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Rovan Pinto

IMPACT OF FLASH CRASHES ON MARKET STRUCTURE

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UNIVERSITY OF VAASA
Faculty of Business Studies
Author: Rovan Pinto
Name Topic of the Thesis: Impact of Flash Crash on Market Structure
Name of the Supervisor: Vanja Piljak
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ABSTRACT

The Flash Crash of May 6, 2010 was one of the biggest flash crashes ever to be recorded in the history of the US stock markets. The Dow Jones Industrial Average sank down to 998.5 its highest intraday fall. Other indexes also met with the same fate resulting in a very low overall market sentiment. The impact of Flash crash created havoc in the market and new developments have come up in 2015 which points to manipulation. This clearly shows stronger need for regulatory intervention to curb such events from happening again.

The thesis investigates abnormal market returns over a period of one year starting from three months before the crash. The paper constructs an event time line to clearly indicate how stocks reacted before, during and after the Flash Crash. The paper examines abnormal returns from twenty one stocks of the Dow Jones Industrial Average. The results indicate that the stock return on the day of the crash is negative while the returns on subsequent trading days are low due to negative market sentiment towards the event. However the effect of the negative return is restricted only for one or two days after the crash.

KEYWORDS: Flash Crash, Algorithm Trading, Market Sentiment.

1. INTRODUCTION

Stock market crashes have been persistent since a long time. It has been taking place since the time of the great depression in 1929. Flash crashes differentiate themselves from the normal crashes because they crash without a valid reason and immediately recover in a span of few seconds. Flash crashes are always more critical than the normal crash and the consequence even worse. Flash crashes have a huge impact on the overall market structure. It affects not only the small common investor but also high volume traders like the institutional traders and foreign institutional investors. Technology has been rapidly increasing. Most of the trades taking place are driven by algorithms. Computer driven algorithms are capable of taking decisions faster than humans.

In this generation of algorithm trading where technology is improving the efficiency it also gives a lot of scope for errors. In recent times the algorithms have got so complicated and due to various glitches in the system or the trading software it could lead to flash crash. Regulators keep blaming algorithm trading for the flash crashes. But it is not necessary that flash crashes are only caused by algorithms. It could even be possible to cause a flash crash due to an error caused by the trader while punching orders. The May 06 2010 event of the flash crash caused havoc in the US markets. Dow Jones industrial average was down by 1000 points. Investors lost substantial amount of money and it greatly affected investor sentiment. The concern over the regulatory authority unable to curb such event does affect the investors greatly. It could also drive investors out of the market greatly affecting liquidity. The prime responsibility of the regulators is to protect the interest of the investors. But with events like flash crash occurring raises a lot of questions on whether regulators need to contribute more during events like flash crash.

The analysis of the SEC/CFTC report (report 2010) provided great insight into the events of the flash crash. The report noted that some stocks were traded as high as $100,000 while some as low as a penny. This shows how severely the trades were affected due to the crash. The report had suggested various possible factors that contributed to the flash crash. Some of the factors included loss of liquidity, execution of a large sell order in the E-mini and cross market arbitrage. But in 2015 the event of the flash crash took a very different turn as new developments started to come up on the cause of the flash crash. CFTC has accused a London based trader Navinder Singh Sarao and his company Nav Sarao Futures Limited PLC for using automated system to

manipulate the market on the day of the flash crash. The techniques used consisted of Spoofing and using Layering algorithm (CFTC v. Sarao, 2015) to create a false sense of direction that was favorable to him. Currently investigation are in progress against Navinder Singh Sarao and his company for their involvement in the flash crash. But this development has provided a new direction on the cause of the flash crash and it could provide opportunities for future research to find the cause of the crash by factoring in manipulation.

Immediately after the flash crash the need for stringent policies to curb such practices has taken utmost priority. However Angstadt (2011) has suggested in her paper not all regulation has been implemented. Similarly she also has mentioned that SEC/CFTreport (report 2010) does mention various recommendations but no specific timeline was given for its implementation. However certain key policies have come into immediate effect. The SEC/CFTC (report 2010) suggest that immediately after the crash it has implemented individual stock circuit breakers. Similarly new regulations have also been implemented in respect to broken trades. Such regulations contribute immensely in boosting investor confidence and can lead to a long term growth in the financial markets.

Various research papers have focused on the events of the flash crash. Most of the papers do agree that liquidity crisis holds prime responsibility for the crash which was again indirectly caused by certain contributing factors. Easley, Prado and O'Hara (2011) have suggested using a metric called as "VPIN" developed by them that could even have the possibility of avoiding the flash crash. Intermarket Sweep Orders (ISO) and their contribution surrounding the flash crash was also been a matter of debate in McInish, Upson and Wood (2014) and Golub, Keane and Poon (2012) paper. The effect of flash crash on shareholders wealth was studied by Boulton, Braga-Alves and Kulchania (2014). But the research done by them did not include the Dow Jones Industrial Average nor the volatility index "VIX". This paper takes forward their work and creates an extension to their existing literature by including an added time frame and focusing the impact on two major US indices S&P 500 and Dow Jones Industrial Average and also taking into consideration the role of the volatility index. This could help in better understanding and could provide more conclusive evidence in respect of the flash crash.

1.1 Purpose of the study

The main focus of the research will be on the events that took place on May 6, 2010 when the Dow Jones Industrial Average lost almost close to 1000 points. It was the second largest intraday fall in the history of Dow Jones Industrial Average. This event drew wide criticism among market participants. It raised serious question whether stock exchanges are fully equipped to handle such kind situation and what kind of risk management tools are the exchanges adopting to curb any further flash crash events. Researchers have published various articles based on this event and have tried to focus more on developing metrics that could indicate the probability of flash crash occurring before the actual event taking place.

The thesis will also try to concentrate on various aspects one being the negative effect that is observed in subsequent trading days after the flash crash has occurred. It is very common to see that markets open lower on the next trading day and there is a decline also in volumes in subsequent trading days. It is important to test whether such a negative effect is due to negative sentiments caused by the flash crash or just selling pressure due to profit bookings on higher levels. The common reasoning behind it is due to negative investor sentiment. It is very common to see that after such events investors are more cautious in their approach and often exit positions or book profit till the markets are stabilized and the volatility reduced. Investor sentiments form a very important aspect of the financial markets. Events such as the flash crash could drive away investors from the market that could result in loss of liquidity. Hence the following hypothesis will be tested:

H_0: The flash crash does not have negative effect on subsequent trading days.
H_1: The flash crash does have a negative effect on subsequent trading days.

The research paper from Boulton, Braga-Alves and Manoj Kulchania (2014) have found negative returns after the flash crash. Taking into account similar premise the above mentioned hypothesis could be justified to ascertain and provide further evidence on the negative impact of the flash crash on subsequent trading days. The focus of the analysis will be mainly be on the negative effect on subsequent trading days while other aspects will contribute to broadening the theory in regard to the flash crash.

