INVESTIGATING FINANCIAL FRAUD IN HIGH FREQUENCY TRADING: CONTEXT AND DRIVERS

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Abstract

Financial markets are very important components of the world economy and at the same time, their structure has changed substantially over the last thirty years primarily due to the use of information and communication technologies. Market monitoring and surveillance is an important process to the financial markets in order to ensure that market rules and policies are met as well as to detect any act or attempt of manipulation.

Recently, a new kind of trading has emerged, High Frequency Trading, which allows traders to place and execute orders within milliseconds via computerised programs. It is still unclear whether existing market systems are capable of carrying out effective monitoring and detecting inconsistencies in trades at such high speeds. This paper provides an initial approach to firstly, develop a broad understanding of financial markets, financial fraud and the role of high frequency trading and secondly, to discuss and exemplify market monitoring challenges in the context of high frequency trading.

Since this is such a recent phenomenon with no confirmed cases of market manipulation to the best of our knowledge, the paper attempts to answer whether there are certain conditions that could benefit market manipulators. The paper employs the use of business intelligence techniques to analyse historical data and identify what types of indicators could be employed for monitoring purposes. The initial analysis shows indications of possible violations of the regulations that were not dealt with and that under a very high volume of orders scenario, it is possible that the market systems are not able to cope. Finally the paper introduces the **"zero duration oxymoron"** phenomenon where if the baseline price for the calculation of the compliance of the quotation standards rule is not uniform across exchanges, the same quote could be considered valid in one exchange and not valid in another.

Keywords: financial markets, high frequency trading, financial fraud, business intelligence, zero-duration quotes, zero duration oxymoron

1. Introduction

Securities' trading has its roots back to the seventeenth century and the Amsterdam stock exchange (Michie, 2006). Essentially securities' trading is based on the problem of searching. Buyers try to find sellers that want to sell their securities at low prices and sellers try to find buyers who are willing to buy their securities at the highest possible price. Traders are trying to find other traders willing to trade the quantity they want and they may be acting on behalf of clients or trading their own securities (Harris, 2002).

The securities market is a technology intensive global industry, and was well positioned to take advantage of the Internet's strengths as soon as the Internet arrived (Van Der Laan, Shannon, & Baker, 2010). A stock exchange is an important subcategory of the securities market in terms of volume of trading. The focus of this paper is to study stock exchanges as all the stocks traded are listed and in order to qualify for this, stocks have to fulfill certain requirements. Stock trading used to take place in exchanges and trading floors where traders traded between each other in person while nowadays those activities are highly computerised giving rise to fully electronic exchanges such as NASDAQ. The individuals that are involved in the market, sometimes invest their own retirement savings thus a stock exchange needs to ensure ***market integrity*** which means the ability of investors to transact in a fair and informed market where prices reflect information (Ferdousi & Maeda, 2006). A stock exchange also needs to ensure ***market efficiency*** which refers to investors completing low cost trades easily (Comerton-Forde & Rydge, 2006). Market's design and processes have a great impact on its efficiency especially since nowadays markets are in competition and small differences in the speed of transactions might create a shift of crowd from one market to another.

Because of the amount of money involved in daily transactions, securities' markets have often been prone to manipulation. Market Manipulation involves in most cases the attempt to alter the market which is a term that refers to illegal or borderline-illegal actions that result in falsified impressions either about the price of a stock or the supply and demand of it (Comerton-Forde & Rydge, 2006). Back in the 17^{th} century, manipulation came in the form of spreading rumours from table to table in the coffeehouse about the price of a stock (Leinweber, 2001). Nowadays, there have been multiple methods recorded varying from agents trading between themselves to alter a stock price to spam emails spreading online which influence the price of a stock. Market manipulation has a great impact on market's integrity and efficiency (Aggarwal & Wu, 2003). Thus, the market's integrity depends largely on regulation (which is why a stock market is in most cases highly regulated) and the quality of market monitoring and surveillance.

Regulatory environments differ from exchange to exchange and depend largely on its history and conditions. However, one can identify similarities between exchanges of the same jurisdiction such as a common overseeing authority or a common regulatory framework. Examples are the United States and European Union, which could be examined separately. In some cases the exchanges themselves are Self-Regulatory Organizations (SROs), which means that they apply their own listing standards and are responsible for specifying rules and enforcing them. There is also a government regulatory authority with greater enforcement role and responsibilities (Cumming & Johan, 2008). However, regulation on its own is not enough. In order to reduce the possibility of market abuse, market monitoring systems are used to ensure that no regulation has been violated. Generally speaking market monitoring is a task for which exchanges are usually responsible. Regulatory authorities may initiate an investigation at a later stage. The generic description of a monitoring system is that it is a highly computerised surveillance system, which alerts specific staff of unusual trading activity based on orders and executed trades. Normally, it receives different kinds of input (records of daily trades, historical data of stock prices, pieces of text), it performs some kind of analysis based on rules and identified trading patterns and it deploys an alert mechanism and some form of visualisation and evaluations of the analysis results (Diaz, Theodoulidis, & Sampaio, 2011)(Diaz, Zaki, Theodoulidis, & Sampaio, 2011). An alert is raised when a trade does not comply with the existing rules of the market or when a possibility of manipulation has been detected. Checks are also performed on data to verify they are correct, complete and entered in sequence. Despite its importance, a small part in research literature has been devoted to market monitoring whereas the major part is devoted to forecasting the stock prices. Markets' monitoring methods and systems in use have been kept in secrecy and the reason behind this is to prevent manipulators from having any idea about how to avoid detection (Cumming & Johan, 2008). On the other hand, regulatory authorities, exchange venues and investors would like to be able to compare the potential and the capabilities of different monitoring systems in order to have a better judgment on whether to invest in certain markets and which system to trust. Also it would increase the confidence an average investor has on the financial markets.

The latest technological development used in securities' trading is called ***High Frequency Trading (HFT)*** which refers to the use of sophisticated computer algorithms to generate orders and submit those orders to electronic markets at high speed. Sometimes, these algorithms produce a huge amount of quotes within milliseconds. HFT algorithms may act like a middle- trader. They search for patterns in the market and when they discover one they buy the shares and sell them – and make profit as low as a fraction of a penny per share. However as trades happen continuously and shares accumulate so the profit increases. By its nature, HFT can be applied to any sufficiently liquid financial instrument (Aldrige, 2010) but because of their cost of development they are usually property of big firms and companies. HFT is going to be the focus of this paper because of its increased popularity and the part it played in NYSE's crash in May 2010. After NYSE's crash, several additional regulatory proposals were formulated both in the United States and Europe in an effort to prevent this event from occurring again. Some of those proposals updated laws-in-use or they were completely new proposals that resulted from the analysis of what happened in May 2010.

More specifically, this paper addresses the following questions:

1. Are the existing market monitoring systems and the relevant regulation adequate for HFT?
2. Could HFT involve any intentional or unintentional manipulation acts? If yes, could those manipulation acts result in stocks fraud?
3. With trades taking place in milliseconds (and sometimes even faster), is real-time market monitoring feasible?

The approach followed in this paper is to firstly, study the existing regulations and market monitoring and analyse the challenges in market monitoring after the arrival of HFT (Katika, 2011). The analysis is based on examining HFT trading patterns and more specifically, ***quote stuffing*** which is a very large amount of orders started by HFT within milliseconds and ***stub-quotes*** which are quotes that are not executable under normal market conditions because they are too far away from the regular price of a stock (Nanex, 2010a). The analysis is based on the use of business intelligence techniques which are used to describe a set of methods that turn data into information and then into knowledge (Golfarelli, Rizzi, & Cella, 2004). For the analysis, cases have been carefully selected so as to include occurrences of these trading patterns but also normal trades.

The structure of this paper is as follows. Section 2 provides an overview of the securities market. More specifically, it reviews market monitoring approaches and the existing regulations before and after NYSE's crash. Section 3 discusses HFT algorithms, how they work and the types of trading strategies they follow with specific reference to quote stuffing and stub-quotes. Furthermore, it describes regulation updates that have been introduced since the flash crash and highlights some of the characteristics for real-time market monitoring that have been examined in the literature. Section 4 is divided in two parts and contains the analysis of the two HFT trading scenarios: quote stuffing and stub-quotes. The section discusses the evaluation of the results and the implications and recommendations for market monitoring. Finally, section 5 summarises the paper, discusses the limitations of the approach followed and proposes areas for further work.

2. Securities Markets

This section provides an overview of the securities markets and defines in detail HFT and how it influences the process of trading. This section is divided in two parts describing stock markets, regulations and manipulation acts before and after the appearance of HFT illustrating the two cases that are the focus of this paper. Also, a literature review is provided on existent market monitoring systems with specific reference to those that are capable of monitoring HFT trading.

Overview

The first occurrence of securities dates back to mediaeval times (Michie, 2006). Back then it was a way for the government to fund its ambitious plans by borrowing from the very few rich owners. The government's only duty was to pay a fixed interest annually and the debt was permanent but it was still an attractive idea for investors as the government guaranteed this return. Therefore those securities became transferable so that investors could sell them to someone else. The first informal stock market appeared in Amsterdam in the 17th century where the existence of any regulation is doubtful (Michie, 2006). Since then, stock markets started emerging in big European cities such as Paris and London. Securities consist of the following categories: ***debt entities*** (bonds –usually issued by governmental bodies), ***equities*** such as common stocks (often referred to as stocks) and ***derivatives*** (futures and options). The word "stock" usually denotes ownership or equity in a corporation and is normally issued in the form of shares (Teweles, 1998). Accordingly, we have bonds market, stock market or futures market. In this paper we focus on stock markets as stocks are the most algorithmically executed asset class, with over 60% of the total volume of stocks handled by algorithms (Aite Group, 2009). The rest of the markets have less percentage of their trades executed by algorithms.

Stock markets vary from country to country; differences include the regulatory configurations, the monitoring tools and even the terminology in use. However, it is more common to spot similarities between stock markets of the same region and that is why in this paper US and European markets are discussed separately. An initial distinction between stock markets divides them in ***primary*** and ***secondary***. The first time a company separates its ownership in shares and sells them to investors is called primary market. Any other kind of re-selling those shares from the investors to other interested buyers is referred to as a secondary market (Teweles, 1998). All the types of markets about to be discussed will refer to secondary markets.

The role of the stock exchange according to O'Hara (2001) is to provide ***liquidity*** and ***price discovery*** while these two characteristics are interconnected. Liquidity refers to buy-side and sell-side market depth and it is the resting orders placed by market participants to express their willingness to buy or sell at prices equal to, or around the current market price of a stock. If the market offers price discovery, it will consequently be more liquid and vice versa (CFTC & SEC, 2010). Common parts in all stock markets (independent from jurisdiction) are the customers, the brokers, the regulatory bodies, data and the market venues. The customers can be individuals or firms and they can be characterised as institutional ones if they are trading larger amounts of shares or retail if they are trading smaller amounts (Hasbrouck, 2007). The brokers (also known as traders or agents) are in general the intermediates between customers. They can direct orders to market venues or match them internally. They also offer advice and investment guidance. Regulatory bodies supervise market venues and brokers. Data (in the form of trade papers, information on quotes etc.) is an important part of this process as it is the way customers are getting informed on the current situation of the market and decide on their next steps.

A market venue can be (Hasbrouck, 2007):

a) ***Stock Exchange***: A stock exchange is usually an actual place where people used to trade. Nowadays most of them are almost exclusively conducted electronically. A stock exchange is a term used in US. The equivalent term in Europe is "regulated market".

b) ***Electronic Market***: A market that is purely electronic is called electronic market. The most well-known example is NASDAQ, the first screen-based dealer market that allowed traders to trade from their computers, transmit orders electronically and no longer required their physical presence in a stock exchange's floor. NASDAQ was allowed to compete with stock exchanges in 1998.
c) An ***Alternative Trading System*** (ATS); the European equivalent is called ***Multilateral Trading Facility*** (MTF): Those are alternative trading platforms that match orders without passing them through an exchange and without the intervention of a dealer.
d) **Over-The-Counter** (OTC): This is a broad term covering trades that in general do not take place in an exchange. OTC markets may or may not trade listed stocks. They also have limited if-any requirements of papering their trades.
e) A ***Systematic Internaliser*** (SI): It is a company that deals on its own account to execute clients' orders outside any of the aforementioned markets.

Another criterion to categorise a market venue is whether it is national, regional or global. A national stock exchange is the primary financial centre of a country such as NYSE (New York Stock Exchange). A global market is a market merging other markets such as Euronext which is a pan-European market. A regional market venue is an outdated term used mainly in US to indicate markets apart from NYSE such as the Chicago Stock Exchange (Hasbrouck, 2007).

