n while external columns provide a volume information for each price level.

The price difference between BID_1 and ASK_1 is defined as the bid ask spread and can be measured by the number of tick size, that is the minimum price movement of a trading instruments (tick sizes may be different for different financial assets or can change with the asset price).

Limit orders arriving on the market are prioritized by a price and time priority in order to be included in the described book structure.

Suppose we can sample historical data at a pre-determined frequency (e.g. 30 or 60 seconds), the screenshot at all time points will form a time series, S, composed by different screenshots denoted by s_i with $0 > i > k$;

$$S = \{s_0, s_1, \dots, s_k\}$$

In a given point in time t, if the total size of orders at bid side is bigger than the total order size at ask side by a certain (pre-determined) threshold (T_1), the mid quote $\frac{BID_1+ASK_1}{2}$ is expected to increase in the short term.

While, if the total order size of ask side is bigger than the total order size at bid side by a certain threshold (T_2), the mid quote is expected to decrease in the short run.

In the case in which the difference between the total order sizes in bid and ask sides is contained within the threshold no changes in the mid quote are expected.

In order to formalize what just expressed the order book information (OBI) signal is given by;

$$OBS(k, l) = \frac{\sum_{t=0}^{k} \sum_{p=1}^{l} BidSize_{p,t}}{\sum_{t=0}^{k} \sum_{q=1}^{l} AskSize_{q,t}}$$

Where $BidSize_{p,t}$ denotes the size at buy side, $AskSize_{q,t}$ denotes the size at sell side and the arguments l and n denotes how many order book levels will the signal use to calculate the signal value and time (how many screenshots the signal will use to calculate the signal value), respectively.

This indicator is constructed in order to summarize the dynamic shape of the information contained in the order book and gives as output a signal whenever OBS exceeds the predetermined threshold:

$$If\ OBS(k,l) > T_1\ then\ \frac{BID_1 + ASK_1}{2}\ is\ expected\ to\ increase$$
$$If\ OBS(k,l) < T_2\ then\ \frac{BID_1 + ASK_1}{2}\ is\ expected\ to\ decrease$$
$$If\ T_1 < OBS(k,l) < T_2\ then\ \frac{BID_1 + ASK_1}{2}\ is\ expected\ not\ to\ change$$

According to the pre-determined frequency, at each time $OBS(k,l)$ is re-calculated and can give three different signal output that will be discussed afterwards in the trading strategy.

The second source of information that can be treated as an order book signal is the order book flow (OBF). Empirical properties of the order book like properties governing arrival and cancellation of orders can be critical in determining price dynamics. The idea is to look at orders arrival rates at different times or frequency and across different order book levels in order to provide a signal for the MM strategy.

OBF is composed by orders arrival rate (OAR), kill orders rate (KOR) and filled orders rate (FOR) that are the incoming flow (i.e. the rate at which new orders appear per unit of time in each side for each level of price) and the outgoing flows (i.e. the rate at which orders are killed and filled per unit of time in each side for each level of price), respectively. In order to formalize:

$$OBF(k,l,t) = \frac{\frac{OAR_{bid}}{KOR_{bid} + FOR_{bid}}}{\frac{OAR_{ask}}{KOR_{ask} + FOR_{ask}}}$$

Where t is the pre-determined frequency and a rough measure of incoming flows is given by:

$$Incoming\ flow_{bid} = OAR_{bid} = \frac{\sum_{t=1}^{k}\sum_{p=1}^{l} BidSize_{p,t} - \sum_{t=0}^{k-1}\sum_{p=1}^{l} BidSize_{p,t}}{t}$$

OAR_{bid} measured as number of new orders over unit of time can be interpreted as the time required for the opposite order placed by the market maker to be hit. Thus, an increase (decrease) of the order arrival rate on the bid side will determine an increase (decrease) of ask and bid quotes.

$$Incoming\ flow_{ask} = OAR_{akd} = \frac{\sum_{t=1}^{k}\sum_{p=1}^{l} AskSize_{p,t} - \sum_{t=0}^{k-1}\sum_{p=1}^{l} AskSize_{p,t}}{t}$$

Equivalently, OAR_{ask} measured as number of new orders over unit of time can be interpreted as the time required for the opposite order placed by the market maker to be hit. Thus, an increase (decrease) of the order arrival rate on the ask side will determine a decrease (increase) of ask and bid quotes.

In general, whenever there is an increase of order arrival rates the market maker will face stronger competitiveness and is forced to decrease the bid ask spread. In fact, in a perfect market with infinite liquidity the bid-ask spread approximate 0, on the other hand, when the market is becoming less and less liquid, the market maker require an increasingly spread.

In order to calculate the outgoing flow there is the need to keep track of incoming buy and sell orders for each order book level of interest. Recall that market buy and sell orders are such orders placed by investors demanding liquidity and willing to transact immediately.

If an incoming limit buy order is greater than or equal to the ASK_1 price it is considered a market buy order and if an incoming limit sell order is less than or equal to BID_1 it is classified as a market sell order.

Thus, a measure of filled orders rate for each side can be obtained simply summing market buy orders and market sell orders.

More formally:

$$FOR_{bid} = \frac{\sum_{j=1}^{n} AskSize_j}{t}$$

where $AskSize_t$ is the volume associated with the order j that meets $ASK_j \leq BID_1$.

$$FOR_{ask} = \frac{\sum_{j=1}^{n} BidSize_j}{t}$$

Where $BidSize_t$ is the volume associated with the order j that meets $BID_j \geq ASK_1$.

The process for providing a measure of Killed orders rate is much more complicated since it deals with cancellation and modification. An Intuitive approach to identify killed orders has been followed by Khanna, Smith and Zhang (2009)[133].

$$KOR_{bid} = \frac{\sum_{j=1}^{n} BidSize_j^*}{t}$$

Where $BidSize_j^*$ is the volume associated to a killed order j if it occurs in the pre-determined book level.

$$KOR_{ask} = \frac{\sum_{j=1}^{n} AskSize_j^*}{t}$$

Where $AskSize_j^*$ is the volume associated to a killed order j if it occurs in the pre-determined book level.

The most important feature of the OBF ratio is that it may show period of extremely high or low activity in each side of the book order.

The OBF ratio can be interpreted by analyzing numerator and denominator;

Once defined a certain thresholds T_3 and T_4, If $OBF(k,l,t) > T_3$ there is a critical pressure on the bid side and the mid-price will likely increase in the short term. While if $OBF(k,l,t) < T_4$ there is a significant pressure on the ask side and that the mid price will likely decrease in the short term.

Rearranging terms it is possible to express OBF as the product of two different ratios

$$OBF(k,l,t) = \frac{\overbrace{OAR_{bid}}^{(1)}}{OAR_{ask}} \; \frac{\overbrace{KOR_{ask} + FOR_{ask}}^{(2)}}{KOR_{bid} + FOR_{bid}}$$

133 Khanna, K., Smith, M., Wu, D., & Zhang, T. (2009). Reconstructing the order book. *Standford University, Standford*.

Supposing that outgoing flows rates are the same for bid and ask side, in this particular case the OBF is given only by ratio (1), that is the ratio between order arrival rates on bid and ask side; it gives information at each point in time on pressure on both order book's sides.

The last information sources are news information. The last signal (NS) is obtained from market news reported by news agencies such as Bloomberg and Reuters. Recently, with social networks spread, also important leader tweets and Facebook status should be monitored. News can be classified into three different categories;

- Period or recurring
- Unexpected
- Social networks news

The first category includes news issued at regular intervals (for example interest rate announcement by central banks, economic data releases like job reports, earnings report from companies). The "unexpected" news are one-time news that is more likely to be adverse than favorable (such as terrorist attack, earthquake or geopolitical fear).

The last category includes all the information and views that word leaders may express in their social networks account. The main aim is to analyze for each news category the statistical relationship between word patterns and market movement responses. In order to do this, it's required a text analysis model that represents each news title into specific word patterns in vector form *[word1, word2,…]* and assign to relevant word pattern *[verb, noun] or [noun, verb]* a sign *[positive, negative or neutral].* Financial and economic news may lead to strong short-term market movements creating interesting profit opportunity. In market making activity, an event driven based NS generator may provide directional predictions and avoid market trending.