The next aspect will be the impact of High Frequency Trading (HFT)/ Algorithmic trading on flash crashes. The use of modern technology has helped improve the speed of

trading up to microsecond giving HFT an edge over other market participants. Complex trading strategies are executed in seconds using such software. But the practical use of such software is still highly debatable. Whether such algorithms are actually helping traders to make surplus profit is still in question. But there is still a lot of debate on whether such algorithms are the cause of flash crash. The joint report published by CFTC and SEC (report 2010) on the events that took place on 6 May 2010 do clearly state that an automated execution algorithm (Sell Algorithm) was one of the main reasons for the flash crash. Similarly recent developments have also pointed to London based trader who might be involved in the flash crash using automated trading system to manipulate the market.

Circuit breaking mechanism also forms a core part of the financial markets. The volatility in the markets leads to more panic among investors which indirectly causes high selling situations. Circuit breaking mechanism halts the market for a stipulated period of time giving enough time to take account of the situation and come up with better quality decisions. Circuit breakers should have played a crucial role in curbing the flash crash but it did not happen. It is important to understand the nature and dynamics of the working of the circuit breakers to get a clear picture of the reason of its ineffectiveness. Similarly proper regulation should be drawn in respect to its working and investors should also be given better information so they could judge the risk in advance if there is a huge swing in the market.

The final aspect that needs concentration is more towards regulation. The increase in flash crashes indicates that risk management systems were not in place. It is the sole responsibility of the regulator to make sure that such events do not occur. HFT/ Algorithmic trading are often blamed by regulators to be the reason of flash crash. The regulators need to take a different perspective on the way these automated trading takes place. Transition often takes place from old technology to new technology, similar transition is taking place in most developed markets where most traders are switching from manual trading to high complex algorithms. Regulators in such situations cannot impose heavy restrictions on market participants but at the same time it should not give market participants excess freedom to trade on heavy quantities without testing the technology in use. New information has cropped up in 2015 regarding the flash crash as CFTC has alleged Navinder Singh Sarao a London based trader and his company Nav Sarao Futures Limited PLC for their alleged role in the manipulation and causing the flash crash. If the allegations turn out to be true then it could possibly open up loopholes in the system that need to be addressed immediately. Regulators need to take stringent

actions and try to close all possible loopholes in the system so that such events do not occur in the future.

1.2 Intended contribution

Flash crash has been in quite a debate ever since the crash of Dow Jones Industrial Average on May 06, 2010. Most of the research papers until now have focused on regulatory intervention, fragmentation and role of algorithm trading but there has not been substantial research on abnormal returns on a longer time frame. The research paper runs parallel to the research done by Boulton, Braga-Alves and Kulchania (2014) but also adds to their contribution by conducting analysis on a longer time frame and adding the volatility index "VIX" to study role of VIX before, during and after the flash crash. Longer time frames could help to focus on the aftermath of the event and see how investor sentiment changes at a later stage. Similarly VIX could help study the volatility and it would be interesting to take a count on the number of days volatility could remain high after the event.

The limitations of the thesis could be the in-depth review of the flash crash. Since the flash crash is a rare occurrence it makes it extremely difficult and be sure that the analysis could be validated. Since no crash has taken place before on this scale it is hard to create a comparison with other such events. Other limitations of the thesis include the impact of the flash crash on the financial markets across the world. Various researchers have documented the integration of the financial markets across the globe. US boasts of having one of the strongest financial markets in the world. Hence it would be interesting to see the impact of the flash crash on other market indices.

1.3 Structure of the thesis

The thesis has been structured broadly across six different chapters. Chapter one focuses on the introduction aspect of the thesis and includes the purpose of the research, hypothesis and the contribution towards the study. Chapter two focuses on the relevant literature review. Chapter three concentrates on the theory related to the flash crash and includes various key aspects such as causes of the flash crash, regulatory requirements and algorithm trading. Chapter four includes data description and methodology and the

fifth chapter focuses on the important findings of the research. The last chapter concludes the thesis and summaries all the important points of the research.

2. LITERATURE REVIEW

There are various studies conducted on this research topic. Most of the topics associate flash crashes with high frequency trading. The topics discussed are very closely related to the flash crash that took place on the 6th May 2010 when the Dow Jones Industrial Average crashed to around 1000 points. It was the highest intraday crash on the Dow Jones Industrial Average Index.

Boulton, Braga-Alves and Kulchania (2014) focus their research on the events of May 6, 2010 by studying the possibility of earning abnormal profits from the crash. They take into account 29 different stocks for their study that had been cancelled by the exchange due to broken trades as the execution price was beyond the limit of 60 %. The data analyzed was tested for returns, market quality, impact on spreads and the effect on options segment. To determine the returns during the event of the flash crash they studied abnormal returns over a period of 255 trading days and results give a clear indication that there negative abnormal returns of -0.80% on the day of the crash while the CAR is -1.77% for the window period of [0,+1]. The reasoning provided by them is pointed towards stub quotes that got executed at irrational prices.

To analyze the market quality they concentrated their attention on the spreads. The results showed poor market quality which was indicated by the differences in spreads and high transaction costs. The paper also provides evidence of increase in turnover and volumes. Due to debt crisis in Europe occurring during the same time they found it difficult to judge the reason of the actual flash crash as there could have been the possibility of crisis impacting the market quality. The results from the options market have suggested that on the day of the flash crash the options market did record high volatility. The paper gives a comparison between the implied volatility on the day of the crash and the day previous to that and found an increase of 0.102 on the event day. Vega and Gamma also had changed substantially. The final conclusion clearly indicate that market quality was degraded, investors lost significant value and it created negative impact on investor sentiment. Impact was also noted with the sensitivity of options to the underlying assets.

The link between Flash Crash and the market structure was studied by Madhavan (2012). The main emphasis of the paper is on market fragmentation that could have an impact on price movement. He defines two metrics for fragmentation one being

volumes and the other based on quotes that could also be potentially used for calculation of trading competition. The analyses on testing the fragmentation was done using time-series on intraday data. The results indicate that fragmentation is on an all-time high while the results yielded on comparison with the flash crash was also found to be high in comparison to level during previous years.

Comparison was done on exchange traded products and non-exchange traded products to check on the intensity of the impact on both these products due to the flash crash. The results indicated the ETPs were more affected in terms of price while volumes reported were consistently higher. The mean for ISO frequency for ETPs on the day of the flash crash was much higher as compared to the month before and is also statistically significant. Stock options were also tested in the analysis with high differences found on the day of the crash to the month before however the results were not significant. In respect of fragmentation evidence suggests that fragmentation increases with increase in market capitalization. No such evidence is found with quote fragmentation in relation to market capitalization however ISO have a positive relation with quote fragmentation. He also provided evidence to suggest that there is a differentiation between volume fragmentation and quote fragmentation. The final conclusion provided by the paper suggest that market fragmentation plays an important role in defining the spread of the Flash Crash. He also suggests that new policies incorporated by the regulator should also focus on issuing the problems of market fragmentation.