This paper focuses on regulated markets for a number of reasons. Regulated markets have papering requirements. ATS, SI and OTC are required to have a degree of transparency regarding their trades but for instance they are not required to display public quotes that do not meet a specific size threshold (EU, 2004) whereas regulated markets have supervising bodies and therefore, violations are easier to be spotted, historical data is more organised and there is a variety of data providers. As NYSE is historically the primary stock exchange of United States and the market where the cases investigated took place, it is important to understand its architecture and explain its components. Unfortunately, there is little information regarding these in the public domain. Figure 1 provides an overview of NYSE based on public information and although this information is dated, we assume that these components are still in use (Hasbrouck, Sofianos, & Sosebee, 1993) (SEC, 2009a). The difference between NYSE and other stock markets is that it is a ***hybrid market***. This means that it combines an electronic market but there is also a market maker (a person) to take over the execution of trades at some point.

A ***market maker*** is the evolution of the specialist. A specialist used to be a person on the floor of the NYSE specialising on one stock (Hasbrouck, 2004). Any order concerning that stock passed through him. A market maker's obligation is to maintain a "fair and orderly market". In doing so, he must also bid and offer (make a market) when there is no one else willing to bid/offer. The flow of actions when there is a customer interested in placing an order is shown in Figure 1. Firstly, the customer gets in touch with the broker (the broker might be an individual or might be working in an investment firm) to let him know of his will. The broker places the order to the best available exchange and a system known as ***Common Message Switch*** (CMS) is responsible for receiving, validating and passing orders and administrative inquiries to other NYSE systems. CMS also sends execution papers and status messages back to the member firms (NYSE Group Trading Systems Division, 2005). NYSE operates on a first-come first-served type of service. This means that whoever bids first on a certain price will have priority. A market maker has a display book ahead of him displaying quotes in time/price order in an 8-price window (so at any time he sees the 8 best bids and 8 best offers for that stock). The display book shows also the trades at every moment. Since orders are in the display book they can either be executed or cancelled (SEC, 2009a).

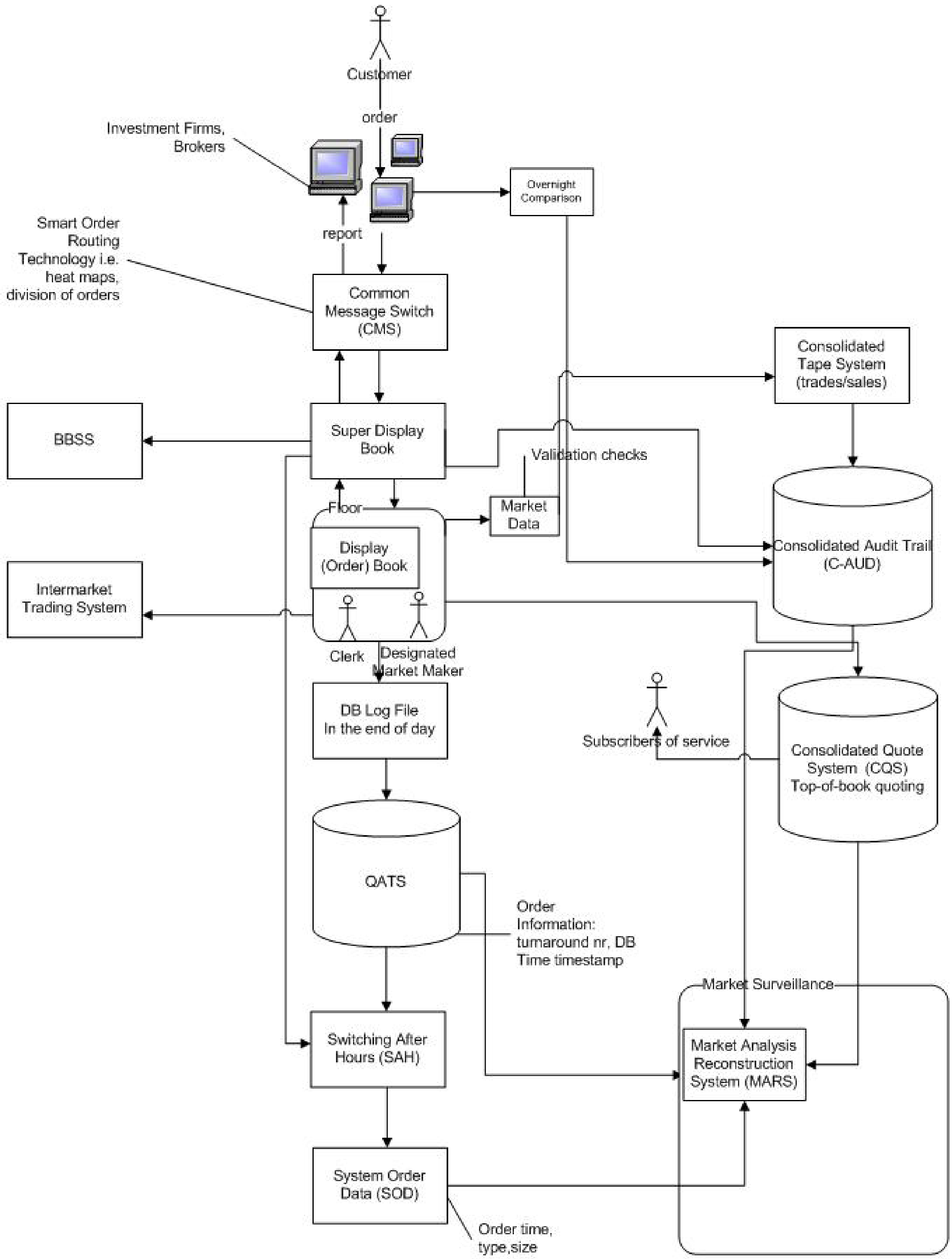

Figure 1: Architecture of NYSE (taken from (SEC, 2009a))

Data additionally goes to the ***Broker Booth Support System (BBSS)*** and at the end of the day, all data contained in the DB is downloaded into the DB log file (SEC, 2009a). After that three databases follow in order: ***Quote Assist Time Stamp (QATS), Switching After Hours (SAH) and System Order Data (SOD)***. QATS includes information regarding any pauses of the system as well as a time stamp of when the quote became available on the display book and a turnaround (time for the order to reach the venue and return a message) time stamp. When the order has arrived at the display book, it gets stamped with the time it became available on it (this time stamp is issued by QATS and confirms that the order is marketable and quotable). This timestamp shows the time an order was available on the display book- not necessarily visible on it and it is called DBTime. The time Super Display Book receives a message acknowledging that the order has been received by the display book is referred to as Otime. Finally, the execution time of an order is called Rtime. Normally, DBTime comes first followed by Otime, followed by Rtime. But if the system is going through a freeze, Otime comes before DBTime because the order does not appear on the DB until the DB is unfrozen.

Two additional databases, which are important for the dissemination of information to the public as well to monitoring services after hours, are the ***Consolidated Tape System (CTS)*** and ***Consolidated Quotation System (CQS)***, both of which are administrated by the Consolidated Tape Association. Securities Industry Automation Corporation (SIAC) operates and maintains CQS since 1978 (M. Collazo, 2010). CQS collects and processes the best equity quotes per listed securities, local issues and bonds from all US Stock Exchanges. In addition, CQS calculates and identifies the National "Best Bid and Offer" (highest bid and lowest offer) based on a price, size and time priority scheme. The Consolidated Tape System contains information regarding the actual trades (including executions and cancellations). Trades are stored in the system so they can processed real-time but also after-hours. For easier tracking, there is a master database by symbol that is updated with each trade. In this database the following information about a stock is stored with its symbol: consolidated high, low, last price and size as well as the last sale and size information for each market that trades that specific stock. Markets have a specific time frame to paper their trade activity (back in 2001 this time frame was 90 seconds) before the trade is marked as late and as a result does not impact the national last sale price. In addition to this, CTS incorporates an automated correction function for when a market papers a trade incorrectly in which case a revised trade paper is re-disseminated. CTS and CQS receive trade and quote information using a standard message format. Within the message there is also a timestamp according to the time the message was initially disseminated (Dermchak, 2001). They then distribute this data to the subscribers of the service (investment firms, data vendors, markets).

Because exchanges send their quotes and trades to those consolidated databases, using a standard message format is important. The ***Financial Information Exchange*** (FIX) is a series of messaging specifications facilitating the electronic communication of trade-related messages (FIX Protocol, 2011) and has been adopted by many markets for order handling. Lastly, ***Consolidated Audit Trail*** (Hasbrouck et al., 1993) provides a timeline of the trading in each stock, identifying the time and size of each trade as well as information on the orders involved in each trade. It integrates information from different sources including CTS, Display Book and member firm input via the ***Overnight Comparison System***. Finally, NYSE also contains some ***Liquidity Replenishment Points*** which are pre-determined price points at which electronic trading briefly converts to auction market trading, in which automatic crossing of orders stops and an indicative price is quoted while orders are accumulated on each side of the book, giving time for investors to fill any imbalances that may have occur due to fast changes in prices. Thus, LRPs are triggered every time an electronic trading results in rapid price movement (NYSE Group, 2006).

Market Manipulation

The market is prone to any action of human behaviour and the attempt to manipulate it is one of them. Manipulation refers to actions that influence the regular condition of a stock either its price or its supply and demand. Sometimes, manipulation can occur without the manipulator trying to achieve profit (unintentionally). Manipulation is not necessarily fraud as a fraud violates a law and it is intentional whereas a manipulation that just appeared has not been explored and forbidden just yet. Securities fraud, in contrast, typically implies improper conduct on the part of a financial market professional towards their client. Securities fraud usually occurs when brokers exploit their clients into trading stocks without having their client's benefit in mind. The main actors of stock fraud usually belong to brokers, corporate executives, market makers or shareholders. A typical securities fraud scenario is a market maker who acts for his own benefit. Although he has received an order from a client to buy a specific stock, he buys it from a second market maker on his own and then sells it to the customer at a higher price. The market maker violated the contract he had with the client to achieve a no-risk gain. This scenario is called ***front running*** (Cumming & Johan, 2008).

Since the foundation of the first Stock Exchange in Amsterdam, market-related manipulations have been an on-going issue. In the beginning, it was all about spreading rumours from one table of the coffeehouse to the other and taking advantage of the gullible clients (Leinweber, 2001). As years went by, manipulation events evolved. Allen and Gale (1992) divided stock manipulation in three major categories: ***action-based*** (a trader who is not bidding in an action), ***information-based*** (spread of rumours and false information) and ***trade-based*** (manipulators trade among themselves in order to create a faulty image of the market). Action-based manipulation is based on events that alter the fundamental value of the stock and usually take place outside a market venue. An example of this could be the selling of a strategic asset, such as patented product, brand, branch, or facility, without the consent and knowledge of the minority interest. . Information-based manipulation occurs every time that false information is spread in public. Relating Allen and Gale's article (1992) with the current situation of the market, we can classify phenomena such as spam emails and insider trading in this category. In insider trading, traders take advantage of information that has not been made public yet to achieve personal gain whereas in financial information manipulation, managers of a company distort the related public information to create a different image of their company than the real one. The third category of trade-based manipulation occurs when a manipulator buys and sells stocks with the intention of altering the market conditions without trying to alter the fundamental value of the stock, spreading misleading information or using information that has not been disclosed to the public.
For instance, in **match trades** and **wash sales** a group of traders could collaborate to create a false impression of demand by buying and selling stocks to each other at prearranged levels with the intention of attracting other investors to buy the stock. As there is no obvious evidence of the collaboration that could be easily spotted in trading data, this type of manipulation is one of the hardest to detect. Another trade-based scenario is called ***painting the tape*** and involves a trader who buys and sells at high rates on a particular stock to give the impression of price movement (Cumming & Johan, 2008).

Market manipulation is more likely to happen in OTC markets, as there are lower requirements for the firms listed there and less strict regulation so manipulators might draw less attention to their actions. Also it is more likely to target less liquid stocks of smaller volume as it is easier to affect their price (Aggarwal & Wu, 2006). However subtle market manipulation might be, it always leaves traces behind. These traces could be found in the number of trades, bank transaction records, historic data of the stock's prices, phone calls between traders even chat logs (Diaz, Zaki, et al., 2011). A one-off manipulative act could be unintentional but a repetitive act enforces an assumption that it might be a fraudulent action.

Regulations

In this section, an overview of the regulation and regulatory authorities is presented. Both the US and European Union markets are discussed and a comparison is provided between the two.

In US, the ***Securities Exchange Commission*** (SEC) regulates the stock and bonds markets (Hasbrouck, 2007). There are other regulatory authorities for the rest of the markets such as the U.S. Commodities Futures Trading Commission (CFTC) that oversees the futures markets. SEC imposes the rules and then assigns responsibilities to SROs, which are under SEC's supervision. SEC can also approve or not the rules that are made by the SROs. The main functionality of an exchange is defined in Regulation NMS (SEC, 2005) and it has been in use since August 2005. Only the main points of this regulation that are relevant to this paper are covered.