4.3.2 Trading strategy

The MM strategy does full time trading quoting simultaneously on both buy and sell sides and managing inventory risk by adjusting the bid ask spread.
Similar to old fashioned market makers, the strategy starts quoting when market open and dynamically change the quotes. It places group of two paired limit orders with equal size on bid and ask side, waiting for other order to come and hit either side. Whenever market condition implies a signal change the MM strategy will adjust quotes modifying placed orders or deleting it with consequent new submission of paired orders.
Market rules such as tick size, trading hours (open time, lunch break, close time) and price patterns are all important rules that need to be considered in implementing the strategy in real markets; In the future study, the goal is try to make the strategy more practical backtesting it in a simulator with real markets tick by tick data for securities in different markets with different liquidity.
The market making strategy have to handle two main processes;

1) risks management
2) quotes management

More in details, the risk management logic (1) consist in a stop loss and in a liquidation trigger. Easley et al. (2011)[134] suggested as a key risk management measure the Volume Synchronized Probability of Informed trading (VPIN) a volume based indicator that measures order flow toxicity (specifically, it calculates trading volume distribution based on a volume-clock) showing its usefulness using the data of the flash crash (see in previous chapter). But, since the presented MM strategy doesn't care about the distinction between informed and un-informed traders, a simple stop loss seems more appropriate as risk management facility, it is a tradition risk management instrument that is usually used to get the strategy out of the market immediately in bad situations.

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[134] Easley, D., López de Prado, M. M., & O'Hara, M. (2011). The microstructure of the "flash crash": flow toxicity, liquidity crashes, and the probability of informed trading. *The Journal of Portfolio Management*, *37*(2), 118-128.

Once a threshold for stop loss is defined, if the realized and unrealized inventory's value becomes lower than the pre-defined threshold the MM strategy will stop and exit market. On the other hand, liquidation trigger is needed because the strategy is designed for intraday trading so that there is no possibility to carry any inventory into the next trading day. In other words, the liquidation trigger avoids overnight risk by closing all holding position at market close, no matter whether the position is losing or making money.
With regard to quotes management (2) the strategy can be considered as a mapping from the strategy current state to the strategy in the next step.

$$f(\Lambda_t, P_t) \longrightarrow \Lambda_{t+1}$$

where Λ_t is the strategy current state, P_t correspond to the pricing formula that takes into account order book and news signals (OBS, OBF and NS) obtained from price time series and news information and Λ_{t+1} is the strategy at next step.

The strategy state at time t is composed by a couples of paired orders with equal size placed at a certain bid and ask price;

$$\Lambda_t = (p_t^{bid}, p_t^{ask})$$

The strategy current state may be modified by the signals that are evaluated at a pre-determined frequency bringing the strategy into the next step;

$$\Lambda_{t+1} = (p_{t+1}^{bid}, p_{t+1}^{ask})$$

The pricing formula (P_t) main aim si to combine in a practical way the signals that are constructed separately.

$$\Lambda_{t+1} = \Lambda_t + [Signal_{OBS} \cdot \alpha + Signal_{OBF} \cdot \beta + Signal_{NS} \cdot \gamma] \cdot Ticksize$$

Each indicator (OBS, OBF and NS) can give a positive, negative or neutral signal.

If the signal is positive (meaning that the mid price is expected to increase in the short term) the strategy will place a more aggressive bid quote (it will increase p_{t+1}^{bid}) and a more passive ask quote (it will increase p_{t+1}^{ask}). In the case that the signal is negative (meaning that the mid price is expected to decrease in the short term) the strategy will place a less aggressive bid quote (decreasing p_{t+1}^{bid}) and a more aggressive ask quote (decreasing p_{t+1}^{ask}).

While if the signal is neutral the strategy will not modify the state $\Lambda_t = (p_t^{bid}, p_t^{ask})$.

α, β and γ are scalars that determines the number of ticks the pricing formula is going to increase/decrease the bid and ask prices whenever the OBS, OBF and NS signals change. The value of α, β and γ may be different for different securities and should be determined using historical data.

As long the fine tuning is more accurate, the strategy could place orders in the right position and avoid risks.

Chapter 5

A MARKET MAKING ALGORITHM FOR THE RIT CLIENT

This chapter will introduce the main features of the RIT Market Simulator Application; an order-driven market simulator that allows students to trade financial securities with each other in real time. The proprietary software developed by the Rotman School of Management provide students with an “experimental learning” approach in order to apply main financial theories in an uncertain simulated market environment.

All RIT cases are designed to focus on specific financial theories and present them in an easy to understand way so that students can explore different strategies and learn how to make good decision when faced with uncertainty about outcomes. This reflects the FRTL main mission to integrate theory and practice.

Figuring out RIT software’s main features can be useful in order to better understand this final chapter of this work that will present a market making algorithm for the Rotman Interactive Trader Client.

5.1 Rotman Interactive Trader Market Simulator Application

The Rotman Interactive Trader (RIT) is a market-simulator developed by the Rotman School of Management that provides students with a practical approach to learning finance.

It allows student to make fast decisions under uncertainty in a controlled environment where they can immediately observe the outcomes of their decisions process.

The possibility to directly analyze the consequences of their decisions in very different situations enable students to learn how to make good decision when the future is uncertain, just the way traders and other professionals are used to do.

The software is widely spreading in US, Canada, Asia and Europe thanks also to the Rotman International Trading Competition (RITC) hosted by Rotman School of

Management, University of Toronto, that is an annual event that brings team of students from universities worldwide to participate in an extremely competitive trading challenge.
The competition has grown over the years in terms of international exposure. This Year, RITC hosted 52 teams from 52 different universities[135] and has been an extraordinary experience for students with a valuable opportunity to meet future finance professionals from across the globe.
Another important event that promoted the RIT Client's spread in Europe is the Rotman European Trading Competition (RETC) built with the cooperation between LUISS Guido Carli University of Rome and the Rotman School of Management at the University of Toronto and hosted by the former in 2012 and 2016.
During the competition students execute trades on the RIT Client after days of training, excel modelling and intensive studying of the case package.
All the cases are designed to teach students about different trading strategies and asset pricing employed in the real market; the simulations are used to build an uncertain and dynamic world in which students never really know what to expect, and is up to them to think about a trading strategy that consider different possibilities and generate profits under "all-weather" condition.
The primary goal of the RITC and RETC competitions is to give students the opportunity to apply their classroom knowledge to simulated markets; that is the main and unique feature of the RIT Client. It gives the possibility to deep-learn what professor has just explained behind the chair by practicing, experimenting and testing strategies learned during the lessons.
The RIT client can be considered as a good alternative to traditional teaching instruments like problem sets or case studies, with the difference that it allows students to face real (simulated) issues similar to what they will find at work; the problems faced by students are no defined in a clear way (as usually happen in a problem set or in a case study) and they have to find their own way to generate profits by excel modelling in the simplest way, applying alternative strategies and thinking from different point of views.

[135] The list of all the teams that attended RITC 2017 and previous year competitions can be found on RITC website: http://ritc.rotman.utoronto.ca/information1.asp?n=2

The Rotman Interactive Trader Client and the Financial Research and Trading Lab (FRTL) of the Rotman School of Management encourage this kind of "experimental learning", that can be defined as the process of learning trough experience or "learning trough reflection on doing"[136].

It represents a completely different and active way of learning with respect to the classical and passive one, it gives the possibility to go deeper into theoretical models applying them by understanding assumptions and encourage innovation because students have to find several ways to fit the models to the simulated market conditions.

The teaching method provided by the RIT Client gives an invaluable experience from an experimental point of view that is also well liked by employers and can generate motivation to lifelong learning.

5.2 Structure and main features

One of the unique features of the RIT Market Simulator Application is that students can remotely connect from home or from university and practice whenever they want because RIT application allows simulation to run 24 hours a day, every day. The set-up is really easy and only requires a computer running the RIT server case file and access to that computer via a port trough any firewalls[137].