Brewer, Civtanic and Plott (2013) used a very different approach in understanding the impact of regulatory intervention on a flash crash. They recreated the Flash Crash by considering a stimulated approach and tested various theories on it. Various regulation were brought to counter the flash crash and the paper concentrates on how effective these measures could prove in the event of a flash crash. The stimulated approach was directed to study the order flow rather than the psychology behind investor's decisions. The stimulation created was then used to determine the impact of order flow on liquidity. The paper describes three solutions to reduce the impact of flash crash and restore market stability. The results from stimulation indicate that when minimum resting time is provided it helps in stabilizing the market by building up liquidity. The analysis for circuit breaking mechanism focused on five different types of circuit breakers. However the call auction mechanism provides better results with swift recovery of the market. The findings from the paper suggested that frequent traders could support liquidity during the time of flash crash. The requirement for resting time may not be very helpful to reduce the impact of flash crash. However call auction could

be helpful if there is an expectation of disruption due to fall in prices. The final conclusion given was that there is no need for intervention as markets do tend to return to normal levels without much interference.

On the day of the flash crash trades got executed at erroneous prices. McInish, Upson and Wood (2014) have claimed in their paper that ISO were responsible for sell volumes of more than 65% for stocks with high price declines and similar reasoning was applied for buy volumes too. The trades were closely examined on various parameters to find evidence of the role that ISO played during the flash crash. The impact of ISO is done using an event study methodology by using VPIN as a measure to calculate the toxicity in the order flow. The paper also concentrates on the influence on the decisions making of investors to use ISO. They describe that ISO have various advantages one being the faster execution speeds by using multiple order. The result suggest the usage of ISO substantially increased on the day of the flash crash. VPIN also indicated a significant rise on days towards the flash crash and continued even after the crash. The paper also suggest that on May 6 2010 market conditions had created a suitable environment for traders to opt for ISO. The final conclusion of the paper suggest there is an impact of ISO on flash crash and it also played a role in increasing the volatility.

One of the most significant findings on the flash crash event was contributed by Easley, Prado and O'Hara (2011). They explain the relevance of order flow toxicity during a flash crash. Easley, Prado and O'Hara (2012) define order flow toxicity as, "Order flow is regarded as toxic when it adversely selects market makers, who may be unaware that they are providing liquidity at a loss". They have also developed a method to measure the order flow toxicity called VPIN. Their analysis reveals that there was shortage of liquidity much before the crash and order flow was rapidly turning toxic for the market makers. Order flow toxicity forces the market makers to exit the market causing illiquidity. The volumes were notably high on that particular day but the market was relatively illiquid. As mentioned in their paper that SEC/CFTC (report 2010) did stress in their report that high trading volume does not indicate liquidity.

The two main observations that were found by the researchers were that VPIN for E-mini S&P future was unusually high close to one week before the crash and that VPIN had reached its highest level at 2.30pm, two minutes before the actual flash crash. The SEC/CFTC (report 2010) did mention in their report that HFT originally boosted liquidity to the market but around 2.41-2.44pm they offloaded around 2,000 mini

contracts. In their study VPIN was also compared to VIX. Both of these indicators are used to measure volatility and should have had the same outcome but it was not the case on 6 may, 2010. While VPIN had a steady increase and reached an all-time high two minutes before the crash, VIX did not have a significant rise till the market had crashed to very low levels.

The main idea of their research was to give a twofold interpretation and potential uses of VPIN. The first interpretation suggested that it could be used to measure flow toxicity at normal levels while at abnormal level it could indicate the market makers would suck out the liquidity from the market by exiting position which could lead to crashes. The second interpretation was that VPIN could be used to monitor crashes which arise out of liquidity though quite rare it does occur. The authors recommended that VPIN should be traded as a contract just like the volatility index. This would enable brokers to use VPIN as a benchmark index; regulators could use the volatility to halt trading to avoid the events like May 6th 2010 from reoccurring and it could also be used for volatility arbitrage.

The paper by Easley, Prado and O'Hara (2011) was contradicted by another paper written by Anderson and Bondarenko (2014). They conduct an in-depth analysis of two metrics TR-VPIN and BR-VIPIN and note their impact on the flash crash. The data used by them is the same as the one used by Easley, Prado and O'Hara (2011) to maintain uniformity. The most important finding in their paper is the results from analysis of TR-VPIN that indicate an historical high after the flash crash which provides evidence that it is not a good indicator for the predication of flash crash. The association between trading intensity and OI was also discussed in the paper. Trading intensity has an impact on OI and since VPIN is derived from OI their findings suggest positive correlation with OI and VPIN. The test done to study the effectiveness of TR-VPIN in predicting flash crash didn't have any exceptional results that could provide any indication or signs of a crash before the actual crash. Similar results were obtained with BV-VPIN. The main reasoning that they came up with was VPIN cannot predict future volatility; VIX index is far more accurate to VPIN for shorter time frames, VPIN construction is linked to the trading intensity of the underlying asset and its predictive power is considered on the basis of trading variation.

There was another paper written by Easley, Prado and O'Hara (2014) to counter the paper written by Anderson and Bondarenko. They tried to explain why the analysis from Anderson and Bondarenko is incorrect and how VPIN is to be interpreted. VPIN

was interpreted quite differently in Anderson and Bondarenko paper because they used a different approach to classify trades in order to get realized volatility measure into VPIN. They mainly associated volatility with VPIN. While the paper written by Easley, Prado and O'Hara measures VPIN using a different direction that relies more on order imbalance. They give more emphasis on toxicity rather than on volatility.

The final paper written by Anderson and Bondarenko (2014) finally tries to put an end to the debate between both sides. They suggest that VPIN was not using usual volatility indicators for prediction but they found that volume and volatility information was important to predict the influence on VPIN. If volume and volatility were controlled then VPIN shows no predictive powers and the tests turn insignificant. They still could not confirm whether VPIN reached a historical high before the crash, whether VPIN plays an instrumental role in forecasting shot term volatility or whether bulk volume is more suitable then tick rule for transaction data. They hope to provide answers in future papers.

Lee, Cheng and Koh (2011) focus their research on the role of positions limits on the flash crash. They used a stimulation approach to recreate the flash crash under various scenarios and tested the impact of positions limits. They couldn't find any direction with the theory of high frequency trading in the role of the flash crash but feel the major contribution is pointed towards various trading strategies. They have also suggested in their paper that the safety net implied by the exchanges like trading halts could have worsened the situation. They also were not convinced with the effectiveness of Liquidity Replenishment Points and also considered the cancellation of trades by the exchange as an unfair practice for market participants as they may not find any incentives in providing liquidity for such future events. The stimulation approach that they recreate was used to test position limits, change in auctions system and using price limits at various levels. The speculation suggested trading venues and dependence in various assets as the biggest contribution for flash so the modeling of the simulation was done considering these two parameters. They also find that price limitation prove to be more reliable method for market stabilization in comparison to position limits. They concluded their paper with various recommendation that could help in market stabilization.