The ***sub-penny rule*** states that a quote should differ from the stock's current price by at least one penny. Regarding the dissemination of quotes, all securities exchanges establish and maintain procedures and mechanisms for collecting bids, offers, quotation sizes, and aggregate quotation sizes from responsible brokers or dealers who are members of such exchange or association, processing them and making them available to vendors. This basically means that each of the 15 participating listed exchanges (shown in Figure 2) is required to send to Consolidated Quotation System the best bid and offer this exchange is willing to trade. The best bid is the highest price someone will pay to buy the stock and the best offer is the lowest price someone will ask to sell his share. Every new quote sent by the exchange is a revision of the prevailing quote and supersedes the previous one (Wharton Research Data Services, 2009).

An NBBO is the ***National Best Bid and Offer*** information, which is the highest bid and lowest offer of all prevailing quotes, issued by various market makers in national exchanges. The Securities and Exchange Commission (SEC, 2005) uses the NBBO information to require brokers to execute customer trades at those best available prices as the order protection rule states (the customer has to obtain the best price from the available quotations).

MarketCenter Symbol	MarketCenter Code	MarketCenter Name
AMEX	**A**	NYSE AMEX
BX	**B**	NASDAQ OMX BX, Inc
CINN	**C**	National Stock Exchange
ADFN	**D**	FINRA
ISEG	**I**	International Securities Exchange
EDGA	**J**	EDGA Exchange Inc.
EDGX	**K**	EDGX Exchange Inc.
CHXE	M	Chicago Stock Exchange
NYSE	N	NYSE Euronext
ARCX	P	NYSE Arca
NSDQT	T	The NASDAQ Stock Market LLC
CBOE	W	CBOE Stock Exchange
PHLX	**X**	NASDAQ OMX PSX
BATSY	**Y**	BATS Y-Exchange Inc.
BATS	Z	BATS Exchange Inc.

Figure 2: CQS Market Participants (Source:(M. Collazo, 2010))

On the other hand, European stock markets are subject to multiple regulators. Every market has its own regulatory authority, for example Financial Services Authority (FSA) that regulates the financial services industry in the UK. In addition to the national authorities, there are some European regulators that supervise all the markets across borders such as **European Securities and Markets Authority** (ESMA). At the moment, each market has its own rules but MiFID was introduced to help integrate Europe's financial markets and empower market efficiency (EU, 2004). The second version of MiFID that was voted by the European Parliament recently tackles some of the issues that were included in the first version and addresses concerns over high frequency trading. MiFID II, among others, requires that all trading venues must ensure that their trading systems are resilient and prepared to deal with sudden increases in order flows or other market stresses. Some of the measures discussed are circuit breakers to suspend trading and resting times i.e., all orders should be valid for at least 500 milliseconds, i.e. must not be cancelled or modified during that time (MiFID II, 2012)

The major features of this directive are as follows. A company covered by MiFID is regulated in its home state but it is able to provide services to customers in other EU member states and still being regulated in its home state. The abolition of the ***concentration rule***, which was sealed with MiFID, meant that companies could trade in any exchange, not only local ones. This situation increased competition and as a result, exchanges altered their fee schedules to the benefit of the investors. Procedures exist to classify clients according to their suitability for an investment product and to approve any financial transaction or investment advice. Certain information needs to be provided when an agent accepts a client's orders, supporting the fact that the agent acts on client's best interest. The best bids/offers and depth of those quotes of market makers must be made available. Companies are required to publish the price, volume and time of all trades in listed shares even if these are executed outside a regulated market. The ***best-execution rule*** states that the result (related to price, speed and other relevant factors) received for a client's order should be the best possible. There is a provision for market makers who are called ***Systematic Internalisers***. In simple terms, a Systematic Internaliser can be a bank who matches the orders of its clients internally without passing through a trading venue. At the same time though its trades have to be transparent and the bank has to provide information about the initial price and the price after.

Insider dealing and other market manipulation practices are referred to as "market abuse" (European Commission, 2004b) and tackled in Market Abuse Directive (MAD). The Directive, which was adopted in 2003, introduced measures to constrain market abuse and empower regulators' cooperation. Its objective is to establish market integrity and protect the investor.
Each stock market has additional regulation suited on its needs. For example, London Stock Exchange (LSE) has incorporated a rule (***Rule 1400***) according to which all orders entered on to the order book are firm. This does not mean that a trader cannot change his orders. It means that he cannot submit an order and cancel or alter it before execution because this can give a potentially misleading impression of the level of liquidity in the market to other participants (London Stock Exchange, 2011).

The most important difference between European and US markets is that the former lacks a Consolidated Tape or a European Best Bid/Offer. Although companies and investors can trade in any market they wish, there is no way that they would know which market provides the best prices except if they are subscribed to all the markets and they calculate the best bid/ask by themselves. Unfortunately this approach is resource (time and money) intensive. Another option is to use the aggregated data of vendors such as Bloomberg and Reuters which charge considerable sums for their services.

Market Monitoring

Manipulative activities can hurt one market in terms of attracting new investors or companies and keeping the existing ones (Cumming & Johan, 2008). They also decrease the confidence a customer has in the market. Therefore apart from appropriate regulation, market monitoring systems are of great importance to identify such activity and oversee the proper functioning of the market. In most cases, the exchange is responsible for market monitoring (Polansky, Kulczak, & Fitzpatrick, 2004). They verify that rules are applied and the systems are not used in a manipulative way. They also have to constantly check the data to ensure that they are complete and accurate and in the proper sequence.

In UK, exchanges perform an initial analysis of the data to confirm that an alert was not a false positive but then turn to FSA to complete the investigation whereas in US, exchanges are also responsible not only for the monitoring but also the investigation. Of course, SEC can initiate parallel activities and can inspect the exchanges to confirm that their systems are efficient. Most of the monitoring systems are automated although there is always some human intervention but the fast rate of trades in practice makes it impossible for any kind of effective manual surveillance during market hours.

Some exchanges and authorities have the funds and the expertise to build their own monitoring system whereas other smaller exchanges do not have the appropriate resources and are using external providers to customise an existing solution for them. The solution has to be customised as each trading venue has its own regulation and probably patterns of manipulation as well. The most dominant example here is SMARTS Group (owned now by NASDAQ OMX) that in the past has installed monitoring systems in multiple exchanges such as the Saudi Arabian Stock Exchange (Cumming & Johan, 2008).

A great number of factors determine the efficiency of a monitoring system (Cumming & Johan, 2008). First of all, the alert parameters should be as accurate as possible to decrease the number of so-called "false alarm" occurrences. In order to achieve this, the monitoring system must define the regular range of price and volume for every stock. Secondly, regarding post-trade analysis, the system should be able to reconstruct all the trading activity (trades, quotes, orders) as well as pair the activity with the corresponding participant. Thirdly, the monitoring system must be trained with all the plausible manipulative scenarios. A very important factor is the quality of the software as well as the level of training of its users. Also, the more informed are the market participants about the existence of a monitoring system and its potential, the less inclined are to attempt something. Regarding cross-market manipulation, the easier it is to access information on various venues, the more efficient the system will be. Finally, regulatory authorities play a crucial role in the efficiency of a market monitoring system. Wherever, an exchange is also an SRO it is more likely to be stricter about enforcing the regulation apart from setting it because it has to cater for its own profit (Cumming & Johan, 2008).

3. High Frequency Trading

This section provides an overview of HFT in terms of its basic characteristics of HFT as well as its basic trading strategies.

Algorithmic Trading and HFT

The evolution of physical trading was electronic trading which was faster, cheaper and less prone to human mistakes such as mishearing trader's orders on the floor or over the phone (Aldridge, 2010). Nowadays, most orders are transmitted electronically and utilise algorithmic trading to optimise trading execution.

Algorithmic Trading is a term referring to the "computerised trading controlled by algorithms" (Prix, Loistl, & Huetl, 2007) and the processing of the computerised orders depending on the current market conditions without human intervention (Chaboud, Hjalmarsson, Vega, & Chiquoine, 2009). It is the use of computerised algorithms to determine the best time to route an order, its size and whether it should be routed across different venues (Aldridge, 2010). Technological progress makes it possible nowadays for sole traders to have their own infrastructure for algorithmic trading (Chan, 2008).

High Frequency Trading is a recent phenomenon that is seen as subset of algorithmic trading (Gomber, Arndt, Lutat, & Uhle, 2011). While it is hard to assign an accurate, unambiguous definition for HFT, it is easier to spot some common characteristics (CFTC & SEC, 2010):

- High number of trades and lower average gain per trade
- Use of high-speed computer programs to generate, route and execute orders

- Servers of those algorithms are usually located closely to the exchange
- The firms that use those algorithms are subscribed to the individual data feeds that exchanges offer
- Very short time-frames for establishing and liquidating positions
- Large number of orders that get cancelled right after submission
- The end of the trading day finds high frequency traders as close to a flat position as possible

HFT has a lot of advantages. It is cost effective in terms of fewer employers needed to complete a trade. The rate of errors is lower as there are no mistakes due to human misjudgments. It increases market efficiency as an order is executed faster. It adds liquidity as high frequency traders make a lot of quotes in a short time. HFT algorithms can be executed at any time as they do not require human intervention so they allow stocks to be traded outside regular trading hours given that electronic foreign exchange markets are open 24 hours, 5 days a week. These algorithms take into consideration various factors to determine how, where and when to trade. These include the price of a security, the size or liquidity available, various timing considerations (e.g. how quickly can an order be executed or when exactly orders should be placed to ensure the biggest chance of execution), how likely an order is to be filled (the "***fill ratio***") and the overall costs of each transaction (HFT Review, 2010). More specifically, factors include:

- **Price** is very important because if it is advantageous, it means a trader can target a bigger amount of securities and achieve a greater profit.
- **Time** is a crucial factor to ensure the algorithm gets first to the market. A number of algorithms incorporate a Time Weighted Average Price component, to calculate the average price of execution across a specified time range (e.g. the last hour of trading).
- The **fill ratio** is the possibility of an order to be executed expressed in percentage. This percentage can be calculated based on statistical analysis and historical data and sometimes there is a minimum threshold for this percentage that is quite reliable.
- The **total cost** of the possible transaction has to be calculated to avoid having a transaction whose profit is less that its cost. The inputs to this calculation are: fees, commissions and taxes imposed by the stock market but also estimated "latent" costs such as opportunity costs, price movement during execution, fluid bid/ask spreads and other not specific inputs.

An important part of a HFT algorithm is the trading strategy that is followed. Generally speaking, those strategies monitor the markets and their products for imbalances in prices. When alerts are raised, a massive volume of orders is generated targeting at taking advantage of those imbalances (Chlistalla, 2011).

Depending on whether the HFT algorithm is responsible for making the decision or optimising it, strategies are accordingly divided in two categories: decision makers and decision optimisers. Decision makers are divided in four subcategories: Rebate Trading, Trading the Tape, Statistical Trading and Liquidity Detection Strategy. ***Rebate Trading*** takes advantage of the two-sided market and profits by earning the bid-ask spread (Chlistalla, 2011). Traders post bids to buy and upon execution post offers to sell. If an order is filled, the market pays the trader that filled it a rebate and charges a higher amount to the broker who took liquidity away. Liquidity rebate trading has been under criticism because it allows traders to basically trade for free by having their commission's costs and exchanges fees covered by the exchange. Trading the Tape strategy contains two subcategories: ***Filter Trading*** strategy and ***Momentum Trading*** strategy. Filter Trading monitors stocks and the news and when a minimum threshold is met, the algorithm buys. Sometimes, the monitoring of the news includes analysing pieces of the news and reaction to these pieces. In Momentum Trading strategy, the algorithm identifies imbalances between supply and demand and takes advantage of it by trading really quickly in order to restore the balance. NASDAQ sells a proprietary data feed (called "TotalView-ITCH") with information such as order and trade counts, order arrival rates, individual order volumes, and cancellation and replacement activity. Here it is easier to spot imbalances and predict the behaviour of other markets by placing orders and changing some parameters depending on the result (Leuchtkafer, 2010). ***Statistical Trading*** strategies' subcategories are ***statistical arbitrage*** and ***technical trading***. In Statistical Arbitrage, traders try to correlate prices between different securities and profit from imbalances in those correlations or they might try to correlate different forms of a tradable index (a derivative and its underlying). An example of this is a correlation between Coke and Pepsi. If one goes up the other one is expected to go up and the algorithm will jump on this expectation and cover the imbalance. The algorithm runs continuously calculating both values. These trades are easier to be executed because they involve little amount of data to be analysed (McEarchern-Gibbs, 2009). Technical Trading means to buy or sell based on pre-defined scenarios of recurring patterns on the stocks. In ***Liquidity Detection***, traders want to find out whether there exist large orders in a matching engine by sending out small orders (ping) to seek for large orders. When a small order is filled quickly, there is likely to be a large order behind it (SEC, 2010a).