This is possible because the RIT application is based on a client/server model:

The server component provides the possibility for the instructor to choose and load the simulation case, modify the case parameters (for example instructors are able to increase or decrease the asset's liquidity), exercise full control on variables governing the market, monitor student's decision in real time and send result and performance reports at the end of the case simulation. Professors can handle all these functions by running the RIT Server Application.

[136] Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*. FT press.

[137] More detailed information on set up and RIT client download can be found here: http://rit.rotman.utoronto.ca/software.asp.

Students instead, have to use the information in the relevant case brief (in which are contained theoretical models) and build an excel based model in order to help them and guide their decisions. Once they are deep in the case brief they will run the RIT Client Application in order to connect directly to the RIT Server and participate in the simulated market. They will only have to open the “RIT Client” by double clicking on the “RIT Interactive Trader 2.0 Client” icon and connect to the server by using IP address and the port of interest (there may be different cases running on different ports on the same server).

Most of the RIT Cases have been developed with an increasing difficulty, from introductory to more complicated cases based on the strategies tested in the previous one.

For each case has been developed a case brief, that is an overview of the main features of the case to be used like a guide to understand the theory behind and build the financial model that will help the students to take trading decisions.

Once the server casefile has been loaded on the instructor’s workstation, students are able to connect to the simulated market through a network connection and once all the students are connected the instructor can run the market and start the simulation (students can practice alone by using the auto-run function, the RIT cases are in fact designed to run iteratively using multiple replications that have a range of potential scenarios, this mean that the same strategy can yield different results depending on the final realization of the scenario).

While the simulation is running the RIT Client gives to the instructor the possibility to monitor participants’ decisions, have full control of the variables governing the market, slow down or stop the simulation and monitor participants’ performance in real time in order to understand if they are implementing a correct strategy. The simulation are perfectly customizable; the RIT Server Casefile are usually programmed in excel and there is the possibility to change the variables that will affect the simulation[138].

[138] For more detail the user guide “RIT- User Guide – Server Casefile Variable Description” available on the password protected webpage explains the role of all the variables and how they will affect the market simulation.

Once the simulation is ended the instructor has the possibility to display the results using the RIT application or generate an individual P&L report and sending back to each individual workstation or also store the results including final P&L, transactions log, time and sales, etc.

In order to perform well in the simulated stochastic (uncertain) environment, the students have to understand the relevant profit opportunities, to identify and manage risks and formulate a multi-level strategy that could work in different market situations.

The cases often require to build an excel-based financial model linked to the simulated market, in order to help traders to take decision under uncertainty. The model may use the RTD (Real Time Data) links to Microsoft Excel that enables to directly connect the excel model to the RIT Client in order to export security bid and ask prices, volumes, open orders, filled orders, time, time remaining, position, etc. All variables that can change every second and are essential to be included in the model in order to get the correct information and implement the strategy.

With the support of the financial model students can connect to the RIT Client (as previously explained) and will be able to monitor the market looking at the implication of their own and other traders' decisions in real time.

Usually, they have to monitor the order book of several securities simultaneously (in order to evaluate the liquidity in the market), constantly monitor their position and realized/un-realized profits on each security, keep track of the open, filled and cancelled orders, monitoring charts illustrating volumes and prices and reading the news provided randomly during the case. This last point is really critical because reading news during trading is a time consuming task that can make you lose profits opportunity. It is fundamental to build a text analysis model inside the main financial model in order to automatically read and evaluate the relevant information on each news provided by the RIT application.

A text analysis model is a tool that can be used for accessing and manipulating digital texts, every digital sentence can be divided in combination of strings in order to extract relevant information. For examples an excel based text analysis model can be very useful because it can extract numbers provided by the news and bringing them into the main financial model. This automatic resource can save a lot of time (and profits) because traders doesn't waste time reading carefully the news and can stay focused on the book (market). Another really important feature of the RIT Client is that clearing prices are determined by the orders from market participants: both students and computerized traders.

The RIT Market Simulator application gives the opportunity to practice in different cases simulating both sell and buy-side roles. There may be cases in which students have to simulate agency trading, algorithmic trading, credit evaluation, fixed income trading, M&A, commodities trading, volatility trading using options, portfolio management, etc[139]. Each of these different cases is set in a different way: Most of the time, computerized traders (ANON traders) are usually used to add liquidity in the market and maintain reasonable market environment especially when the number of traders is very low.

ANON traders' behavior is perfectly customizable, meaning that the instructor can program computerized traders to be uniformed, in this case ANON orders' are submitted randomly according to a predetermined distribution, or, as an alternative, ANON traders' can be partially or fully informed and in this latter case they will drive the market following a pre-determined price path.

Moreover, there may be cases in which traders may have an impact on the market when they sufficient market power to cause a price impact (for example think about institutional investors roles) and cases in which liquidity risk is not an issue, students act as price takers (in this case the ANON traders are used to generate sufficient liquidity so that markets participants' actions don't have impact on price paths).

The last important feature of RIT client is the API support that allows the use of algorithm for placing orders in the simulated market. Students are in fact asked to submit their trading decision manually to the simulated market (by clicking on the book trader or in buy/sell order entry), they have also full control over the order types and can decide between market orders and limit orders. Alternatively, the API support built into the RIT Client allow cases in which market participants has to program Excel or Matlab based

[139] Multi-marketplace (ECN) simulation are also supported allowing for trading cross-listed securities, multi-venue market making and arbitrage strategies.

algorithms to automate orders submission to the market. As we will see in the next chapter, this function is essential for implementing a market making strategy, in which trading decisions requires rapid response.

5.3 A market making algorithm for the RIT client

After describing a theoretical MM strategy based on different signal generators and RIT software main features, an automated market making algorithm built in Visual Basic for Application (VBA) is presented in this chapter after a brief description of market environment.

"Algo 2 Trading Case" developed by the Financial Research and Trading Lab (FRTL) of Rotman School of Management has been designed in order to encourage students to build a market making algorithm in a high frequency environment. Therefore, the security "ALGO" is highly liquid, with really high OAR_{bid} and OAR_{ask}. A natural consequence is that the bid ask spread will be often really small in the order of few ticks (the tick size for "ALGO" security is equal to 0.01).

Traders are encouraged to place limit orders instead of market orders by the presence of rebates for liquidity provision service and fees for placed market orders.

No information on prices are provided, a Brownian motion with no drift is assumed and the optimal inventory position for the strategy is assumed to be 0.

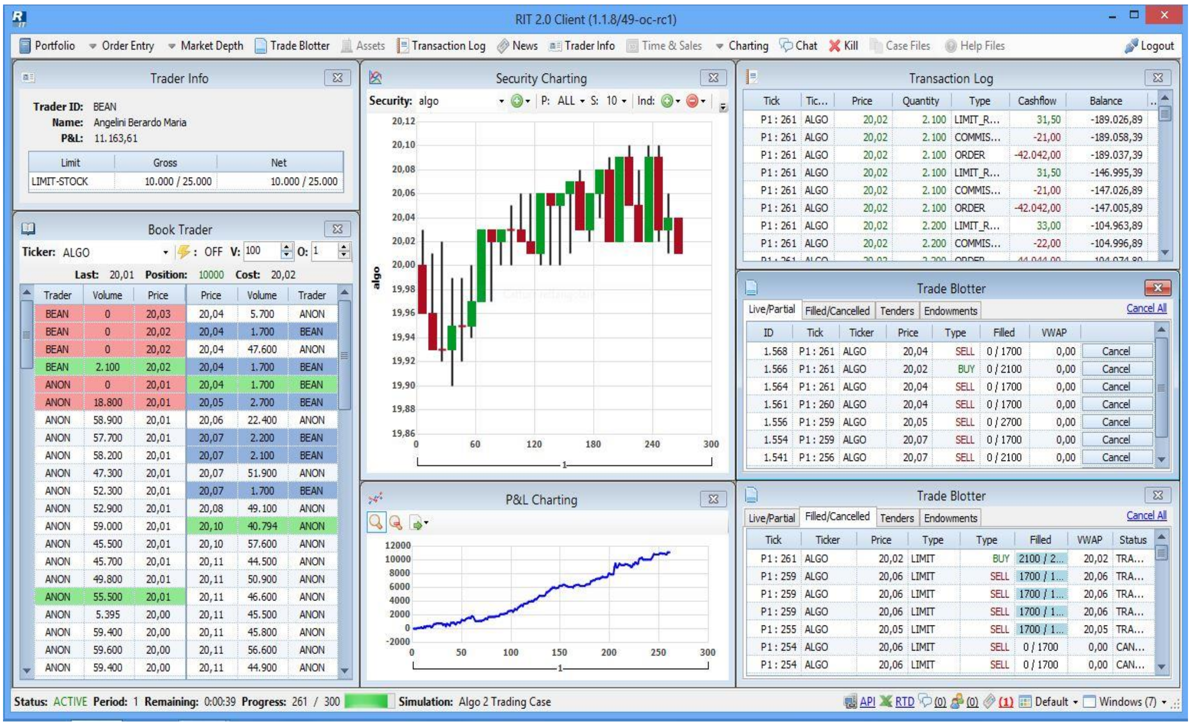
Moreover, if gross and net limits on carrying inventories are exceeded a fine will be charged on P&L, hence, each long or short position on inventories can be considered as a cost. The strategy should inevitably adjust quotes in function of its inventory position in order to not be fined for exceeding gross or net limits.