There was a high inclination towards the role of HFT on the impact of flash crash. Kirilenko, Kyle, Samadi and Tuzun (2015) concentrated their research on the impact of HFT. Their main focus is on the electronic market. They begin their research by

classifying participants on various parameters and then qualify them as intraday intermediaries if they meet the criteria set. Further classification is done and then they are separated into HFT and market makers and also made a note that the price plays a major role based on which market participants decide the volumes to trade and alter their position accordingly. Various other kind of traders are clubbed in a separate category. The analysis of the volume indicate HFT and market makers had a drop in volume on the day of the crash in comparison to three days prior to the crash. They study the price changes on the day of the flash crash and three days prior to it and study the change in volumes in HFT and market makers. The volumes traded during the four days were consistently very low in comparison to the massive sell order projected in the SEC/CFTC report (report, 2010)

The key findings for HFT suggests that HFT is statistically significant and the relationship remains static even during the flash crash however there was a change in relationship for the market makers. Their analysis over the three day suggest that when HFT start buying the prices enter into an upward movement and remain there for 20 seconds after execution. The study distinguishes HFT on the basis of how aggressively they trade. They find prices tend to move in the upward direction for about 20 % if HFT trade aggressively in comparison to 2% on passive trades. Consideration was also given to see the trading pattern of HFT after the bid value decreases and offer value increases. The results show HFT follow a very different pattern as compared to market makers. The final conclusion put forward indicate HFT participant did not overstress and stuck to a consistent approach unlike market makers on the day of the flash crash.

The reasons on what caused the flash crash was studied by Aldrich, Grundfest and Laughlin (2016). In their analysis they have undertaken a thorough examination of the order book to focus on the causes behind various events that contributed to the flash crash. Their research also questions the reasoning behind the allegation put forth by the government of United States of America in respect to a trader called Navinder Sarao's who's was held accountable for the flash crash due to his illegal trading activities. They try to counter this theory put forward and agree with the evidence from the SEC/CFTC report (report, 2010) as they are more in line with their findings. Their approach recreates the flash crash using a stimulation and they find that the set of events that occurred as per the SEC/CFTC report (report 2010) could actually lead to a flash crash like event. The analysis is divided into four different segments first being the analysis of the order book, second the impact liquidity crisis on the order book was checked to

verify the case of Sarao, third stimulations was done to know the origins of the flash crash, fourth they test an anomaly in regard to the flash crash.

To get a better understanding of the messaging scenario on the day of the flash crash they compared the messaging frequency with the date on August 9, 2011. The day when the messaging frequency was recorded the highest at the CME. They found various similarities between both the days which included the time period, volume, messaging rates measured in megabyte per second. The analysis from messaging provides leads to how arbitrageurs who generally are on an advantage when the market turns one sided were unable to find such opportunities during the flash crash. The results from the imbalances provides evidence that suggest Sarao's trading activity might not have a huge impact to the contribution of the flash crash. A significant trading pattern created by the algorithms used by Sarao's might have been misinterpreted for the cause of the actual flash crash. Simulation approach was used to study the origination of the flash crash. The analysis was in line with the SEC/CFTC report (report 2010) which had given indication of hot potato effect. During the research they also find an anomaly that could suggest another reasoning for the flash crash but they didn't possesses any substantial evidence to prove such a fact and have kept it for future research. They try to also suggest the fact that for non-repetition of a flash crash it would be beneficial that new law come into effect taking into consideration of the SEC/CFTC report (report 2010) as their finding are very similar to the report.

The impact of the how past returns could affect the value of stock during the flash crash is studied by Yu (2011). He suggests that contrarian investors have a very important role for such kind of effect. The key aspect of the paper is to get a clear view of the intensity in the drop of prices of some stocks over the other during the flash crash. The analysis for the relation between past stock return and the size of the crash reveals a positive relation which suggest that stock that tend to have better past return have a high intensity for crashing during a flash crash. The reasoning provided by them is pointed to stocks with low liquidity generally halt trading during flash crash. The research also focus on the relative value trading and studies various strategies deployed by these kind of traders and find a negative correlation between past return and the size of the crash. Their findings also suggest contrarian traders could play a role in the reduction of liquidity shock.

Menkveld and Yueshen (2015) take a different perspective in comparison to all other previous literature. The common notion suggested by most literature was that the seller

was made to pay as he demanded additional liquidity but their paper suggested that the seller was made to pay a premium for demanding additional liquidity. Their findings include that the crash did not occur due to the consequences of price pressure. The analysis also gives a broader picture of cross market arbitrage that had halted and due to this most investor were restricted to trade in a single exchange and this in turn lead to liquidity crisis. This analysis is also connected to the algorithm used by the large seller and the result from the analysis are in line with SEC/CFTC report (report 2010) which stated the algorithm was targeting a 9% volume for executions. Their analysis reveal that the broken arbitrage could have brought about a change in market dynamics as the large seller continued to sell in the market without consideration to change in market conditions. Their final conclusion suggest that the cost for demanding liquidity could prove to be extremely expensive if there is occurrence of broken arbitrage. This news could be very disturbing and cause huge impact to the institutional investors as they tend to depend on cross-market arbitrage.

The smaller version of flash crash can be termed as mini flash crash as it has been the prime focus for Golub,Keane and Poon research paper. The time frame considered for the study is limited to only four months but months picked for the study is seen to be the most volatile for the time period from 2006-2011. They categorize the mini flash crash into two categories ISO initiated and auto-routing-initiated on the basis of origination. Their findings suggest a higher proportion of crashes occurring due to ISO than auto-routing. There were also a set of criteria that was supposed to be met to qualify for each of the categories. The research also focused on the participants responsible to have caused the crash and indicated a higher possibility of HFT players for the ISO trades. The findings suggest that the spread difference increased widely immediately after the crash. The intensity of the crash is also at an alarming rate of below 1.5 seconds and the effect stays for a minute. They also concentrate their analysis of locked and crossed market which is banned as per the regulation of NMS. They find a major percentage of locked and crossed NBBO quotes to occur after the crash within a time frame of 1 minute while a lower percentage to occur before the crash. The analysis of the quoted volumes suggest that there is an overall reduction in volumes after the crash. Liquidity was a concern during the flash crash and the paper focuses on the concept of fleeting liquidity which is created artificially to provide false sense of liquidity to provide direction to the market. They set predefined criteria that had to be met to prove fleeting liquidity present in a mini flash crash. The results did prove that fleeting liquidity was present.

The main conclusions derived from the research did suggest that the regulation did help in integrating markets but since the rise of algorithm driven trading this arrangement have led to various complications in the market. The core problem suggested was due to various exchanges present in the US market leading to a diversification of liquidity across exchanges and reducing the liquidity in each market which could also give an unfair advantage to the algorithm traders. Their paper also gives suggestion to investors to focus on the impact that their orders could have before placing their orders. They hold ISO responsible for the flash crash and have mentioned that traders using ISOs have full knowledge of the situation as the use of ISO is subject to use of limit order similarly they also have knowledge of the liquidity present in the market. So the manipulation could be done in purpose rather than it being done unknowingly. Regulatory action was also called for just as many other research papers focused on it and the stringent measures needed to be taken on those involved with the crash.