Decision Optimizers include momentum ignition strategy, algorithmic shredding, and low latency strategies. ***Momentum Ignition Strategy*** is when the proprietary firm initiates a series of orders and trades in an attempt to ignite a rapid price move either up or down (Kauman, 2010). ***Algorithmic Shredding*** shreds information that would otherwise have been useful to other market participants. This term can refer to the breaking up of large orders into small, individual orders and using false bids and offers and other games to cover their intentions (Chlistalla, 2011). ***Co-location*** is a very important strategy that allows HFT traders to be as fast as possible because HFT systems are located in the same data centres as the stock exchanges. However, the major source of profit for HFT traders is their ability to bid in multiple markets where a low latency strategy can be applied. One of the proposed approaches for a low latency strategy across multiple markets is to add an intermediate node between the servers of the trader and the stock exchange (Wissner-Gross & Freer, 2010). Table 1 provides an overview of the aforementioned HFT trading strategies:

<table>
<tr><th colspan="5">Decision Makers</th><th colspan="3">Decision Optimisers</th></tr>
<tr><td>Rebate Trading</td><td colspan="2">Trading the Tape</td><td>Statistical Arbitrage</td><td>Liquidity Detection</td><td>Momentum Ignition</td><td>Algorithm Shredding</td><td>Co-location</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Filter</td><td rowspan="2">Momentum</td><td>Statistical</td><td rowspan="2"></td><td rowspan="2" colspan="3"></td></tr>
<tr><td>Technical</td></tr>
</table>

Table 1: Summary of HFT Trading Strategies

A ***flash order*** is a phenomenon that benefited from HFT speeds. Essentially, it is an order with marketable price that gets flashed to certain participants (that have paid a fee to subscribe to this service) before it is disseminated and can get traded by the rest of the customers. A flash order has a voluntary character and it is at a marketable price (SEC, 2009b). Prior to flashing, it interacts with any contra side at the NBBO and if there is no interest it gets flashed. High Frequency Traders must respond within one second. Only then, does the flash order get disseminated to other markets. The story of existence of flash orders dates back to the first days of NYSE and it is the equivalent to "the crowd" of NYSE (SEC, 2009b). Exchanges are required to make their best bids and offers available in the consolidated quotation data except orders that are executed immediately after communication or cancelled immediately. So a flash order's success is based on this: some traders have the privilege to see and trade on it before anyone else. A flash order benefited those who wanted to provide liquidity but didn't want to display their interest publicly. As a result, flash orders attract a lot of this kind of investors- in most cases representatives of big companies that do not want to reveal their strategies but wish to increase their chances of executing a transaction that they would not be able to execute in the displayed quotations markets. On the other hand, a flash order contains certain dangers as it could lead to a 2-tier market where the public would have no access. According to SEC (2009b), disadvantages include the lack of transparency, the information asymmetries and its impact on investor confidence. Flash trading undermines basic principles of fairness and transparency in markets by creating a market that conceals prices and price disparities from the general public. Market participants with the most advanced technology can take advantage of flashed orders before those orders can be viewed and filled elsewhere, using that information not always to fulfil the order, but rather to execute trades elsewhere based on this information.

The ***flash crash*** was named like this because it all happened within a time frame of minutes, like a "flash". On May 6 in 2010, a little after 2.30 p.m. the equities and futures markets experienced some weird conditions which got worsened because of HFT allowing a large amount of trades being executed ultra-fast (CFTC & SEC, 2010). During the hours before the flash crash, major equity indices fell over 4% compared to their price the previous day and in no more than half an hour their prices fell an additional 5-6%. Soon, they recovered and the end of the trading day found their prices no more than 3% from their closing price the previous day (CFTC & SEC, 2010). Over 20,000 trades across more than 300 securities were executed at prices more than 60% away compared to their prices the previous hours. Moreover, many of these trades were executed at prices of a penny or less, or as high as $100,000, before prices of those securities returned to their "pre-crash" levels. At 1 pm, LRPs in NYSE had already been triggered more times than in a normal trading day and various markets had a declining liquidity.

The events can be separated into four phases (CFTC & SEC, 2010):

I. From 1 pm to 2.41 pm, individual stocks had declined about 4% compared to their previous prices. It all started with an investment firm initiating a sell program to sell a total of 75,000 E-Mini contracts using an automated execution algorithm ("Sell Algorithm"). This was a classic case of algorithmic trading. The decision was to sell 75000 contracts to the June 2010 E-Mini Market to target an execution rate set to 9% of the trading volume calculated over the previous minute. The algorithm chose to do it without regard to price or time and managed to finish the trades in 20 minutes. All those selling trades were consumed mainly by HFT traders, fundamental buyers in the futures market and cross-market traders who trade based on imbalances between different product markets of the same security. Especially, the last category of traders was the one who transferred the crisis to other markets.

II. From 2.41 pm to 2.45.28 pm (a phase that lasted barely four minutes) trading volume had a dramatic increase while prices of the affected stocks decreased another 5-6%. During those critical four minutes, high frequency traders were alarmed because of the lack of demand. As a result they began to buy and then resell contracts to each other which generated a "hot-potato" volume effect as the same positions were changing between the same hands. Between 2:45:13 and 2:45:27, HFTs traded over 27,000 contracts, which accounted for about 49% of the total trading volume, while buying only about 200 additional contracts net.

III. From 2.45 pm to around 3pm broad market indices recovered but many stocks and other trading products suffered great price variations and recorded trades for as low as one penny or as high as $100,000. The explanation behind this is that there was a second lack of liquidity. As mentioned in (CFTC & SEC, 2010), automated trading systems used by many liquidity providers temporarily paused in reaction to the sudden price declines observed during the first liquidity crisis. These built-in pauses are designed to prevent automated systems from trading when prices move beyond pre-defined thresholds in order to allow traders and risk managers to fully assess market conditions before trading is resumed. As a result, participants found no demand of buying or selling interest and started getting rid of their shares in prices close to zero or infinitely high. These trades occurred because of so-called stub-quotes, which are quotes generated by market makers (or the exchanges on their behalf) at levels far away from the current market in order to fulfil continuous two-sided quoting obligations even when a market maker has withdrawn from active trading. We are going to describe stub-quotes in more detail in the next section of manipulation occurrences regarding HFT.

IV. The last phase, which initiated around 3 pm, allowed those stocks to recover and regain their losses a little before the closing time. Lastly, after the market closed, the exchanges cancelled all those obviously erroneous trades.

The events of flash crash allow us to highlight some issues regarding the market behaviour. It appears that the automated execution of a large sell order can trigger extreme price movements, especially when algorithms do not take price into consideration but care only to exhaust their pile of stocks. The interaction between automated execution programs and algorithmic trading strategies can cause disorder in the market which can propagate rapidly. When there is significant volatility, high trading volume is not necessarily a reliable indicator of market liquidity. Furthermore, stock markets are highly connected and therefore, knock-on effects can be significant. There is usually not a problem if one participant decides to withdraw during a trading phase but if large numbers of traders do the same then a liquidity crisis might arise.

Manipulation Acts in HFT

So far there has not been any confirmed case of market manipulation that HFT has been blamed for. However, this paper attempts to explore if there are any "weird" occurrences that could provide manipulators with an opportunity. For example, traders could profit by inserting tiny amounts of latency in transactions. Market monitoring can only be efficient if latencies can be measured and controlled. Existing monitoring methods can detect anomalies in milliseconds but not in microseconds (Kay, 2009). It is possible for a trader to use side-channel attacks (indirect information related to the computer such as the electromagnetic emanations from screens to understand what is happening in the machine) to create small delays between orders and their execution that would result to his advantage. What these traders would be doing is send an extreme number of packages through a data stream, which would delay the data long enough for someone to get first in the market and profit from them and because these delays happen in scale of microseconds, they would go unspotted (Kay, 2009).

The flash crash brought onto the surface two phenomena: quote stuffing and stub-quotes. ***Quote stuffing*** is a phenomenon that takes place when a broker or trader sends an extremely high number of quotes (maybe thousands) for one stock in a single (or less) second (Nanex, 2010a). Sometimes these quotes may be well out of the National Best Bid/Offer so they are not destined to be executed, as we will see further down when talking about stub-quotes. On the other hand, these quotes might be of a normal price and get executed. In this case, we often observe a large number of quotes or trades get cancelled right after. Nanex (Nanex, 2010b)keeps a record of the most interesting occurrences of quote stuffing which include cases with 4000 quotes within 2 seconds in one exchange. The first time this phenomenon was detected was because of analysing and visualising these quotes. During this process, peculiar shapes were detected (Nanex, 2011).

Figure 3 shows one of them called "the knife", which appeared when observing the quotes of a stock in the BATS exchange (Nanex, 2010c). The red line that resembles a knife shows the offers while the deep red one that is below that and it's a fairly straight line shows the best offers at that time. One can notice that the offers are not trying to match the best offers therefore they have low chance of getting executed and that the offers have symmetry in their prices. It can be argued that these algorithms are creating noise in the market to confuse other traders (Madrigal, 2010). The firm that sends them could ignore them but for the rest of the firms it is difficult to discriminate between these quotes and regular bids and this fact gives them an advantage of milliseconds that is crucial in today's market.

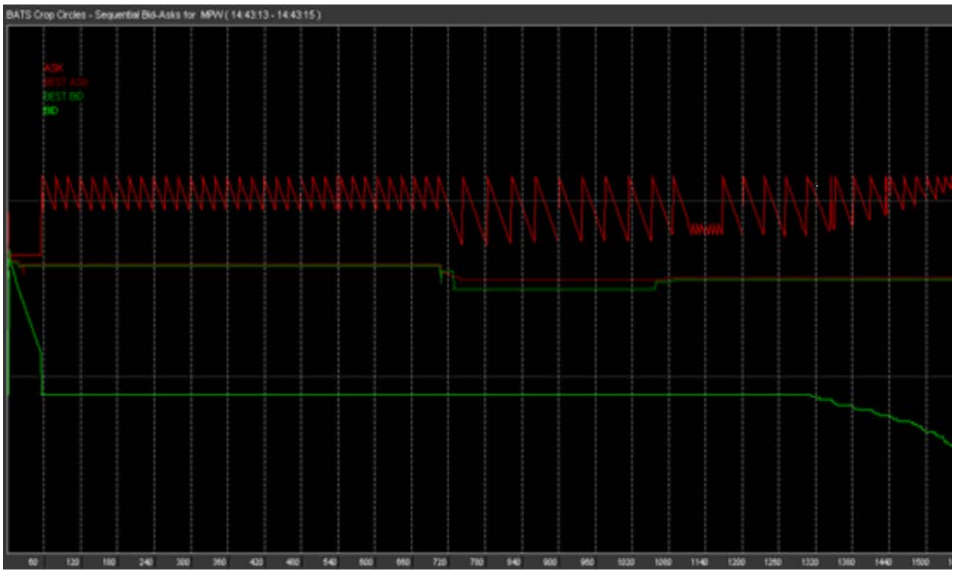

Figure 3: Knife (Source:(Nanex, 2010a))

Quote Stuffing serves two purposes. Firstly, it creates the impression that there is non-existent demand for a particular stock. When quote stuffing appears in the form of quotes that are within a normal price range, it creates a false impression about the direction of a price. Most of the times those quotes get cancelled right after being submitted by the firm itself. Secondly, it delays the market systems and also the competitors' systems not only because they are trying to make sense out of all these quotes but also because these quotes queue up on a market's system which adds additional delay to already heavily used systems. The reason of the delay is that within an exchange, data is carried on a communication link but those links have a fixed capacity. For example a T1 line carries 24 channels of 64Kb/s. This means that it can basically carry 24*64*1000=1536000 bits every second. If an exchange was using a T1 line, then when it would receive more quotes/second than what could be carried through a line, there would be a delay.

Figure 4 shows how much the number of quotes per day has increased over the years (Nanex, 2010d). Information comes from three different data providers of consolidated quotes: Consolidated Quotation System, NASDAQ and Options Price Papering Authority (OPRA). It is clear in Figure 4 that the number of quotes after 2010 has doubled compared to 2008. With these rates, it is difficult to predict what the needs in capacity will be in the future. Delays are apparent not only within one exchange's systems but also with regard to disseminating information to consolidated databases in order to calculate NBBO. As a result, at least in the second case somebody who has subscribed directly to the exchange's feed (where dissemination is faster as it is not consolidated) gets a hand on data faster. It is important to mention here that data leave the same time to individual exchange feeds and consolidated feeds but the latter experience latencies exactly because it is consolidated and it has to concentrate data from all the participating exchanges. As a consequence, investors could feel their orders are not treated, as they should be, based on the information they have and that they are disadvantaged compared to subscribers of proprietary feeds (Nanex, 2010a).