The following screenshots gives an idea of RIT client user interface;

The "Trader Info" window provide the Trader ID required for the log in and updates in real time P&L, gross limit and net limit.

The "Book Trader" collects all the order placed by ANON traders and other market makers denoted with different trader ID (notice that the number of traders is really important for parameters tuning; according to economic theory as long the number of market makers increase, the strategy should adjust the quotes for a more liquid market environment). Red book levels suggest each filled order in given point in time while the blue levels show new quotes placed.

Figure 19 - RIT Workspace screenshot



The workspace is perfectly customizable in order to meet each trader preference, for example may be useful to maintain in the middle the security and P&L charts in order to have an idea of performances with different price volatility and trends (anyway, in this case the workspace has merely an illustrative purpose since human interaction with the client is not needed).

On the right side there are the "Transaction Log" and "Trade Blotter" windows that are really important once the algorithm is programmed in order to verify the strategy. Live, filled and cancelled orders can be constantly monitored in real time.

The market making algorithm is programmed in VBA and uses Application Programming Interface (API) in order to communicate with the client.

After downloaded the client application, it is necessary to build an excel spreadsheet and copy the following code into a new VBA module in order to run the algorithm. A walk-trough video will be also provided in order to show the algorithm running.

Starting from the excel spreadsheet, the flowing screenshot gives the guide lines to follow;

Figure 20 - Excel model screenshot

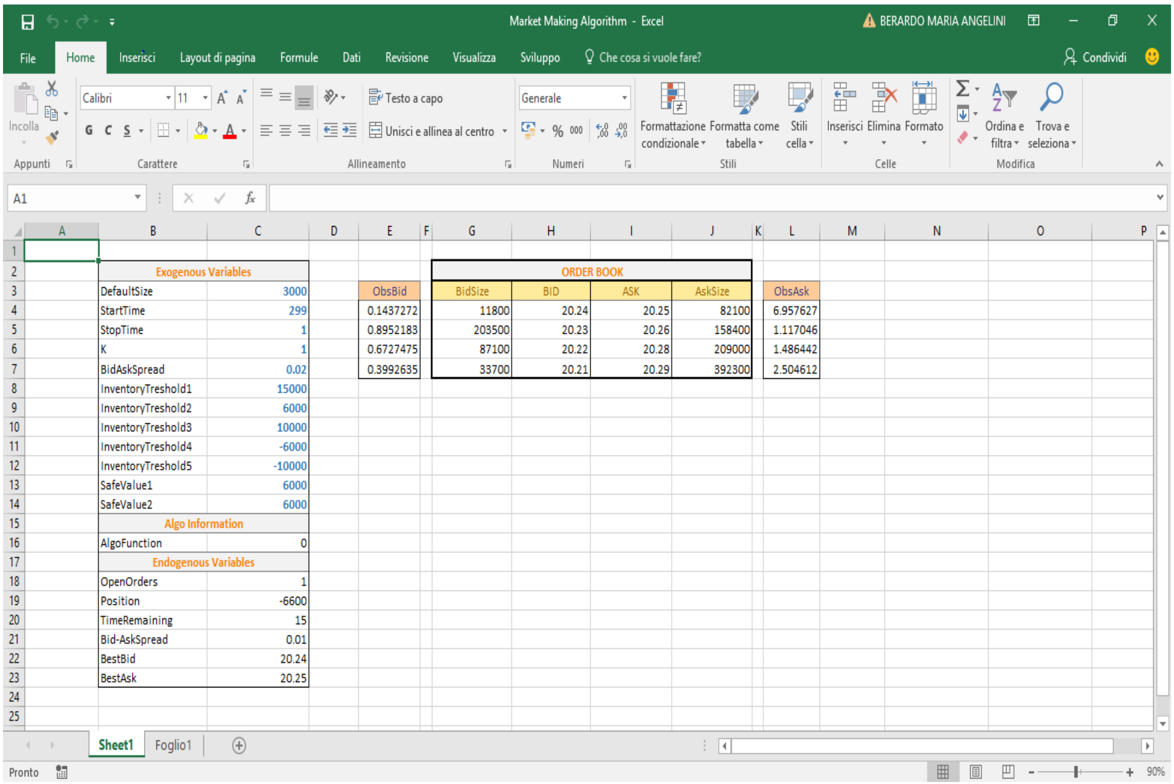


Table (B2:C23) contains exogenous variables, endogenous variables and the Algo function "MarketMaking". The variables in bold blue (exogenous variables) must be set manually in the light of individual risk profile and preferences.

Default size defines the volume for each order that will be placed by the Algorithm, it can be set between 0 and 5000 (naturally, there is also the possibility to handle paired orders with different volume by increasing the number of DefaultSize variables).

StartTime and StopTIme determines the time at which the algorithm starts and stop trading, notice that "Algo 2 Trading case" trading period is five minutes, it is reasonable to start after one second (when time remaining is 299 seconds) and stop the algorithm at the end of the period.

K is a signal threshold for the order book signal (a reasonable range of values are between 1 and 2). BidAskSpread is a really important variable that determine the trading logic, since we are in a high frequency market environment the suggested value is 0.03 (this value allows the algorithm to set paired orders with a one tick bid ask spread).

Inventory thresholds are all risk management variables that influence the algorithm behavior on the basis of carrying inventory (higher threshold implies higher risk to be fined for exceeding gross or net trading limits).

Finally, SafeValue1 and SafeValue2 are threshold needed for killing orders, higher values imply higher risk to incur in a fine. For programming simplicity each cell has been renamed, the following table illustrate each name correspondence:

Figure 21 - Name correspondence

AskSize1	=Sheet1!$J$4	ObsAsk1	=Sheet1!$L$4
AskSize2	=Sheet1!$J$5	ObsAsk2	=Sheet1!$L$5
AskSize3	=Sheet1!$J$6	ObsAsk3	=Sheet1!$L$6
AskSize4	=Sheet1!$J$7	ObsAsk4	=Sheet1!$L$7
BestAsk	=Sheet1!$I$4	ObsBid1	=Sheet1!$E$4
BestBid	=Sheet1!$H$4	ObsBid2	=Sheet1!$E$5
BidAskSpread	=Sheet1!$C$7	ObsBid3	=Sheet1!$E$6
BidSize1	=Sheet1!$G$4	ObsBid4	=Sheet1!$E$7
BidSize2	=Sheet1!$G$5	OpenLimitOrders	=Sheet1!$C$18
BidSize3	=Sheet1!$G$6	Position	=Sheet1!$C$19
BidSize4	=Sheet1!$G$7	SafeValue1	=Sheet1!$C$13
DefaultSize	=Sheet1!$C$3	SafeValue2	=Sheet1!$C$14
FourthAsk	=Sheet1!$I$7	SecondAsk	=Sheet1!$I$5
FourthBid	=Sheet1!$H$7	SecondBid	=Sheet1!$H$5
InventoryTreshold1	=Sheet1!$C$8	StartTime	=Sheet1!$C$4
InventoryTreshold2	=Sheet1!$C$9	StopTime	=Sheet1!$C$5
InventoryTreshold3	=Sheet1!$C$10	ThirdAsk	=Sheet1!$I$6
InventoryTreshold4	=Sheet1!$C$11	ThirdBid	=Sheet1!$H$6
InventoryTreshold5	=Sheet1!$C$12	TimeRemaining	=Sheet1!$C$20
K	=Sheet1!$C$6		

Cell C16 contains the MarketMaking function[140] that will be defined in the VBA code, you need to call back all the function's arguments (syntax as follow) in order to run the algorithm.