Angstadt (2011) has focused on the various changes brought in by the regularity authority and the future impact of the initiatives taken by SEC. Her take on the SEC/CFTC report (report 2010) suggest that the report only focus on the event of the flash crash but did not concentrate or give a timeline when the regulations recommended will come into effect. She does mention that the regulatory authority have given priority to some of the recommendations and new policies have come into immediate effect such as introducing circuit breakers for single stocks, removal of stub quotes, new regulations in terms broken trades. The paper also focus on the obligation of HFT as they tend to be liquidity providers. The finding of SEC/CFTC (report 2010) clearly had stated that liquidity had fallen short in the market. Similarly correlations were being drawn between the drop in liquidity and high frequency trading. The theory provided in the paper also suggested of the drop in numbers of market makers due to electronic systems coming into place making executions very swift. New regulation made also did not provide any emphasis on the role of market makers nor was there a need for registration of market makers. This created a loophole giving advantage to HFT to play the role of market maker without having to register.

The paper has provided analysis on the change in role of liquidity providers in terms of their obligation and their advantages. Previously exchanges did provide the incentives and made the market makers to take up some obligations in regards to providing liquidity. Soon the obligations were curtailed and freedom was provided to markets makers as regulations did not provide clear understanding of their responsibilities. Her paper has provided indication that obligations must be set for the liquidity providers by

the concerned authorities and in return they should also provide some incentives for providing liquidity. Emphasis was also laid on the co-location and data feed. Computer servers located close to the exchanges trading system result in getting undue advantage as it provides immediate quotes and an advantage to traders having such an arrangement. Another area of focus was data feed since additional data feed was provided by some data providers which had more information than the national consolidated data feed she suggested for further research on its acceptance. The research study also focuses on the order cancellation as they could be considered as a form of manipulation and had some role in the crash.

3. THEORETICAL BACKGROUND

This chapter will focus on the theoretical aspect of the study. Since algorithm trading/High frequency trading is very closely associated to flash crash the relevant theory is added to this chapter. Flash crashes are events that are quite rare in real time scenario so it is very important to review the history and past trends of flash crashes. Trading errors, circuit breaking mechanism and scope for better regulation will also be covered in this chapter.

3.1 History and Past Trends

Stock markets are bound to be very volatile. Index's rise and fall, investors gain and lose but the estimation of volatility put forth by the investor always has a certain limit to it. But when those limits are crossed investors wealth is eroded to a great extent and it is often referred as stock market crash. Stock market crashes have been occurring right from 1819 to the present 2007-2009 United States Bear Market. Stock market crashes are quite persistent but they do take place for a definite reason. These reasons could vary from financial crisis, recession to various kinds of scams in the market. Stock market crashes occur generally due to state of panic.

Flash crashes are quite different from normal crash. It takes place in a matter of seconds while a normal crash does takes place over a longer period of time. Flash crash does not have a valid reason for a crash it generally takes place due to errors while trading. If you take a look at the history of flash crashes we don't have to turn far back in terms of time duration because most of the flash crashes are all recent phenomena. They have started to take place recently because investors are adopting more complex strategies and algorithms to execute trade. Flash crashes are not only restricted to US but it has also occurred in other countries such as Singapore, China and India which provides clear indication of two main reasons one that investors are rapidly migrating from traditional trading platform to more advanced algorithm trading/ HFT software's and second that individual traders are dealing with bulk quantities indicating increase in turnover of volume. The most significant flash crash that ever took place occurred in the United States of America on 6th May 2010 when the Dow Jones Industrial Average crashed by almost 1000 points. The SEC/CFTC (report 2010) was published on September 30, 2010 give deep insights as to what led to such drastic turn of events.

3.2 Factors Causing the Flash Crash

A flash crash which generally tend to have a quick fall and recovery can be associated with various reasons. On May 6, 2010 the Dow Jones Industrial Average had one of its highest intraday losses due to the Flash Crash. The SEC/CFTC report (report 2010) suggested various reason for the Flash Crash. There is a need to have an in-depth analysis of the reasons behind the Flash Crash to avoid any future occurrences of similar events. Various regulatory changes have been implemented and come into effect immediately after researching on various factors that caused the crash. The SEC/CFTC report (report 2010) have presented a chronological order of the happening of the event much prior to the actual event taking into account all factors including the concerns arising from European Debt Crisis.

3.2.1 Liquidity Crisis

The Flash Crash was a result of extreme selling by market participants but not enough buyers to absorb the trades leading to a fall in liquidity and causing prices to crash to extreme low levels. Liquidity Crisis is mentioned as the core reason in the SEC/CFTC report (report 2010) and its evident with any type of crash including the financial crisis that if the market lacks liquidity to support the selling pressure it will result in huge fall in prices. The crash cannot be restricted to one particular instrument and it is evident to find the effect in several other tradable assets as most markets are linked with one and other. Similarly derivatives are instruments that have a direct replication to the base underlying asset. So a fall in the underlying asset will also result in the fall in the future & options market.

The SEC/CFTC report (report 2010) finds that both E-mini and SPY lacked liquidity resulting a fall in prices. Both the funds are correlated with each other as they replicate the S&P 500. The analysis reveal that E-mini and SPY reached its lowest point not at the same time this was due to a sudden fall in liquidity in E-mini much before than SPY. There was also a halt on the E-mini which helped for it prices to recover but no such halt took place on the SPY. The role of cross-market arbitrage was also discussed as they enabled to close the gaps between E-mini and SPY until the fall in liquidity observed in E-mini. After E-mini individual stocks also faced the liquidity crisis. The event lead to different actions taken by various market participants. Large market traders who used superior trading system had in build design to halt trading if prices crossed certain predefined limits. This gave them time to reassess their situation and

change their strategy taking into consideration various factors. Immediately after reconsideration various market participant came up with alternate strategies while some considered exiting from the overall market. Following the event the prices did recover within the span of few minutes but due to low market sentiment the price continued to be negative.

3.2.2 Large Sell Order

The Flash Crash event that occurred on May 6, 2010 was contributed by a various events. The trading day that started with uncertainties from the European Debt was relatively stable as the day progressed. The actual fall in price as reported by SEC/CFTC report (report 2010) occurred due to an institutional investor who initiated a bulk sell order using a sell algorithm through an automated trading system. The execution mechanism was set to give consideration only to volume resulting the whole order to get executed in 20 minutes. Initially some market participants absorbed the sell order but soon they started reversing their positions resulting to a Flash Crash.

3.2.3 Cross Market Arbitrageurs

Arbitrageurs are traders who simultaneously trade in different markets to profit from the price inefficiency. The SEC/CFTC report (report 2010) have viewed cross-market arbitrageurs as one of the main reason for the transmission of the liquidity crisis to individual stocks and across various markets. In the absence of the cross-market arbitrageurs there could have been a possibility of isolating the Flash Crash only to E-mini contracts. Cross-Market arbitrageurs can build various strategies to suit their trading strategy. The role played by cross-market arbitrageur in transmission of the liquidity crisis can be ascertained by an example given in the SEC/CFTC report (report 2010) where they have mentioned that if the cross-market arbitrageurs are trading simultaneously in two different market and the prices start to drop in one of the market than the arbitrageurs will soon start to reduce their bids and offer prices in the other market too. The report also suggest that the main preferred markets for cross-market arbitrageurs was the E-mini as it possessed high liquidity, SPY and stocks from the S&P 500 index. Most of the cross market arbitrageurs halted trading during the crash while other who were trading noticed that E-mini was responsible to get prices back to normal level in the SPY and for the stocks in the S&P 500.