A ***stub-quote*** is a quote at a price so far from the prevailing market that normally its aim is not to be executed at all. There can be two kinds of stub-quotes, automatic ones and quotes sent by the market makers (CFTC & SEC, 2010). A market maker has to maintain a continuous two-sided quotation at all times. When there is no external quote available, he should trade from his own account. If he does not want to provide liquidity or his liquidity is exhausted, he could submit a stub-quote. The next question to be addressed is why someone considers bidding an apparently not competitive quote as it happened in the Flash Crash. According to (CFTC & SEC, 2010), there are many reasons why someone would trade in such prices. Some participants responsible for routing customers' orders think that they are obliged to satisfy a customer's wish at the NBBO and when NBBO lies in stub-quotes levels then the trade is executed in those prices. Some participants assume that the trade will be broken afterwards and want to avoid orders accumulating in their systems. Finally, in the case of algorithmic or HFT trading, some algorithms trade all the way down to stub-quotes thinking they are hitting NBBO (which at that time is equal to a stub-quote).

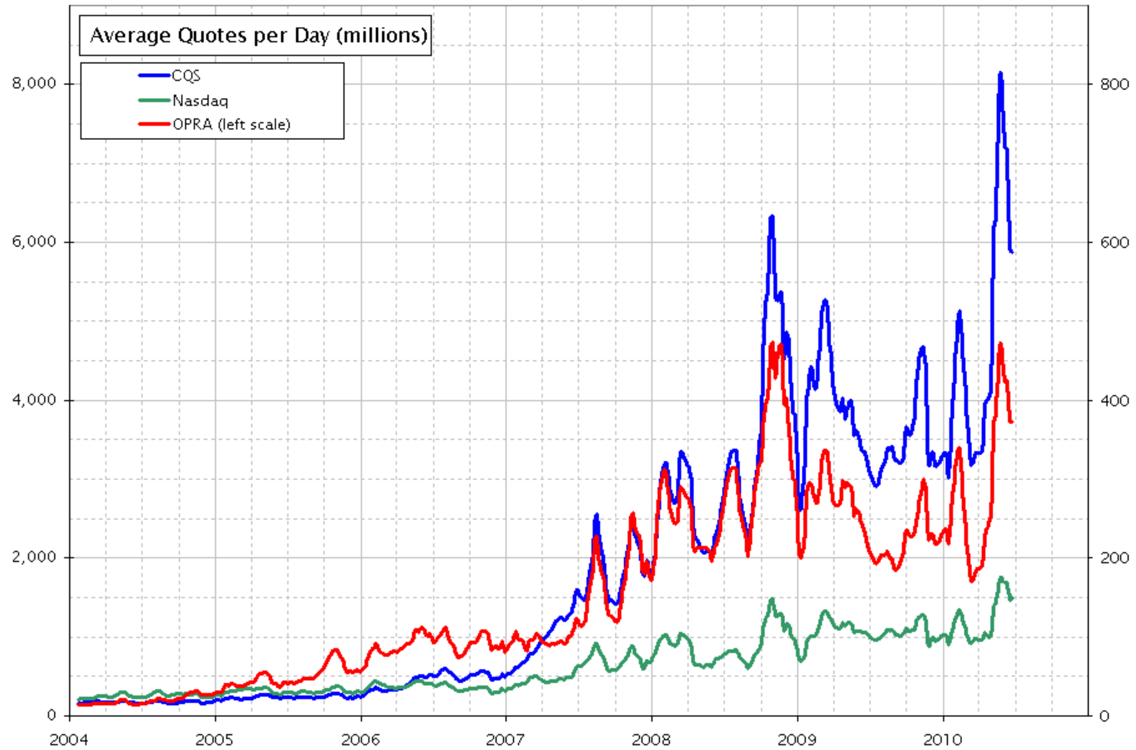

Figure 4. Quotes per day (Source:(Nanex, 2010d))

Regulation Updates since Flash Crash

HFT has been present in the stock markets for a few years now but it was not until the flash crash that regulatory bodies realised that maybe existing regulations are not adequate to prevent the market from experiencing another flash crash. In US, updates to regulation are proposed in the lifecycle of an order that apparently lacked sufficient control: broker-side orders, quotes and trades. As far as the broker-side is concerned, risk management controls are applied to brokers with market access. These controls target especially ***naked access*** i.e., allowing high-speed traders and others to buy and sell stocks on exchanges using a broker's computer code-their special pass, without requiring from them to fill any form or undergo any special control. Other controls include a) a price collar that will reject orders that are not reasonably related to the quoted price of the security b) post trade surveillance for manipulation should occur in a timely fashion c) compliance with regulatory requirements should happen in a pre-order entry basis and d) rejection of duplicate orders (SEC, 2010a).

Regarding flash orders, there has been a proposal to eliminate them as they benefit only those participants who have access to HFT systems (SEC, 2009b). A possible solution would be to include everything in the consolidation tape so that there are no orders flashed to certain participants but rather they all see them. New stricter rules could also be applied for the price of quotes. A rule that is seen as necessary in order to promote fair and orderly markets, protect investors and reduce the risk of trades occurring at irrational prices is the ***Quotation Standards for Market Makers*** rule. This states that any quote cannot be more than a certain percentage away from the NBBO (SEC, 2010b). If the stock belongs in the S&P or Russell 1000 indices and the quote is placed during market hours then the quote cannot deviate more than 8% from the NBBO. If the quote is about the aforementioned stocks but it is placed during pre-market hours then it should not be more than 20% away from the NBBO. Finally, if a quote is made about one of the remaining stocks then it should be within 30% of the NBBO. In the absence of a NBBO, same percentages apply but consolidated last sale should be used as a reference point. Table 2 provides a summary of this rule.

Which stock does it include?	**When is this rule applied?**	**What is the percentage of deviation?**
S&P, Russell 1000, ETPs	Market hours	8% (with an additional 1.5%)
S&P, Russell 1000, ETPs	Pre-market: before 9.45am and after 3.35pm	20% (with an additional 1.5%)
remaining NMS securities	Market and Pre-market hours	30% (with an additional 1.5%)

Table 2: Quotation Standards for Market Makers Rule

In order to constrain sudden movement in prices of a stock, SEC proposed an additional rule (SEC, 2011) that requires from listed exchanges to disseminate a special indicator over the Consolidated Tape resulting in a trading pause. This rule is called ***Inter-Market Volatility Trading Pauses*** and was firstly applied to the stocks that belonged in S&P index (Standard & Poor's, 2012) to be slowly expanded to the rest of the stocks as shown in Table 3. According to this rule, trading will pause for five minutes if the price moves more than 10% from the price in the preceding 5-minute window. If prices deviate from those boundaries an additional percentage, then these trades will be characterised as erroneous and will be cancelled. An ***erroneous trade*** is the last stage a mistake is allowed to arrive.

Applied Since	**Which Stock is Involved**	**What does the rule say**
June 2010	S&P	If price moves >=10% from a price in the preceding 5-min period, pause trade for 5 minutes
September 2010	S&P, Russell 1000, ETPs	Same as above
June 2011	Include all NMS securities	Same for the previously included stocks. For the remaining: If price <$1 => 50% If price >=$1 => 30%
August 2011	Limit up limit down	

Table 3: Inter-Market Volatility Trading Pauses

For similar reasons, the European Commission developed the Review of Markets in Financial Instruments Directive (MiFID) and Market Abuse Directive (MAD). Although, the financial crisis does not seem to have resulted in an increased volume of market abuse in the EU, it has brought onto the surface how important it is to react quickly to information for the average investor's confidence to the markets (EU, 2010a). As far as MAD is concerned (EU, 2010b), one of the proposals is to extend the definition of market manipulation to include any attempt to secure by person (or multiple persons acting in collaboration) the price of one or several trading products at an artificial level. The scope of the directive could be extended to include other markets such as OTC and other trading products such as derivatives while new papering requirements could be defined(EU, 2010b). The flexibility that MAD offered to the member states regarding the implementation of the regulatory framework has resulted in great variations between countries. Therefore it has become very challenging for firms to trade in different markets, as they have to take into consideration the different variations of the rule.

In the European Commission, the MiFID consultation attempts to address a number of issues of concern to financial markets (EU, 2010a). This includes a proposal to define HFT as a subset of algorithmic trading and a proposal that HFT firms should be asked to register as investment firms since even a very small firm could behave in the same way as a large one. It is all about the software they use- and not the number of employees as it is relatively straightforward nowadays for an individual trader to set up their own HFT trading platform (Chan, 2008). This registration will mean stricter regulations and robust risk controls before accessing the market i.e., on the broker's side (EU, 2010a). As part of the MAD consultation, feedback has been requested on whether companies that use algorithmic trading should be obliged to inform the appropriate authorities about the algorithms they use and how they function(EU, 2010b). Another proposal is that if a HFT trader executes significant numbers of trades in financial instruments on the market then he should continue providing liquidity in that financial instrument on an on-going basis subject to similar conditions that apply to market makers. As far as the trading venues are concerned, there are numerous proposals. Trading venues could have circuit breakers and perform stress testing to ensure resilience of their systems. They should also offer access to co-location in an equal and fair way to everyone. It is also proposed either that orders should remain valid more time in the order book before being cancelled or that the ratio of orders/transactions calculated for each participant should not go above a specific level. Finally, there is a suggestion for the creation of a post-trade consolidated tape for the whole Europe, which could be available to subscribers at a reasonable price (EU, 2010b). However, a pre-trade consolidated tape system similar to the one in US, would increase costs and it is quite difficult achieve as European markets are not as harmonised compared to the U.S. markets.

Comparing US and Europe in terms of regulation updates, it is obvious that Europe is still making basic steps in the field of HFT. For example, if there is no consolidated tape but still participants are permitted to trade in any market, there is no way for them to know if they are bidding the best price available and therefore achieving maximum gain. Furthermore, there has been no proposal regarding stub-quotes. Of course even if there had been, it would concern individual markets, as there is no European best bid/offer calculated on a European basis. On the other hand, MiFID proposes the establishment or an orders/ trades ratio, which will prevent quote stuffing. For the moment there is no comparable provision in the US.

Real-time Market Monitoring

In EU, it is estimated that between 13 to 40% of total share trading is from HFT (EU, 2010b). This implies that the use of real-time monitoring facilities could provide a possible solution that will allow markets and regulators to discover patterns and outliers in trading events with low-latency. One of the technological areas that could be investigated is ***stream processing systems*** that allow for the processing of input streams of trading transactions without the need to store them (Stonebraker, Çetintemel, & Zdonik, 2005). ***Complex event processing*** (CEP) is a stream-processing engine that can apply business technology techniques to events without the need to store those events by making it easy to identify ”complex” sequences of events (A followed by B, then C) with temporal (within 5 seconds) or spatial (within 5 miles) constraints (Palmer & Džmuráň, 2008). It had been successfully applied across the life cycle of an HFT trade. For example, firms use it as the core of algorithmic trading: “Buy 200 shares of ACC if the price of IBM is 3% higher than in the last 30 seconds”. Recently though, it is being considered as a possible solution for market monitoring.

The fundamental difference between CEP and other methods used in market monitoring is that instead of taking events and running queries over them, you take the queries and run the events through them. It allows for pattern recognition and also has rule-engines that raise alarms when they spot interesting patterns. Manipulative scenarios could be argued that are known and their behaviour has been studied in the literature. For example, a regulator may be looking for a certain increase of a stock's price that is immediately followed by another increase of another stock's price. Certain patterns keep coming up so it is wiser to index those patterns in multiple tables and stream all the data past them until you find a match (Rooney, 2011). For example, an effective CEP system could keep track of executed and cancelled orders as they stream and place them as input to a correlation engine that pairs executed and cancelled orders from the same participant within a specific timeframe. When the ratio of total cancelled to total executed orders goes beyond a threshold, an alert will be raised (Mukherjee, Diwan, Bhattacharjee, Mukherjee, & Misra, 2010).

However, with the increased sophistication of technology, manipulation attempts are not always pre-defined and manipulators might employ new scenarios. Even though Complex Event Processing is efficient when it comes to spotting existent scenarios within streaming events, it is not as useful when it comes to observing the data and discovering new manipulation scenarios. Therefore an effective monitoring system should be able to use unsupervised methods (Ferdousi & Maeda, 2006). Unsupervised methods do not need prior knowledge of fraudulent and non-fraudulent transactions in a historical database, but instead detect changes in behaviour or unusual transactions. An advantage of using unsupervised methods is that previously undiscovered types of fraud may be detected and could be used as a complementary to complex event processing. One of the well-known examples of unsupervised methods is ***Peer Group Analysis*** (PGA) (Ferdousi & Maeda, 2006). This method analyses the evolution over time of a given object (the target) relative to other objects that have been identified as initially similar to the target in some sense (the peer group). The success of this method lies on statistical modelling over a period of time. PGA detects individual objects that begin to behave in a way distinct from objects to which they had previously been similar. Each object is selected as a target object and is compared with all the other objects in the database, using either external comparison criteria or internal criteria summarising earlier behaviour patterns of each object. Based on this comparison, a peer group of objects most similar to the target object is chosen. Furthermore, it is not only important to spot a manipulative pattern when it takes place but it is equally important to be able to investigate alternative scenarios, be able to integrate pieces of information from different sources, be able to investigate cross-border scenarios and in general, be able to support the activities of a human market monitoring analyst (Diaz, Zaki, et al., 2011).