[140] Notice that the MarketMaking function will appear between the excel functions once the VBA code is entered in a new module

$$= \text{MarketMaking(TimeRemaining; StartTime StopTime; DefaultSize; BestAsk; BestBid; SecondAsk; ThirdAsk; ThirdBid; FourthAsk; FourthBid; ObsAsk1; ObsAsk2; ObsAsk3; ObsAsk4; ObsBid1; ObsBid2; ObsBid3; ObsBid4; BidAskSpread; k; Position; OpenLimitOrders; BidSize1; BidSize2; BidSize3; BidSize4; AskSize1; AskSize2; AskSize3; AskSize4; InventoryTreshold1; InventoryTreshold2; InventoryTreshold3; InventoryTreshold4; InventoryTreshold5; SafeValue1; SafeValue2).}$$

Endogenous variables and the constructed order book are obtained in real time from the client. The RTD function in excel[141] is able to retrieve real time data from the RIT client. In general, the syntax for any RTD command is;

$$= RTD(\text{progID, server, [Field1],[Field2], ...})$$ [142]

In particular, our endogenous variables are obtained as follow;

$$\text{C18} = \text{RTD(rit2.rtd, ,"ALGO", "LIMITORDERS")}$$ [143]

$$\text{C19} = \text{RTD(rit2.rtd, ,"ALGO", "POSITION")}$$

$$\text{C20} = \text{RTD(rit2.rtd, ,"ALGO", "TIMEREMAINING")}$$

$$\text{G4} = \text{RTD(rit2.rtd, ,"ALGO", "AGBSZ","1")}$$ [144]

$$\text{H4} = \text{RTD(rit2.rtd, ,"ALGO", "AGBID","1")}$$

$$\text{I4} = \text{RTD(rit2.rtd, ,"ALGO", "AGASK","1")}$$

$$\text{J4} = \text{RTD(rit2.rtd, ,"ALGO", "AGASZ","1")}$$

Finally, order book signals are obtained as explained in chapter 6. Notice that since we are dealing with a high frequency environment with no planned news information, the only signal we are interested in is the OBS with $\alpha = 1$.

---

[141] "DATITEMPOREALE" in the Italian excel version

[142] Since RIT client is likely being run locally, this argument is left blank.

[143] For the Italian version the syntax is $\text{C18} = \text{DATITEMPOREALE(rit2.rtd; ; "ALGO"; "LIMITORDERS")}$

[144] Last argument indicates the level of the book, simply change the last argument for obtaining other book level aggregate information.

Once the excel spreadsheet is ready, is enough to enter the following VBA code in a new module and open the RIT Client in order to run the algorithm.

Comments are expressed inside the code in green.

```
'The following raws only serve to create a variable able to stop automated excel computing for some defined milliseconds
Option Explicit
Declare PtrSafe Sub Sleep Lib "kernel32.dll" (ByVal dwMilliseconds As Long)
'Function MarketMaking and its component definition
Function MarketMaking(TimeRemaining, StartTime, StopTime, DefaultSize, BestAsk, BestBid, SecondAsk, SecondBid, ThirdAsk, ThirdBid, FourthAsk, FourthBid, ObsAsk1, ObsAsk2, ObsAsk3, ObsAsk4, ObsBid1, ObsBid2, ObsBid3, ObsBid4, BidAskSpread, K, Position, OpenLimitOrders, BidSize1, BidSize2, BidSize3, BidSize4, AskSize1, AskSize2, AskSize3, AskSize4, InventoryTreshold1, InventoryTreshold2, InventoryTreshold4,
InventoryTrehold5)
'API command needed for activating the software API
Dim API As RIT2.API
Set API = New RIT2.API
Dim status As Variant
'The algorithm will run only between the values defined in StartTime and StopTime cells
If TimeRemaining < StartTime And TimeRemaining > StopTime Then
    'Algorithm main logic component, it will check if the bid ask spread is greater than or equal to the value set in the cell BidAskSpread
    If BestAsk - BestBid >= BidAskSpread Then
        'The algorithm is checking if the inventory position is less than the predefined threshold in cell InventoryTreshold1
        If Abs(Position) < InventoryTreshold1 Then
            if the previous conditions are both satisfied the algorithm will place two paired order; a sell limit order with volume equal to
```

```
                DefaultSize value and price equal to BestAsk – 0.01 and a Buy limit
                order with volume equal to DefaulSize value and price equal to
                BestBid + 0.01
                status = API.AddOrder("ALGO", DefaultSize, BestAsk - 0.01, -1, 1
                status = API.AddOrder("ALGO", DefaultSize, BestBid + 0.01, 1, 1)
        ‘The end if closes the just above condition
        End If
‘if instead the main logic component is not verified
ElseIf BestAsk - BestBid < BidAskSpread Then
        ‘The algorithm then is checking if the inventory position is less than the
        predefined threshold in cell InventoryTreshold2
        If Position < InventoryTreshold2 Then
                ‘if previous condition are both verified it will check for OBS2 to be
                less than the value defined in the K cell and for OBS3 to be grater
                then the value set in cell K
                If ObsBid2 < K And ObsBid3 > K Then
                ‘if the above condition is verified the algorithm will place a buy
                limit order with volume equal to default size value and price equal
                to ThirdBid + 0.01
                status = API.AddOrder("ALGO", DefaultSize, ThirdBid + 0.01, 1, 1)
                ‘it will now check for the couple OBS1 and OBS2 to be less and
                grater then K, respectively
                ElseIf ObsBid1 < K And ObsBid2 > K Then
                ‘And will place a buy limit order with volume equal to DefaultSize
                and price equal to SecondBid + 0.01
                status = API.AddOrder("ALGO", DefaultSize, SecondBid + 0.01, 1, 1)
                ‘Finally it will check if OBS1 is greater than K
                ElseIf ObsBid1 > K Then
                ‘And if the condition is verified, it will place a buy limit order with
                volume equal to DefaultSize and price equal to BestBid
```

```
        status = API.AddOrder("ALGO", DefaultSize, BestBid, 1, 1)
        'The end if closes the previous if condition
        End If
'The algorithm have now to handle inventory risk in order to avoid fines
ElseIf Position > InventoryTreshold2 And ObsAsk1 > K Then
'If the above condition is verified it will place a sell limit order in
order to reduce carrying inventories
status = API.AddOrder("ALGO", DefaultSize, BestAsk - 0.01, -1, 1)
'A step forward inventory management condition is provided
ElseIf Position > InventoryTreshold3 And ObsAsk1 > K Then
        'If it is verified the algorithm will place a sell limit order to further
        reduce carrying inventories
        status = API.AddOrder("ALGO", DefaultSize, BestAsk - 0.01, -1, 1)
'The end if close the condition
End If
'For symmetry, the algorithm will now check if the inventory position is
less than the predefined threshold in cell InventoryTreshold4
If Position > InventoryTreshold4 Then
        it will check on ask side, for OBS2 and OBS3 to be less and greater
        than K, respectively.
        If ObsAsk2 < K And ObsAsk3 > K Then
        'if the above condition is verified the algorithm will place a sell
        limit order with volume equal to default size value and price equal
        ThirdAsk - 0.01
        status = API.AddOrder("ALGO", DefaultSize, ThirdAsk - 0.01, -1, 1)
        'it will now check for the couple OBS1 and OBS2 to be less and
        grater then K, respectively
        ElseIf ObsAsk1 < K And ObsAsk2 > K Then
```

```
            'if the above condition is verified the algorithm will place a sell
            limit order with volume equal to default size value and price equal
            to SecondAsk - 0.01
            status = API.AddOrder("ALGO", DefaultSize, SecondAsk - 0.01, -1, 1)
            'Finally it will check if OBS1 is greater than K
            ElseIf ObsAsk1 > K Then
            'And if the condition is verified, it will place a sell limit order with
            volume equal to DefaultSize and price equal to BestAsk
            status = API.AddOrder("ALGO", DefaultSize, BestAsk, -1, 1)
            'It close the condition
            End If
        'The algorithm have now to handle inventory risk in order to avoid fines
        ElseIf Position < InventoryTreshold4 And ObsBid1 > K Then
            'If the above condition is verified it will place a buy limit order in
            order to reduce carrying inventories
            status = API.AddOrder("ALGO", DefaultSize, BestBid + 0.01, 1, 1)
        'A step forward inventory management condition is provided
        ElseIf Position < InventoryTreshold5 And ObsBid1 > K  Then
            'If it is verified the algorithm will place a sell limit order to further
            reduce carrying inventories
            status = API.AddOrder("ALGO", DefaultSize, BestBid + 0.01, 1, 1)
        'It close the condition
        End If
    'It close the main logic if condition
    End If
        'The following lines main aim is to avoid fines for exceeding trading limits
        by killing orders in dangerous book order situation
        If Abs(Position) > SafeValue1 And OpenLimitOrders > 12 Then
            API.CancelOrderExpr ("ticker = 'ALGO'")
        ElseIf Abs(Position) < SafeValue2 And OpenLimitOrders > 24 Then
```

```
            API.CancelOrderExpr ("ticker = 'ALGO'")
        End If
'It closes the starting if condition
End If
'it ends the function
End Function
```