3.2.4 S&P 500

E-mini and SPY are a direct replication of the S&P 500 index. There arises a possibility that the fall in prices that was observed in the E-mini was caused due to S&P 500. To verify this claim the SEC/CFTC report (report 2010) described the detailed analysis carried out by them. They took into consideration the order book for E-mini and SPY and compared it against the stocks present in the S&P 500 index. The analysis suggests that prices of S&P 500 remained relatively stable during the entire duration right from the start of the day even during the decline that began at 2.00 pm. The rapid descend began in S&P 500 after 2.30 pm and again the order book remained fairly stable. The drastic fall in the buy-side depth began at 2.45 pm and hit a low at 2.49 pm after which the reversal trend began in the S&P 500. After the in-depth analysis and comparison between the order books in the E-mini, SPY and the S&P 500 they found that the fall in the buy-side liquidity initially began in the E-mini and was then followed in the SPY and S&P 500. The analysis also indicates that E-mini was the first to recover from the crisis much before than the SPY and S&P 500 giving a clear sign of that the liquidity crisis was initiated by E-mini.

3.2.5 Intermarket Sweep Orders

Various factors were considered by the SEC/CFTC report (report 2011) that possibly lead to the Flash Crash. The intermarket sweep orders was one of the factors not taken in to consideration in the detailed analysis presented in the report. The evidence of the impact of Intermarket Sweep Order on Flash Crash could be critical for traders to change the direction of execution of their limit orders if there is a reoccurrence of such an event in the future.

McInish, Upson and Wood (2014) have analyzed the impact of Intermarket Sweep Order on Flash Crash while also taking into consideration the trading aggressiveness and liquidity supply. During the Flash Crash extreme price movements was noticed and in their research paper they have defined this extreme price movement and have also found close to 20 stocks that had extreme price movements during the Flash Crash. They study the Intermarket Sweep Order on the day of the Flash Crash and compare it with the use of it from the beginning of the month till the end. They also use VPIN metric to validate the toxicity in the order flow of the ISO before the Flash Crash.VPIN for ISO consistently stayed high before the Flash Crash and maintained its high level

after the crash also. The impact of ISO remained to be inconsistent on the Flash Crash but it resulted in high volatility.

3.2.6 Trading Strategies

Most of the traders use trading strategies to execute trade. Trading strategies can be simple or complex using various automated trading systems. While trading strategies are built to meet specific demands of the investors it could also lead to transmission of liquidity and volatility from one market to another. Lee, Cheng and Koh (2011) have focused on the changes that could have been possible if position limits would be implemented on the day of the Flash Crash. While most of the research papers find high frequency trading linked to the Flash Crash they find no connection between the two instead find trading strategies more relevant. Similarly they also point towards circuit breakers and consider its role crucial in accelerating the issue. They regenerate the events of the Flash Crash by taking a simulated approach using various techniques on a computer. Nine different simulations were recreated which was then tested for 3 different alternatives namely position limits, price limits and changing the auction pattern to discrete time from continuous time. The conclusions drawn indicate that lack of liquidity in the market is caused due to one sided participation that is brought about by the trading players who anticipate the direction of the market. They suggest changes in the trading strategies in accordance with the market conditions had an impact on the Flash Crash rather than high frequency trading.

3.2.7 Stub Quotes

Stub quotes have often been associated with Flash Crash in various research literatures. Stub quotes are orders placed far beyond the markets current prices by market makers. They generally are not meant to be executed which is the reason they are kept at the extreme ends of the market. On the day of the Flash Crash these quotes did get executed and was considered as one of the factor that ignited the already worse situation.

The SEC/CFTC report (report 2010) gives a brief description of the reason for the placement of stub quotes. The report mentions that market makers have to place quotation on both sides of the market in compliance with rules set by the exchange to ensure fair functioning of the market. Since these prices have no relevance for the market makers they are often kept at the extreme ends of the market ensuring non-execution of these quotes and are done so only for the purpose of compliance.

Exchanges gives various options to market makers to choose the process of generating stub quotes either automatically or that move up and down simultaneously with respect to the price movements. On May 6, 2010 the report found that more than 20,000 trades were broken by the regulatory authority FINRA and the stock exchange on account of violation in respect to regulation pertaining to erroneous trades. On the day of the crash the execution of the market orders were done on the basis of liquidity available in the market which unfortunately happened to be the stub quote as there were no other orders available. Stub quotes do not have a limit so they keep generating automatically and this lead to continuous executions of the orders. The report concluded that most of the orders executed through stub quotes were from the retail investors which got executed at stub quotes level as markets makers had stopped providing liquidity to the market during the time of the crash.

3.2.8 Liquidity Replenishment Points

Liquidity Replenishment Points is a feature common to traders of the NYSE. It typically acts like a circuit breakers but in a very different way. SEC/CFTC report (report 2010) have considered LRP as an indirect factor that could have been possibly responsible for the Flash Crash. The report suggests that LRP are typically used to reduce volatility by bringing about a change in trading system. Such a halt can be beneficial in reducing the intensity of a crash as the trading halts for the automated segment with a short time frame between 1 second to up to 2 minutes. The key differentiation between a circuit breaker and a LPR is that the later as mentioned by the report is only to reduce the speed on the opposite direction of the market not to completely halt the trading. The LPR is revoked once prices get reverted back within LRP limits but can again be imposed again depending on the situation. The investors are at advantage as they can pull out of the market at any possible time before execution.

The day of the Flash Crash LPR were being continuously triggered at an extremely high rate as compared to any other normal trading day. The analysis of the report was also based on interviews taken by various market participants. Most of the trading system of investors had automatic routing mechanism that could transfer orders to other exchanges in case if the LPR is implemented on the NYSE. The implementation of LPR did not cause any effect in the transition of orders to the other exchanges. But most traders withdrew from the market after the constant implementation of LPR as they considered it as a sign of distress in the market.

The SEC/CFTC report (report 2010) while focusing on the involvement of the LPR took into account the number of broken trades in the market. A high proportion of the broken trades did not belong to the NYSE while the one's that did 42 stocks had implementation of LPR with durations for 10 or more seconds. The analysis done was to focus on first the executions at other exchanges in exchange of liquidity present in NYSE and second was to determine whether NYSE responsible in attracting more liquidity during LRP from other exchanges. The report provides evidence that liquidity on NYSE did not have a high contribution to the executions on other exchanges due to the fact that buy side depth for NYSE was completely depleted and no trades were taking place on exchanges other than NYSE. No evidence was also found in regard to NYSE attracting liquidity. The role on LRP in the crisis was only restricted to the withdrawal from the market due to the consideration of continuous implementation of LRP as a sign of distress but no evidence in respect to liquidity crisis was found making the association between the Flash Crash and LRP totally unrelated.