4. Case Studies

In the previous sections, we presented a broad review of how modern financial markets operate and the challenges that have arrived after the introduction of new high frequency trading technologies. In this section, we study two case studies that relate to stub-quoting and quote-stuffing as these scenarios help us illustrate the kind of issues in trading and monitoring that may arise when using the HFT technologies. The following sub-sections discuss each of the case studies and identify what measures could be implemented to solve, or at least mitigate, some of the problems that are presented.

4.1 Stub-quotes analysis, and NBBO calculation related issues

This section discusses the analysis of a stub-quoting case. More specifically, it discusses the dataset used, the preprocessing of the data, the analysis scenarios, the results and their implications. A stub-quote as was explained earlier, is a quote that is far away from the National BBO and it usually lies in non-marketable levels (either close to zero or extremely high). It could be argued that a stub-quote puts in danger the stability of a market, as there is the risk that this quote will be executed under stress conditions where liquidity is exhausted, similarly to the events that took place during the flash crash. A monitoring engine should distinguish valid quotes from stub-quotes and not permit the latter to be executed in a trade. This requirement comes from the ***quotation standards for market maker*** regulation shown in Table 2 (SEC, 2010b) that was valid at the time of the flash crash. The quotation standards depend on the type of stock and the time that the order is placed and define a specific percentage that the quote can deviate from the National Best Bid/Offer.

The selected dataset concerns the trading history of the stock of Market Vectors Agribusiness (stock symbol MOO) and iShares MSCI EAFE (stock symbol SCZ) on May 6, 2010 during the flash crash in BATS stock exchange. The specific stocks and time frame were selected because they are indicative of how the HFT market behaves during stress conditions. The MOO and SCZ stocks both belong in the last category of the quotation standards for market maker regulation (see Table 2) so a quote for those stocks should not be more than 30% away from the NBBO to be considered as valid. The dataset was obtained from NASDAQ Data-On-Demand (NASDAQ OMX Group, 2011) and includes all top of the book quotes sent to the exchanges on the 6th May 2010.

Within the same second, quotes from various market makers are provided in chronological order in milliseconds. Every new quote made by a market maker is a revision of the prevailing quote and supersedes the previous quote, either because the previous quote was consummated by a trade, or some of the existing bids and asks were modified or expired or cancelled by the market participants themselves, or there was an influx of new bids and new offers from market participants within that exchange. All the quotes were treated as market maker quotes which is a simplification of what would normally be the case. However, from the datasets it is not possible to distinguish market maker quotes from non-market makers ones. This assumption can be considered as a worst case scenario analysis.

The first step in the analysis is the calculation of the National Best Bid/Offer. For this, it was assumed that all markets operate on the same “clock” and the timestamps for the quotes are all fully synchronized and comparable. The calculation of the NBBO was done across all markets and it was calculated on the basis of the best bid and offer at the end of every second. More specifically, for each market center we selected the last bid and offer quotes of each second and then choose the best bid and offer across all markets to be the national best. An alternative way to calculate the NBBO is to calculate the best bid and ask quotes during a whole second across all markets. That is, within a second, one way to calculate the NBBO considers the "best of the last" of the quotes and alternatively, one can use the "best overall quote”. The disadvantage of the alternative way is that the best quote within a full second may not be valid or "alive" at the end of the second due to the order being expired, matched, or cancelled before the second was over.

An important matter for the calculation of the NBBO relates to the **"zero-duration" quotes**, which is defined as a quote that is alive for less than 1 millisecond. A trader might argue that a quote with zero duration is intended to be executed immediately if possible or not executed at all. This seems to be reasonable from a business perspective as it assumes that the matching process should take place as soon as the quote arrives at the exchange. Quotes are timestamped with a millisecond granularity and enter a queue for processing. The quote is then checked against both the local order book and the NBBO.

This introduces another important issue for the monitoring of quotation standards. If the incoming zero duration quote is better than the actual NBBO price, we assume that it will take the best position in the book, and thus update both the correspondent NBBO tape and the best positions in the local book. However, this may create secondary issues as long as the NBBO remains unchanged for the following second, the NBBO will contain prices that are not really alive, or that were only the best for less than one millisecond. Moreover, if no further corrective actions are taken this glitch can be propagated to other markets as they will take the best price in the NBBO as their reference price and re-route orders correspondingly to the market were the best prices are available. This will increase the traffic of re-routed messages to a market which may not have the necessary liquidity to match the incoming orders, and in case they do have the liquidity, orders will match at prices that are no longer valid. Although we arbitrarily chose to update and disseminate the NBBO every second, this is an important assumption because even if the NBBO is updated every time a new best quote is received, the time between updates may not be long enough for the information to propagate to all linked exchanges and traders, and thus, different exchanges and traders may work with different versions of the NBBO depending on how fast or slow they receive and process the incoming information. This uncovers a critical situation; if the baseline price for the calculation of the compliance of the quotation standards rule is not uniform across exchanges, the same quote could be considered valid in one exchange and not valid in another. We call this phenomenon the **“zero duration oxymoron”**

Assuming that this problem is ignored, we proceeded to estimate the distance or gap between a bid or ask quote with respect to the one second-update version of the NBBO and study what proportion of such quotes were inside the boundary that is considered valid according to the quotation standards rule. The selected period included all quotes between "14:29:00" and "14:30:35", both extremes included.

Stub-quote Analysis for MOO

Figure 5 presents a graphical representation of the “inside” or “outside” the quotation standards analysis. We can observe that for the period in analysis more than 55% of the quotes were outside the valid quotation zone, i.e. they are stub-quotes. Following the colour coding of the bars, we can also appreciate that almost all of the stub-quotes were submitted to the 'Z' BATS market.

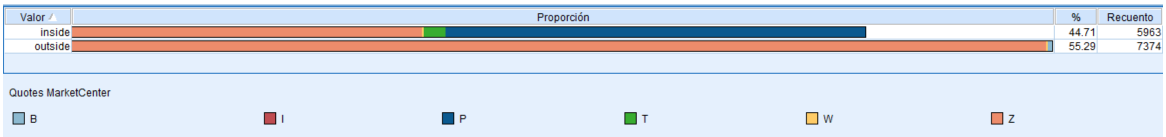

Figure 5: Proportion of Bid and Ask quotes that follows the quotation standard for MOO.

Figure 6 focuses on bid quotes, and the distance between the NBBO and each bid quote is represented as a bid gap. The colour of each point represents the market to which the quote was sent, the shape represents if the quote was inside or outside the valid zone, and the size of the point reflects the number of stocks that were quoted.

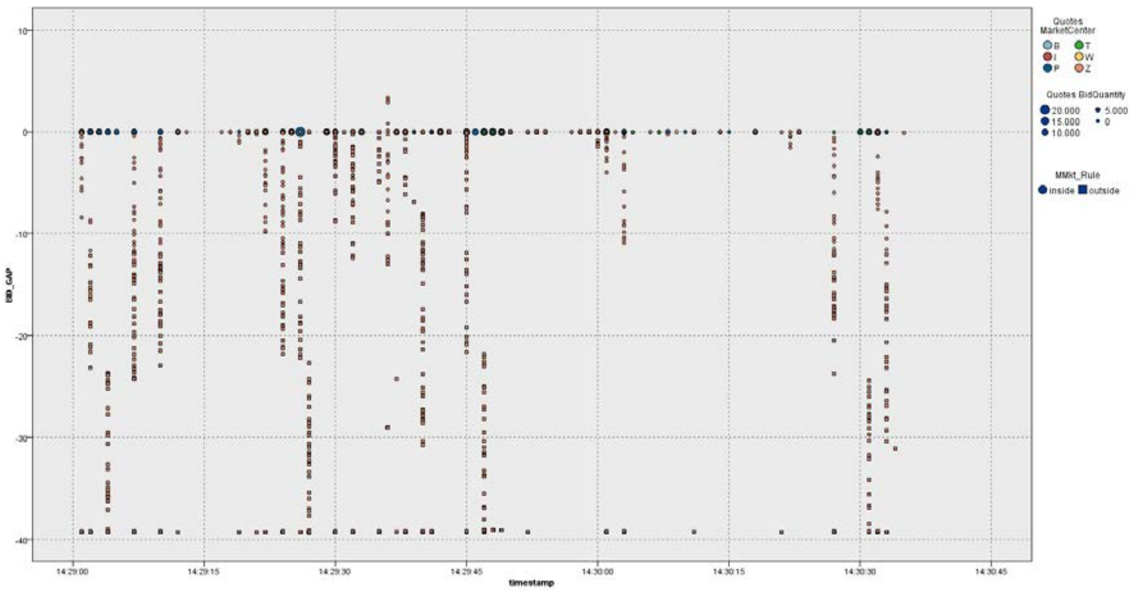

Figure 6: Detailed Bid quotation standard Analysis for MOO

From Figure 6, we can observe that a significant proportion of quotes were up to $40 away from the NBBO, a great proportion of which were actually more than 30% away of the National Best Bid (NBBid). Moreover, it is possible to notice that the majority of invalid quotes were sent to the 'Z' BATS market and that they were valid for a very short period of time, i.e. less than 500 milliseconds

Figure 7 give us more information with respect to the typical size of valid and invalid quotes. It is possible to appreciate that 100% of the quotes of small size (size less than 50) were outside the quotation standards, and similarly, 66% of the quotes with sizes from 51 to 200.

Quotes BidQuantity_cat		inside	outside	Total
0 to 50	Count	0	36	36
	Row %	0.000	100.000	100
	Column %	0.000	0.488	0.270
2000+	Count	1601	0	1601
	Row %	100.000	0.000	100
	Column %	26.849	0.000	12.004
200 to 2000	Count	1003	760	1763
	Row %	56.892	43.108	100
	Column %	16.820	10.306	13.219
50 to 200	Count	3359	6578	9937
	Row %	33.803	66.197	100
	Column %	56.331	89.205	74.507
Total	Count	5963	7374	13337
	Row %	44.710	55.290	100
	Column %	100	100	100

Cells contain: cross-tabulation of fields (including missing values)

Chi-square = 2,593.004, df = 3, probability = 0

Figure 7: Bid quantities analysis for MOO

Figure 8 and Figure 9 show the same analysis for the ask quotes. From these figures, it is possible to infer that a similar phenomenon took place i.e., that an important proportion of ask quotes was up to $1,000,000 away from the NBBO, that the majority of such quotes was of small size (less than 200) and that were submitted to the 'Z' BATS market.

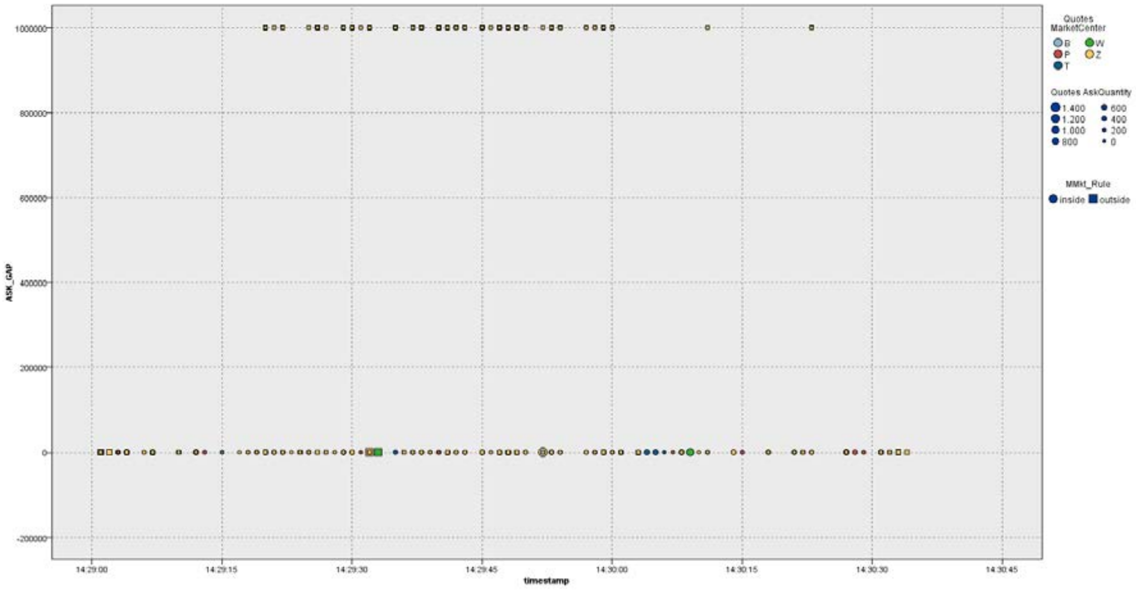

Figure 8: Detailed Ask quotation standard Analysis for MOO

Quotes AskQuantity_cat		inside	outside	Total
0 to 50	Count	0	25	25
	Row %	0.000	100.000	100
	Column %	0.000	0.339	0.187
200 to 2000	Count	441	613	1054
	Row %	41.841	58.159	100
	Column %	7.396	8.313	7.903
50 to 200	Count	5522	6736	12258
	Row %	45.048	54.952	100
	Column %	92.604	91.348	91.910
Total	Count	5963	7374	13337
	Row %	44.710	55.290	100
	Column %	100	100	100

Cells contain: cross-tabulation of fields (including missing values)

Chi-square = 24.294, df = 2, probability = 0

Figure 9: Ask quantities analysis for MOO

Stub-quote Analysis for SCZ

Performing a similar analysis for the SCZ stock, we can observe in Figure 10 that an even greater proportion of quotes, 84.11%, were outside the quotation standards.