Once entered the above code in a new VBA module, the MarketMaking function will appear between excel functions and once it is entered in cell C16 as previously explained, the algorithm is ready to start trading.

An illustrative video of the algorithm working can be found at the following link and RIT performance report for that particular case is then presented below.

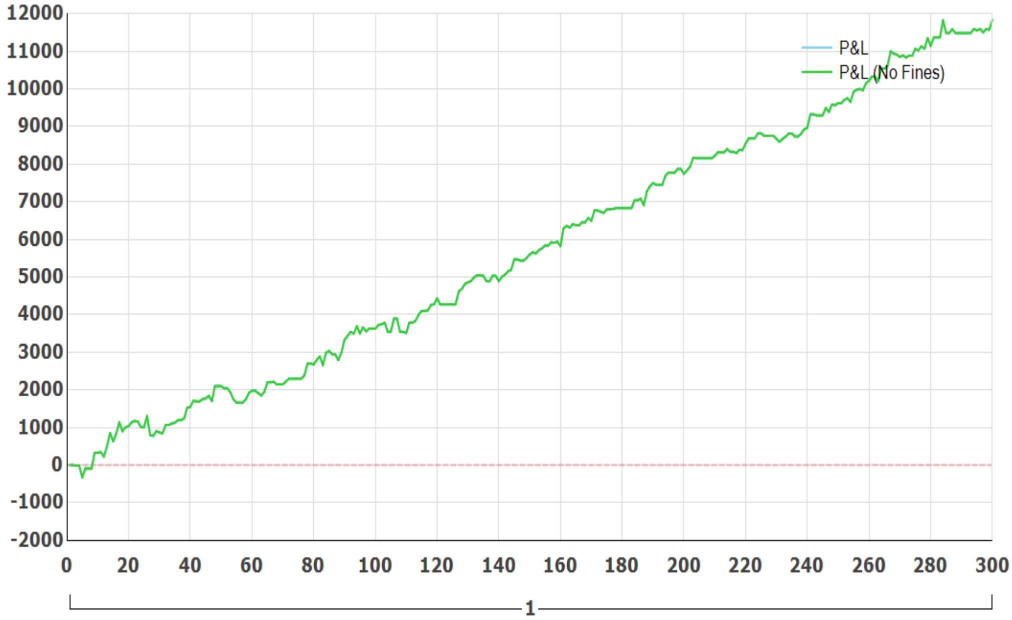
https://www.youtube.com/watch?v=4UG_MYF8Xv4

In the random case faced by the algorithm In the video, it made 527 trades with a buy Volume Weighted Average Price (VWAP) of 19.9989 and a sell VWAP of 20.0125, generating fine for 11353.00 and rebates for 15409.50. The strategy final profit & loss is 11835.5.