3.2.9 Declaration of Self Help

Liquidity was the considered as one of the main reasons for the Flash Crash. Hence it was important to study all the factors in depth that could have led to the possibility of creation of a liquidity crisis which could have ultimately led to the event of Flash Crash. The role of self-help declaration on the liquidity was also taken into consideration in the SEC/CFTC report (2010). Declarations of self-help is considered one of exceptions to the Rule 611 that focus on the issue of "trade-throughs". The implementation of the rule 611 (a) makes it necessary to have policies in place to check on the prevention of trade execution at any other price except the "protected quotation". The rule 611 (b) deals with the exceptions to the rule that have to be followed in line with the regulation set. The exception was created to address the problem of any kind of malfunctioning in using the protected quotations. The report also suggests about the exception in ISO orders that when combined with the self-help can authorize the ISO order to utilize self-help mechanism to skip protected quotation.

On the day of the event as mentioned in the report, self-help was initiated on NYSE ARCH by two exchanges Nasdaq and Nasdaq OMX BX. Both the exchanges disclosed about their action on implementing the self-help through their website thus giving full knowledge to the market participants. But even with having knowledge about the implementation of self-help most investors continued trading the similar way without bringing any change. The role played by self-help as questioned by report could have

led to problem in liquidity as and when the other two exchanges started to redirect the orders while skipping NYSE Arca causing a fall in volumes at NYSE Arca. Analysis was done of the volumes in NYSE Arca before and after the implementation of Self-help. Similarly a comparison of the executed sell orders at NYSE Arca and orders of Nasdaq that were bypassed was done to get a complete picture. The analysis done couldn't find a direct connection that could indicate that self-help declaration was responsible for the liquidity crisis during the time of the crash however it did manage to close the price gap between NYSE ARCA and other exchanges.

3.2.10 Market Data

Market information is very important to investors. Every investor must receive the right information at the right time. The timing of the information can give an undue advantage to the recipient if the information is received before others. It is necessary for the purpose of fair practice that market data is passed to everyone at the same time. SEC/CFTC report (report 2010) has mentioned issues in market data that could have possibly contributed to the liquidity crisis on the day of the Flash Crash.

The report mentions of two different data feeds that is available for the clients. One being the proprietary data feed that gives clients an advantage as it is delivered directly to clients making them receive information much faster. The other information transferring process gives out consolidated information to clients and it is relatively slower as it goes through the securities information processor who is responsible for preparing the market data and sending it out. The report finds that on May 6, 2010 information was not being sent of out swiftly as it did usually and found NYSE was conducting upgradation work on its systems that deal with market information. The delays were blamed on high volumes and some stocks faced delays of over 20 seconds. The delay are quite prevalent in the market but the report gave extra emphasis on the how the delays impacted on the day of the Flash Crash.

The report suggest most of the trading systems do face delay but these delay are quite small mostly of less than 10 milliseconds. Many large participants and retail investors who tend to use proprietary data feed shouldn't have faced any delay as compared to those using consolidated information. As the proprietary data and system using consolidated information get information from two different sources delay in one should not cause any issues in the other. CTS and CQS data feeds consists of system giving out consolidated information and delays on them did impact those using proprietary data

feed. The report considered the possibility of data integrity made trading system to freeze which led to drop in liquidity. Those using CTS and CQS system the delays played a crucial role in deciding whether to halt trading completely. One of the hypothesis analyzed was whether clients receiving information from proprietary feeds have an advantage on those who receive consolidated information. But this hypothesis was ruled out as there is virtually no possibility of such an advantage as the orders get executed on the quotes finally available on the exchange and the actual prices on the exchange differ from the prices on the consolidated data feed.

They have stated one exception to this hypothesis called dark pool which gets through by referencing the price and it could give an advantage to the investor by transferring order to the dark pool and then to the exchange making it possible to grab the spread from the pricing difference. But the report suggests that the possibility of this happening is quite restricted as the order may not get through and since large percentage relies on proprietary data feed.

3.2.11 CFTC V. Sarao

The SEC/CFTC report (report 2010) covered most of the reasons that led to the crash but some new evidence has come up in 2015 when CFTC blamed a London based trader Navinder Sarao and his company Nav Sarao Futures Limited PLC for using certain set of algorithms to manipulate and profit from the flash crash. CFTC has ascertained that his actions were responsible to have caused the flash crash and criminal proceeding have charged against him and his company. Navinder Sarao has been able to profit $8.9 million from such illegal transaction. (USA v. Sarao, 2015)

The allegations laid down by the CFTC has mentioned that Sarao had been using certain automated trading system to manipulate the market and gain heavily from such transaction (CFTC V. Sarao, 2015). It also mentions that he has been entering large orders into the system with no intention of execution but only to give the market a false sense of direction. The manipulative practices alleged by CFTC includes spoofing by using layering algorithm that involves filling the sell order book with large orders on different price levels. When the prices moved closer towards the order the algorithms modified the order further away so that they would not be executed but at the same time made sure they appeared in the order book. Most of the orders were later cancelled. This algorithm would succeed in creating artificial volatility which could then be used for his benefit. The allegation claim that defendants have gained close to $40 million using

such manipulation tactics. CFTC has also suggested that certain set of traders make decisions based on the order book. If the order book has a large amount of sell orders then it gives an indication that the market prices will fall from current level. Similarly strategies using automated systems are also build relaying on the order book. If Sarao used such manipulation all such traders would be on a disadvantage.

The allegations also state that Sarao was able to benefit from both sides of the market. The layering algorithm used by him could cause the price to drop and he would benefit by taking short position. Similarly as the prices drop he would stop the algorithm which would again lead to prices surging and he would benefit by taking long positions. As he traded in high volumes the profit made was enormous from such transaction. Another method used was spoofing by using 188/289 lots this was used mutually along with the layering algorithm. Similarly a 2000 lot was used to create a false sense of execution on the side that was favorable to the defendant by placing it on both sides and then immediately deleting the order. On the day of the flash crash too they have suggested that he has used 188/289 lot spoofing on a time frame between 11:17 am and 1:40pm. This led to the drop in E-mini futures which eventually contributed to the flash crash.