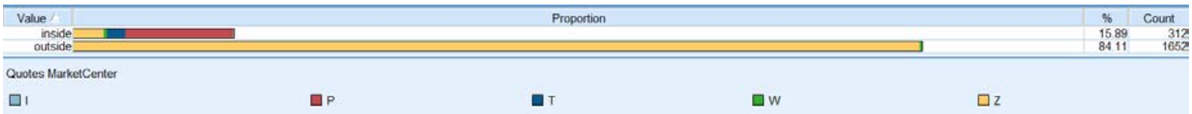

Figure 10: Proportion of Bid and Ask quotes that follows the quotation standard for SCZ

In Figure 11 focus on bid quotes, and the distance between the NBBO and each bid quote is represented as a bid gap. The colour of each point represents the market to which the quote was sent, the shape represents if the quote was inside or outside the valid zone, and the size of the point reflects the number of stocks that were quoted. We can interestingly observe that there seem to be a pattern in which bid quotes sequentially reach lower levels, perhaps with the intention of confusing other traders.

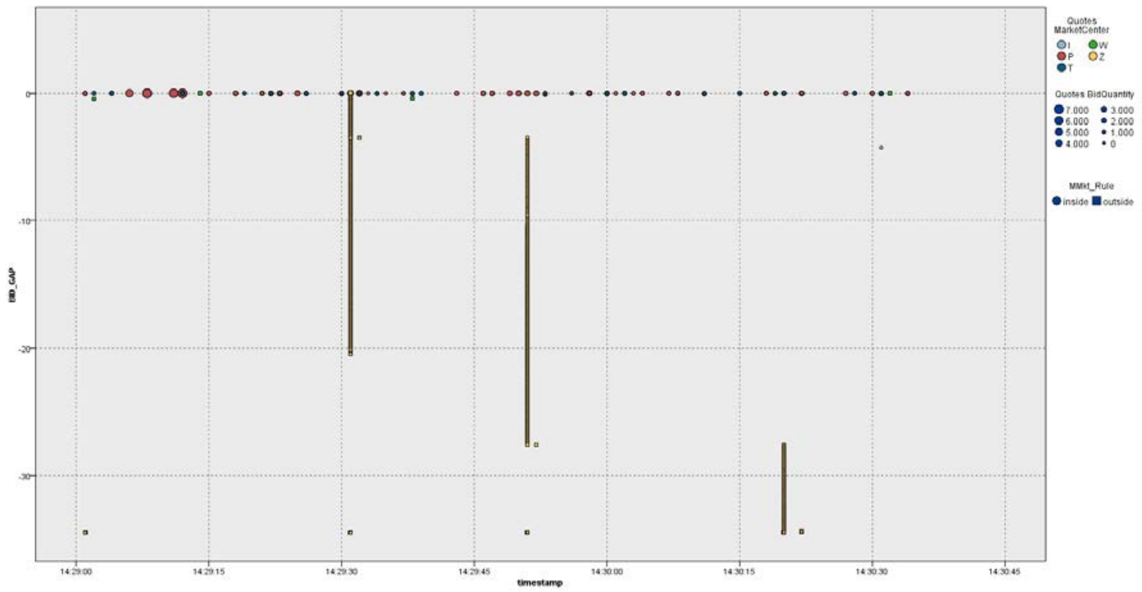

Figure 11: Detailed Bid quotation standard Analysis for SCZ

Figure 12 give us more information with respect to the typical size of valid and invalid bid quotes. . It is possible to appreciate that more than 94% of the bid quotes of small size (size less than 200) were outside the quotation standards and that there were no quotes of size less than 50.

Quotes BidQuantity_cat		inside	outside	Total
2000+	Count	27	0	27
	Row %	100.000	0.000	100
	Column %	8.654	0.000	1.375
200 to 2000	Count	192	7	199
	Row %	96.482	3.518	100
	Column %	61.538	0.424	10.132
50 to 200	Count	93	1645	1738
	Row %	5.351	94.649	100
	Column %	29.808	99.576	88.493
Total	Count	312	1652	1964
	Row %	15.886	84.114	100
	Column %	100	100	100

Cells contain: cross-tabulation of fields (including missing values)

Chi-square = 1,254.711, df = 2, probability = 0

Figure 12: Bid quantities analysis for SCZ

Figure 13 and Figure 14 show the same analysis for the SCZ ask quotes. Figure 13 it is possible to infer that a similar phenomenon took place i.e., that a proportion of ask quotes was $1,000,000 away from the NBBO.

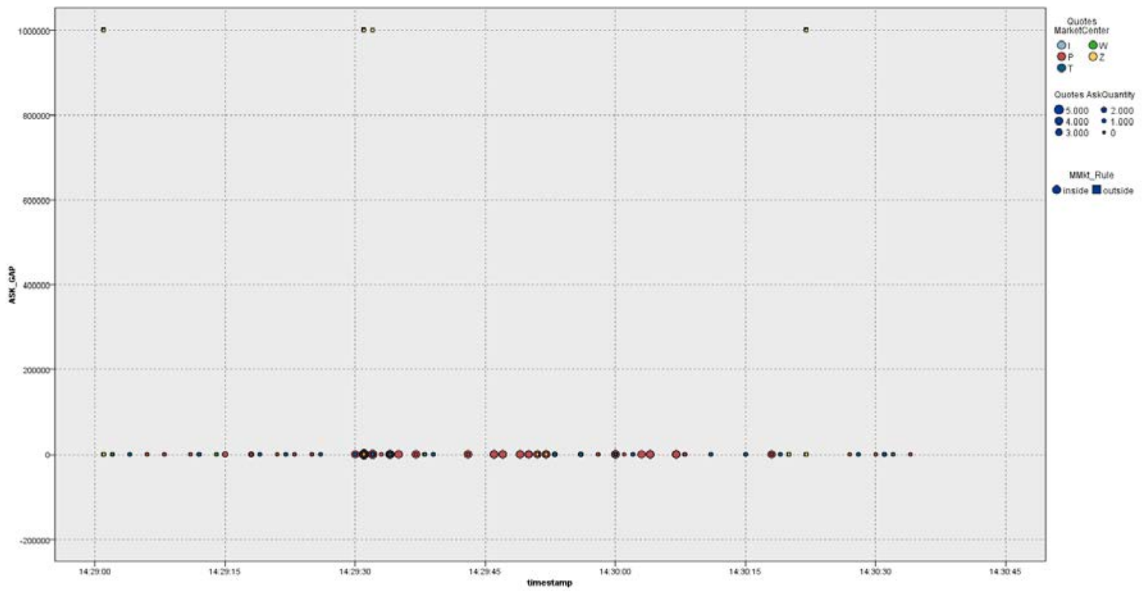

Figure 5.9: Detailed Ask quotation standard Analysis for SCZ

Figure 14 give us more information with respect to the typical size of valid and invalid ask quotes. It is possible to appreciate that the majority of the ask quotes were of small size (50 to 200) and more than 96% of them were outside the quotation standards.

Quotes AskQuantity_cat		inside	outside	Total
0 to 50	Count	0	4	4
	Row %	0.000	100.000	100
	Column %	0.000	0.242	0.204
2000+	Count	52	0	52
	Row %	100.000	0.000	100
	Column %	16.667	0.000	2.648
200 to 2000	Count	194	0	194
	Row %	100.000	0.000	100
	Column %	62.179	0.000	9.878
50 to 200	Count	66	1648	1714
	Row %	3.851	96.149	100
	Column %	21.154	99.758	87.271
Total	Count	312	1652	1964
	Row %	15.886	84.114	100
	Column %	100	100	100

Cells contain: cross-tabulation of fields (including missing values)

Chi-square = 1,489.093, df = 3, probability = 0

Figure 14: Ask quantities analysis for SCZ

The limitation of our analysis lies on the fact that the data came indirectly from the CQS (through NASDAQ DOD). This means that we only get the best bids and ask of every second and we do not see the full depth of the display books. On the other hand, if the “best” quotes (highest bids, lowest asks) are labeled as stub-quotes, we can be positive that at every second there were even more stub-quotes than what we analyse in this paper.

4.2 Quote stuffing analysis

The purpose of the quote stuffing analysis is to demonstrate the consequences of increasing dramatically the traffic of messages that are sent to an exchange and the implications of this phenomenon on quality of execution. More specifically, the consequences will be examined under the view of one of the SEC regulations that requires that investors should *always* have the opportunity to execute trades at the best possible available price (SEC, 2005). Under this, we assume that an investor should have the opportunity to have access to the NBBO prices and decide whether to place an order or not. Failure to succeed at this process would put brokers and traders at a disadvantage compared to other investors that have timely access to both valid and current information about the best prices.

To exemplify this, our quote stuffing analysis will focus on a particular stock i.e., the General Electric stock (symbol: GE). As before, the dataset was obtained from NASDAQ Data-On-Demand and include all top of book quotes between 14:43 and 14:47 on 6th May 2010 for three exchanges, namely NASDAQ OMX (Symbol B), BATS (Symbol Z) and NYSE Euronext(Symbol N).

Figure 15 shows the best bid price for each exchange. From inspection, it is possible to argue that there seems to be an almost perfect alignment between NASDAQ (blue) and BATS (green) bids prices, and that NYSE (orange) bid prices are “shifted” slightly to the right, i.e. representing a possible lag or latency that investors trading at NYSE seem to be suffering.

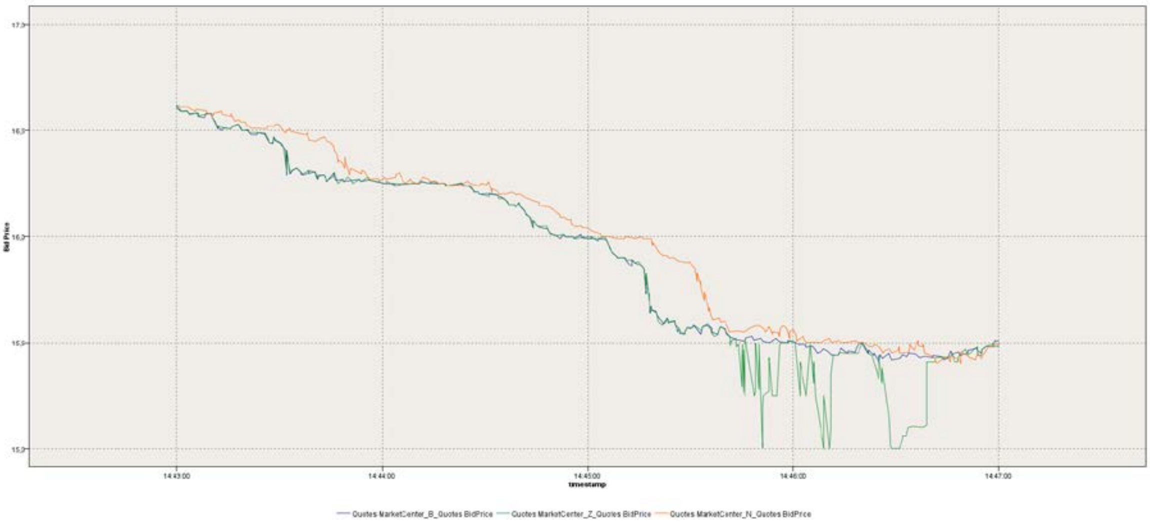

Figure 15: GE Bid prices in NASDAQ (B), NYSE (N) and BATS (Z)

According to Nanex (Nanex, 2010e), this shifting or lag between the prices at NYSE and the other markets could be explained due to the large number of messages (quotes) that were received by NYSE. In order to test this hypothesis, we first created an indicator that reflects the difference in prices for the best bid between the NYSE and the average of the best bid prices at NASDAQ and BATS. We then took the squared root of the average squared difference for intervals of 3 seconds, and accumulated the number of quotes (messages) that were received in that interval.

Figure 16 shows the result of plotting these two indicators. We can see how there seems to a positive relation between peaks of messages and the difference that it is produced. Whenever the number of messages to be processed by the NYSE exchange (red line) increases a difference in prices with respect to the other exchanges immediately follows (blue line).