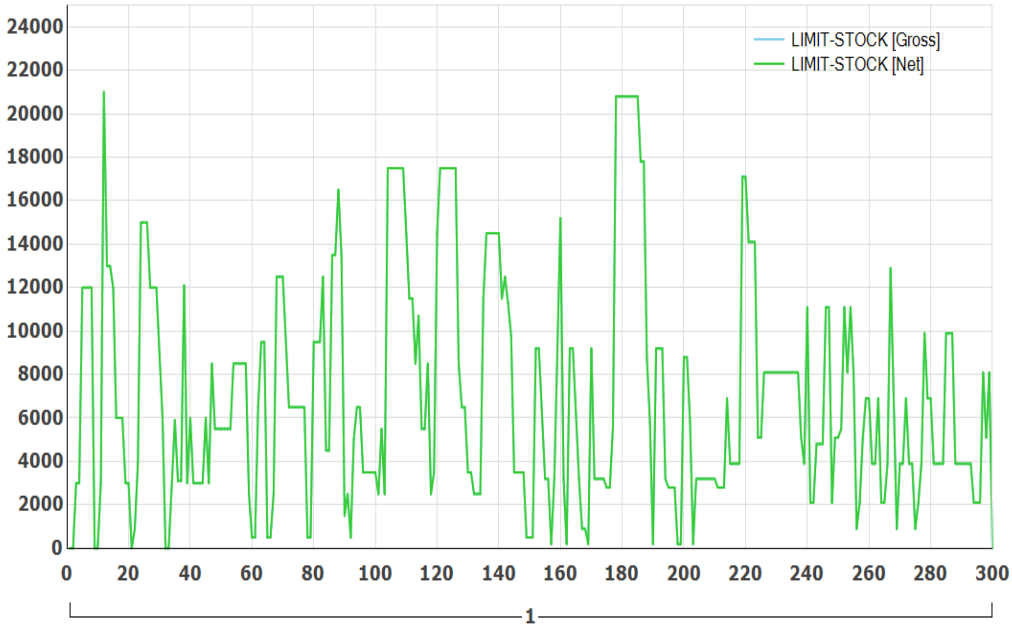
RIT Performance Report

Trader: BEAN
Simulation: Algo 2 Trading Case

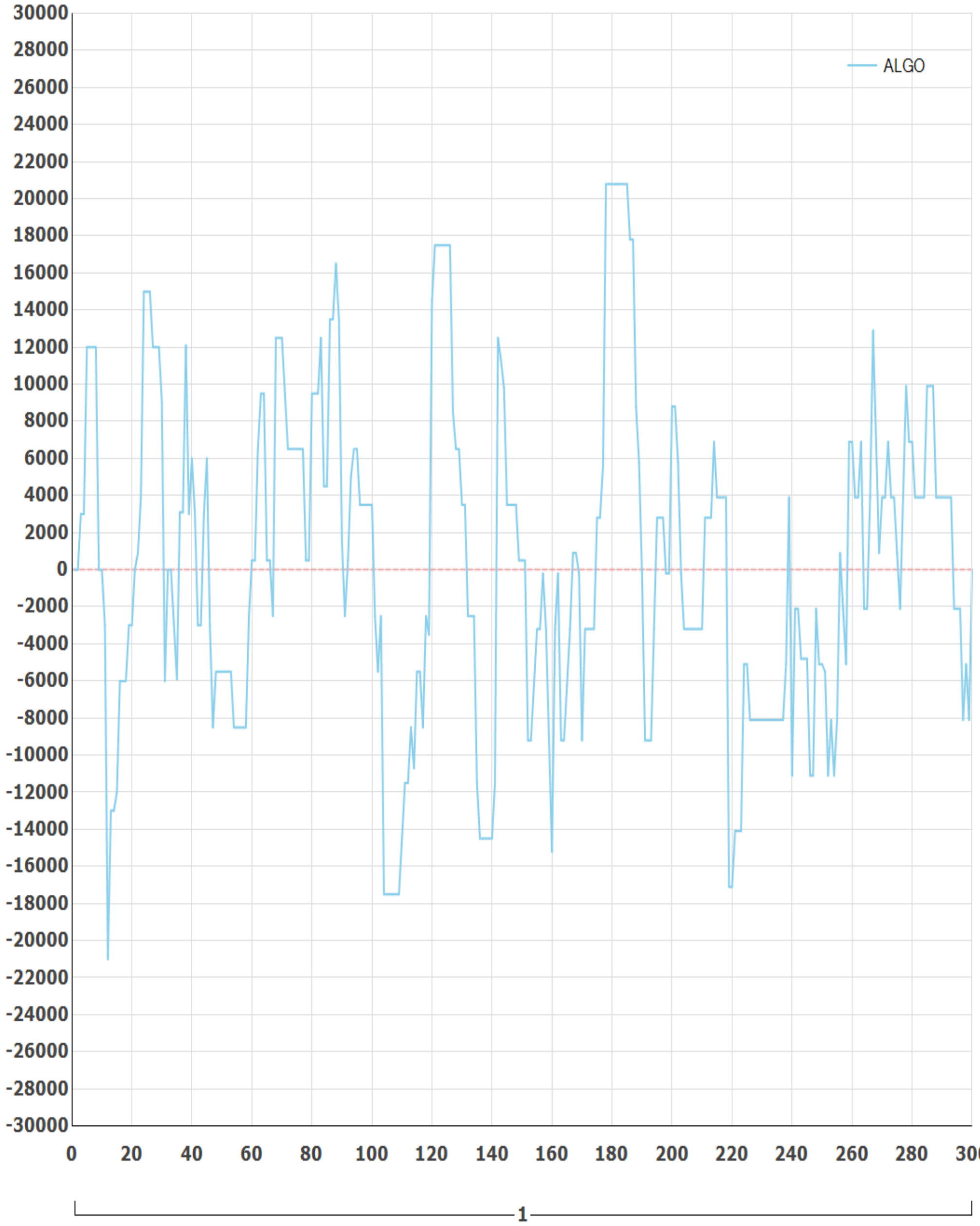
Trader P&L Chart



Trading Limit Chart



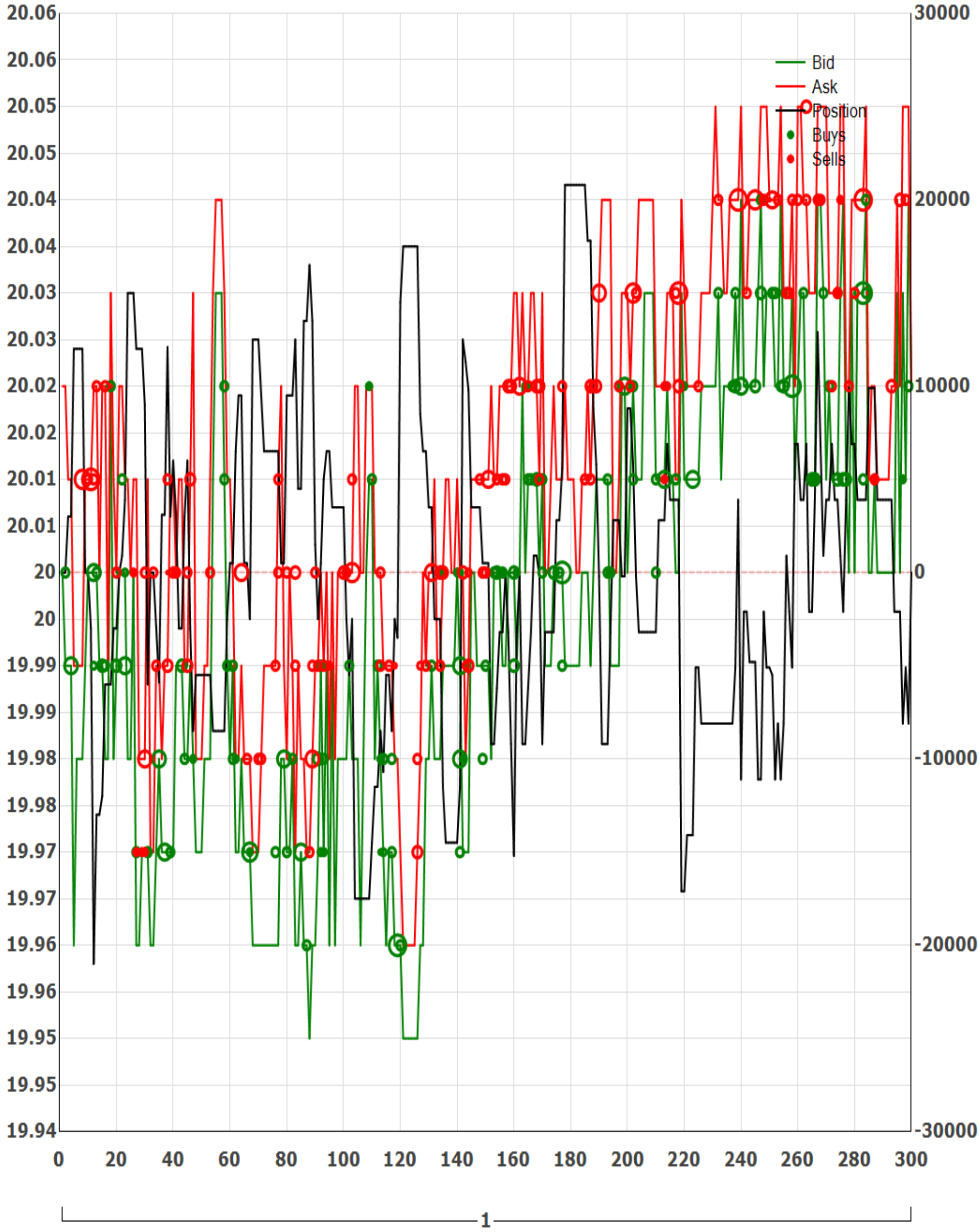
Position Chart



RIT Performance Report

Trader: BEAN
Simulation: Algo 2 Trading Case

ALGO Chart



RIT Performance Report

Trader: BEAN
Simulation: Algo 2 Trading Case

Security P&L Summary

Ticker	Realized P&L	Unrealized P&L	Commissions	Rebates	# of Trades	Buy VWAP	Sell VWAP	Buy Contracts	Sell Contracts
ALGO	11,835.50	0.00	11,353.00	15,409.50	527	19.9989	20.0125	570,200.00	570,200.00
TOTAL	11,835.50	0.00	11,353.00	15,409.50	527				

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ABSTRACT

The presence of High Frequency Trading systems has been unveiled by the sudden, rapid and unmotivated Dow Jones *flash crash* that occurred on May 6, 2010[145].

High Frequency Trading is a mode of intervention on financial markets that uses sophisticated software and hardware tools to implement high frequency trading managed by math algorithms.

The flash crash caused an immediate investigation by the Securities and Exchange Commission (SEC)[146] and the inevitable attention from media all around the world.

SEC[147] established during the same month the involvement in the collapse of May 6, 2010 by high frequency trading systems, thus excluding the responsibility of out-of-control electronic systems.

However, it was difficult to find out if the impact of HFT systems on the market in that situation was positive or negative.

On the one hand, the presence of systems capable of performing high-speed operations has certainly aggravated the descent phase of the prices, but on the other hand, at the time of turnaround, those same systems have allowed a sudden recovery in only 10 minutes[148].

The simple observation of the discordant effects of High Frequency Trading systems is a sign of the complexity of the subject.

A "forerunner" of High Frequency Trading can be recognized in the "SOES Bandits"[149] phenomenon, in the mid 90s.

This is a particular type of *trader*, considered very aggressive, that carries out a number of transactions per day (hundreds) with the specific aim of capturing the slightest oscillation

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145 On May 6, 2010, the Dow Jones index lost around 8% within a few minutes, dropping from 10,650 points to less than 10,000 points, then recovering to 10,520 points in the next 10 minutes

146 SEC is the US federal agency responsible for supervising stock exchange.

147 *Security and Exchange Commission* "*Preliminary Findings Regarding the Market Events of May 6, 2010*"- *Advisory Committee*, May 18, 2010.