Figure 16: GE average standard difference of bids between NYSE and BATS and NASDAQ and accumulated number of quotes for 3-seconds windows between 14:43 and 14:47

To confirm this, Figure 17 shows the scatter-plot of the same relation, including a linear trend that it is statistically significant at the 10% level (Pearson´s *r=0.198*, linear equation: Y=0.043+ 8.25E-005X, Adj. R^2= .026, F statistic= 3.034 [sig = 0.086], and t-statistic for $Beta_1$= 1.742 [sig = .086]).

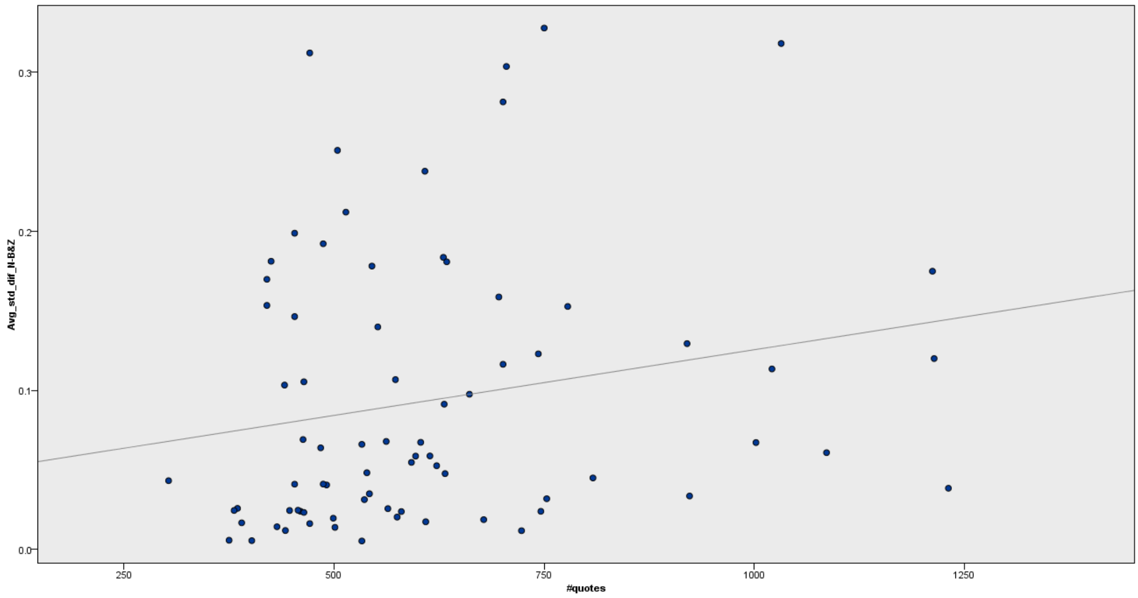

Figure 17: Scatter plot GE average standard difference of bids between NYSE and BATS and NASDAQ versus accumulated number of quotes for 3-seconds windows between 14:43 and 14:47

According to Nanex (Nanex, 2010a), the timestamping process of NYSE is to blame. They claim that NYSE stamps its quotes not the moment they arrive to their trading system but the time they are visible on the display book. This would explain this difference in price values. If there is a queue of quotes then the subscriber of the feed sees the first one on the queue but this is not the "real-time" quote. In fact the "real-time" quote would be placed at the end of the queue to be disseminated moments later (Nanex, 2010a). This would imply that when NYSE receives a lot of requests then its communication system gets delayed. This is a plausible explanation if we think that all quotes get disseminated through communication links with finite capacity as was discussed in Section 2. When a certain maximum capacity is reached then delays in the process of updating the book are inevitable.

Figure 15 has some blind points though. There are certain episodes in which increases in the traffic did not follow increases in the gap. In order to understand the phenomena with more detail, we studied the relation between the gap and the number of stub-quotes (percentage of quotes 8% away of the NBBO – rule applicable to GE stock) and the relation to the average life duration and size of the quotes.

Figure 18 shows the percentage of the stub quotes per exchange. As we can see, all the quotes for NYSE (symbol N) are within the 8% limit in relation to the NBBO so we can argue that the gap is not due to the number of stub quotes.

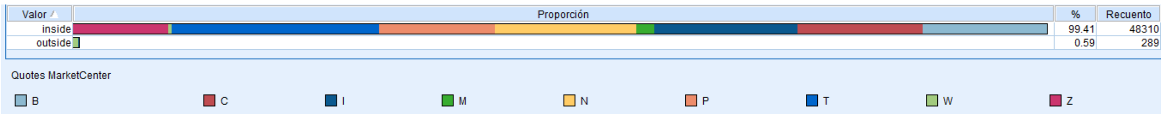

Figure 18: Proportion of Bid and Ask quotes that follows the quotation standard for GE

We then tried to analyse the duration (end-time of a quote minus start-time) and size of the quotes. Figure 19 shows the frequency distribution of the quotes duration grouped in ten groups of equal frequency (deciles) across all markets. Here we can see that the majority of the NYSE quotes (symbol N) are in class 2 – the shortest duration and this might indicate that because of the short duration, they stay less time in the display book and as a result, it can be argued that they create additional latency which can justify the gap between the NYSE and the other two markets.

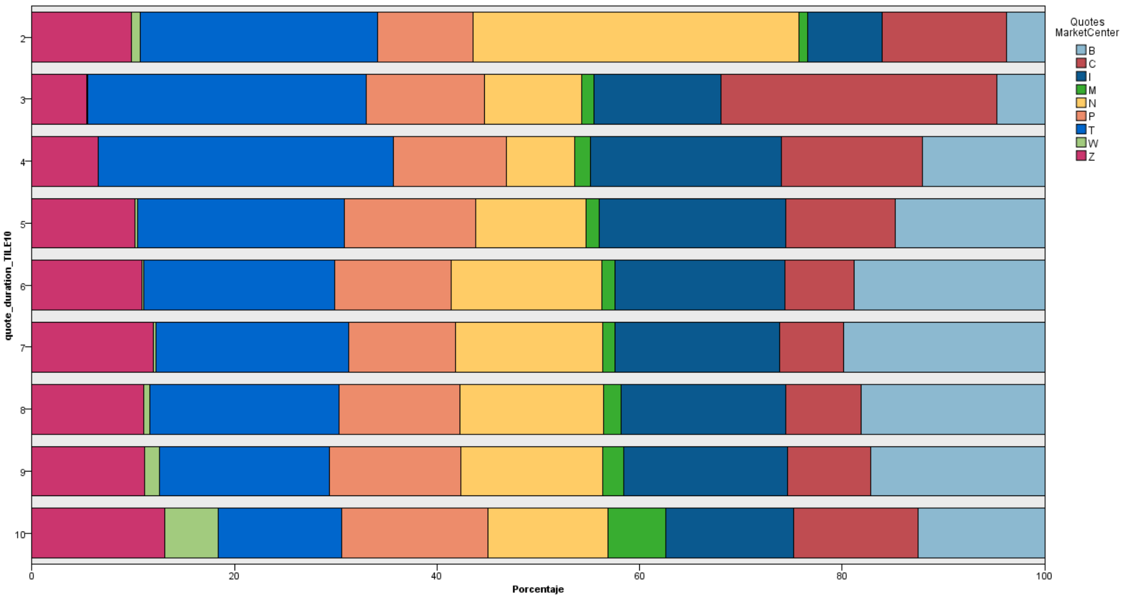

Figure 19: Lifetime of Quotes in NYSE (symbol N - orange)

Figure 20 shows the frequency distribution of the quotes sizes grouped in ten groups of equal frequency (deciles) across all markets. Here we cannot observe any significant pattern in the NYSE quote sizes (symbol N) and we can observe that in terms of percentages, the NYSE quote sizes are in general less than the other two markets. So, we can assume that quote size cannot provide an explanation for the gap.

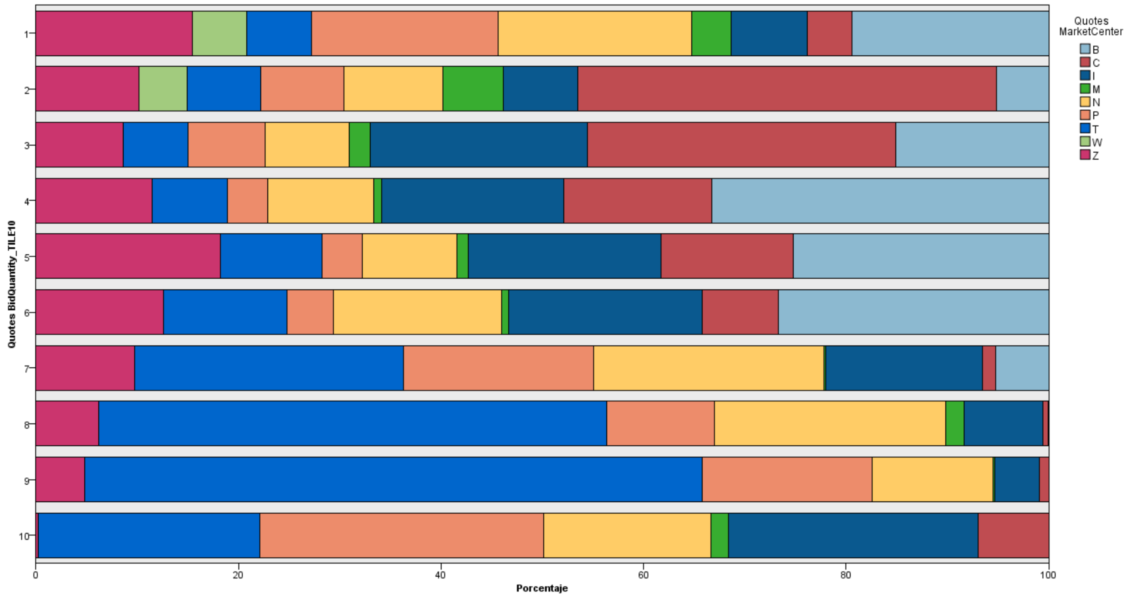

Figure 20: Size of Quotes in NYSE (symbol N - orange)

The limitations of this analysis lie again on the fact that we use data from the CQS. Ideally, we should be able to get all quotes made on NYSE that day. This could help to reveal more interesting observations in relation to the number of quotes, their prices, sizes and duration.

5. Summary

The paper discusses the broader context in relation to the way financial markets operate under HFT and the issues that need to be considered in order to understand better how existing systems operate. In order to achieve this, the paper examines the background of market monitoring and financial markets in order to gain familiarity with the domain and understand the characteristics of a market monitoring systems. Furthermore, existing regulations are examined for the US and European jurisdictions and relevant monitoring requirements that the design enhancements should satisfy are identified.

The paper attempts to answer whether there are certain conditions that could benefit market manipulators and it employs the use of business intelligence techniques to analyse quote stuffing and stub-quotes and identify what types of indicators could be employed for market monitoring purposes. Through the analysis of the two cases for quote stuffing and stub-quotes it is shown that it is possible, under certain conditions, to undermine the efficiency and integrity of the financial markets and that current market monitoring systems are not well-equipped to identify such trading scenarios in real-time. More specifically, the analysis shows that sometimes the existing market monitoring systems do not detect stub-quotes resulting in trades in peculiar prices. It also shows that the prices an investor sees can vary from exchange to exchange. This variation was correlated with the huge number of quotes an exchange may receive by one firm and it is shown that this can cause delays in the dissemination of real-time quote information.

Finally, the paper introduces the phenomenon of **"zero duration oxymoron"** where if the baseline price for the calculation of the compliance of the quotation standards rule is not uniform across exchanges, the same quote could be considered valid in one exchange and not valid in another.

There are certain limitations of this work. The datasets used were incompatible (different resolutions) and this raised issues when merged that could have been avoided. The lack of appropriate data for the analysis required is a major issue (Theodoulidis & Diaz, 2012). The cases that were studied are a sample of what is happening and they involve cases that SEC or Nanex brought to the surface. It is more than possible that there have been further manipulative events that have gone unnoticed or times when manipulation was possible but did not occur. Finally, this paper examines small datasets because of the challenges imposed by the very high volume of quotes and lack of optimised ways to run the experiments.

It is true, therefore, to say that on the experimental side, this paper just scratches the surface of what is known about cases of stock market manipulation in HFT and there are various implications of the proposed models that could be tested further. This type of analysis could be applied to even more stocks in order to understand if the occurrences that were spotted are parts of certain patterns that could be identified over time. Another idea is to obtain data from the exchanges that would present the full depth of the display book instead of only the best bids/offers at any moment. It would be useful to analyse the full quotes that are sent to an exchange every second instead of constraining the dataset to a specific stock. Regarding quote stuffing, additional cases could be examined in terms of the delays between NYSE and other exchanges and comparative analysis between the different cases could be carried out.

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