148 Note that after the famous stock market crash of October 19, 1987 the Dow Jones index took over a year to recover a percentage of loss comparable to that recovered in just 10 minutes in May 2010.

149 *Small Order Execution System*, *Harvey Houtkin* "*Secrets of the SOES bandits*".

of the price of financial instruments or taking advantage by the delays of *market makers* in updating the ask or bid prices.

In those same years, SEC contributed to the emergence of High Frequency Trading, allowing the use of *Electronic Communications Network* [150] (hereinafter ECN) as alternative trading systems compared to regulated markets.

By combining ECN and a Von Neumann machine[151] it was therefore possible to take advantage of an alternative market, where buyers and sellers could meet automatically without having to operate through brokers and dealers, as it happened on regulated markets. From the beginning of the new century, continuous technological and financial innovations have facilitated the spread of trading activities based on the use of mathematical algorithms that act on stock, options, bonds, derivatives and *commodity* markets with very similar goals of the pioneers "SOES Bandits".

These algorithms have as *input* the data for any market in real time and as *output* precise trading decisions automatically initiated by the entry, modification or cancellation of orders on different trading platforms. The duration of the transaction is generally very short, investment positions are held for a variable time, from a few hours up to fractions of a second.

HFT is now responsible for major volumes in the main developed markets, in some stock exchanges it is estimated that high-frequency trading transactions are more than 70% of the total.

It also almost clear that these strategies can be used only by some market participants, or those who can afford the high cost of advanced technology[152].

The increasing spread of the phenomenon in the markets has given a major boost to the debate between supervisors and academically.

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[150] ECN means an electronic network outside the regulated markets that allows exchanges of financial instruments. In the EU regulatory system ECN correspond roughly to the MTF (Multilateral Trading Facility) covered by MIFID.

[151] It is an architecture-based computer developed by John von Neumann, which consists of five core components: CPU (central process unit), random access memory (RAM), input unit, output unit and system BUS.

[152] Among the best known operators to make use of these technologies, are *Goldman Sachs, Morgan Stanley*, *GETCO*, *Renaissance technologies, Citadel Investment Group*, *Jane Street Capital*, *Wolverine Trading* e *Jump Trading*.

The economic literature, despite the absence of unanimity, identified the risk that the HFT amplify the systemic impact of shock and adversely affect the integrity and quality of the market (efficiency in price discovery, volatility and liquidity).

In particular, the increasing popularity of HFT could compromise the correct process of price formation, moving them away from the underlying economic fundamentals and reducing, significantly, the signaling value. In addition to this, there is a possibility that the degree of HFT participation in trading affects the volatility of financial instruments, amplifying any fluctuations.

As regards the impact on liquidity, some studies[153] show a positive effect, while the operational evidence instead records that in turbulent conditions High Frequency Traders (hereinafter HFTr) may lead to an absorption of liquidity[154].

Finally, one of the most relevant issues related to the risks arising from the use of HFT strategies is the possibility of implementing potentially manipulative pricing strategies by leveraging the higher operating speed and the high complexity of the algorithms.

The danger of such strategies has been implicitly admitted even by an operator such as Goldman Sachs in the embarrassing affair of Sergey Aleynikov[155], who was arrested in summer 2009, after leaving the company, on suspicion of having taken possession of the source code used for HFT operations.This story ended with the intervention of the FBI.

On that occasion, to justify the severity of the incident and request the assistance of the Federal Bureau of Investigation, Goldman Sachs was forced to reveal the potential hazards arising from the possession of these codes, which gave the holder the power to subject the market to considerable disruptions[156]. From Goldman Sachs's statements it is clear that the possession of such source codes implies the possibility of altering the market, and thus the concrete confession and the real possibility, for this and perhaps many other companies, to manipulate the market.

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[153] Jovanovic, Menkveld "*Middleman in limit order markets*" (2011),
Riordan e Storkenmaier "*latency, liquidity and price discovery*", *Journal of financial markets* (2011).

[154] In operating practice we refer to the liquidity offered by the HFTr with the term "*Ghost liquidity*" to highlight a seeming liquidity, ready to disappear in particularly turbulent market conditions.

[155] Russian programmer who emigrated to the United States in 1990, he worked for Goldman Sachs from May 2007 until June 2009, with a salary of $ 400,000. He was then arrested July 3, 2009 and sentenced to 97 months imprisonment.

[156] This affair was the starting point for the analysis of the famous writer Michael Lewis, "*Flash Boys: a Wall Street Revolt*".

The present work has the objective to analyze the functioning and the main strategies of HFTr, understand the scope, examine the effects and analyze the discussion on regulation. Once described the phenomenon and the main features, it will be presented a market-making theoretical strategy as well as the construction step by step of an algorithm able to perform automatically negotiations (without any human interaction) on the Rotman Interactive Trader client (RIT), a software owned by Rotman University in Toronto. RIT is the market simulator that is used in the Rotman International Trading Competition (RITC)[157] and Rotman European Trading Competition (RETC)[158], the two largest and most important trading competitions at university level.

The first chapter will define the phenomenon and the diffusion of HFT and analyze the events of May 6, 2010 (*flash crash*). In recent years, the economic literature and numerous empirical studies have proposed several definitions, more or less extensive, of HFT. Some of these, for their extreme simplicity, fail to grasp the complexity of the phenomenon. There is general consensus in considering HFT an operating mode and not a strategy in itself, focused on the speed of acquisition and processing of market information and reaction to such information (*low latency*).

The second chapter will analyze the effects and risks arising from the use of high frequency systems along with the international regulatory framework and the main legislative proposals to regulate this phenomenon. Research has produced several theoretical and (more often) empirical contributions, in which it is attempted to determine the possible repercussions of the market participants' significant speed increase in operating[159] on:

- systemic risk of shock contagion on a single market;
- quality of the market in terms of price information, volatility and liquidity;
- implications for market integrity.

[157] About RITC: http://ritc.rotman.utoronto.ca/
[158] About RETC: http://retc.luiss.it/about-retc/
[159] In terms of timing, modification and cancellation of trading orders.

The third chapter will present an overview of the main strategies of HFTr, to better understand the operational manner in which HFTr participate and influence the financial markets. The common and distinctive element of the strategies implemented by high-frequency systems is the ability to insert, delete and modify thousands of orders at high-speed. Another feature of such systems is the continuous activity, which allows them to immediately adapt to the different market situations. Taking advantage of the extreme speed, they can suddenly change their positioning, adapting to market behavior and insert/delete orders of purchase/sale by the order book. Systems are also able to constantly analyze the degree of liquidity on the market, adapting their positioning. The characteristics of these systems also allow to exploit or avoid increases and declines of liquidity through immediate reactions.

The fourth chapter will study in deep the main function of liquidity provision made by the HFTr and will present a theoretical market-making strategy. Market makers are unique entities in a market environment. The U. S. Security and Exchange Commission defines a “Market Maker” as a firm ready to buy and sell a particular stock on a regular and continuous basis at a publicly quoted price. Unlike other participants that have always exposure to potential future states of the world, market making (MM) players main objective is to ensure a risk free profit or to facilitate trade that otherwise might not occur. In chapter 4 will be presented a theoretical framework based on MM literature and a simple market making strategy.

Finally, an application of the suggested strategy will be presented in Chapter 5 with a step by step construction of a MM algorithm for the Rotman Interactive Trader Client (RIT); an order-driven market simulator that allows students to trade financial securities with each other in real time. The proprietary software developed by the Rotman School of Management (University of Toronto) provide students with an “experimental learning” approach in order to apply main financial theories in an uncertain simulated market environment. All RIT cases are designed to focus on specific financial theories and present

them in an easy to understand way so that students can explore different strategies and learn how to make good decision when faced with uncertainty about outcomes.
Figuring out RIT software's main features can be useful in order to better understand this final chapter that will present a market making algorithm for the Rotman Interactive Trader Client with the main aim of helping LUISS students approaching for the first time algorithmic trading and looking for participating to future RETC and RITC trading competition.

Good luck and «VICTORES VICTVRI».