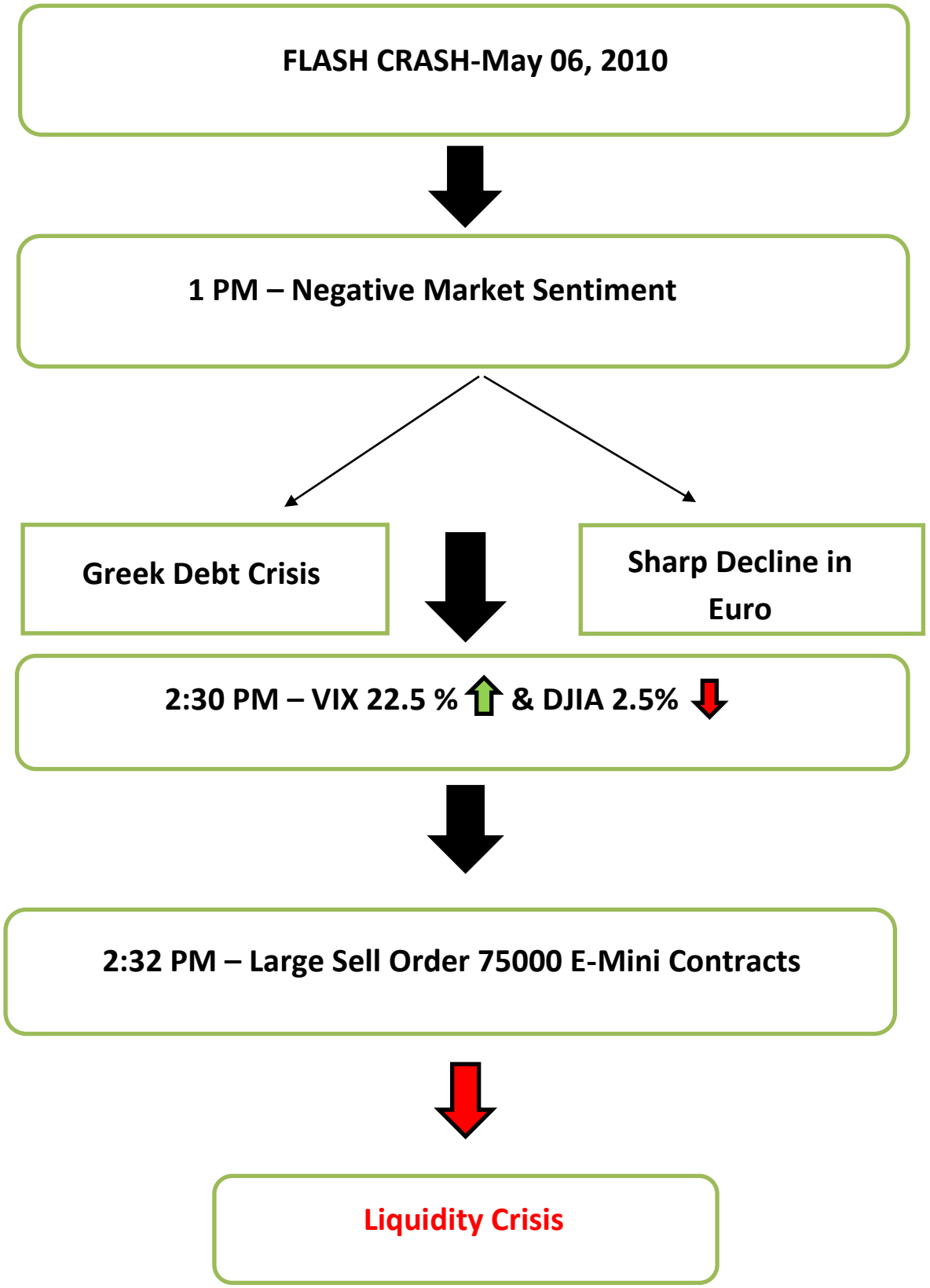

Figure 1: Time Line of the day during the Flash Crash Event Day on May 06, 2010. Source: SEC/CFTC report (report 2010)

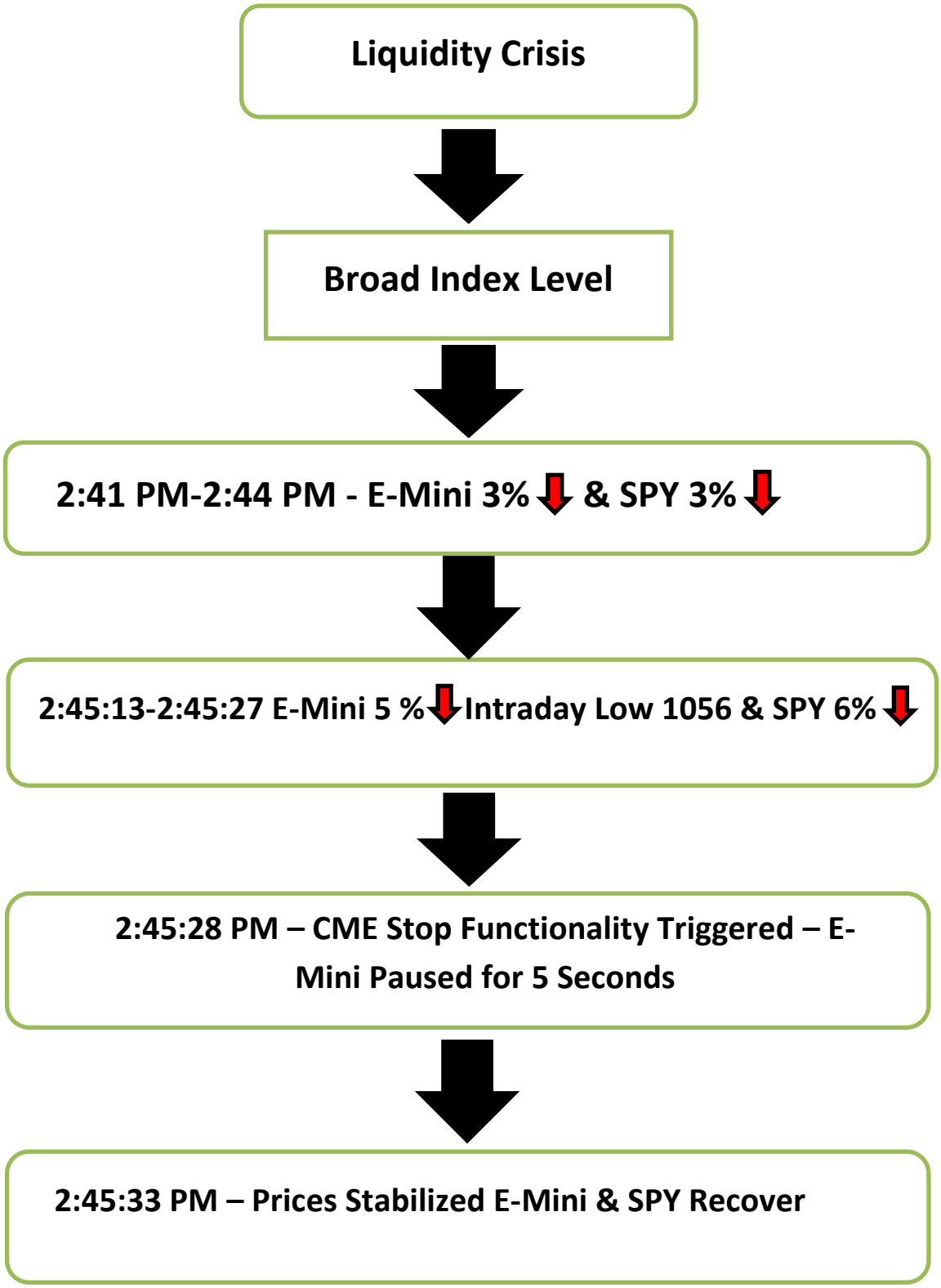

Figure 2: Liquidity Crisis in E-Mini and SPY during the Flash Crash on May 06, 2010 Source: SEC/CFTC report (report 2010)

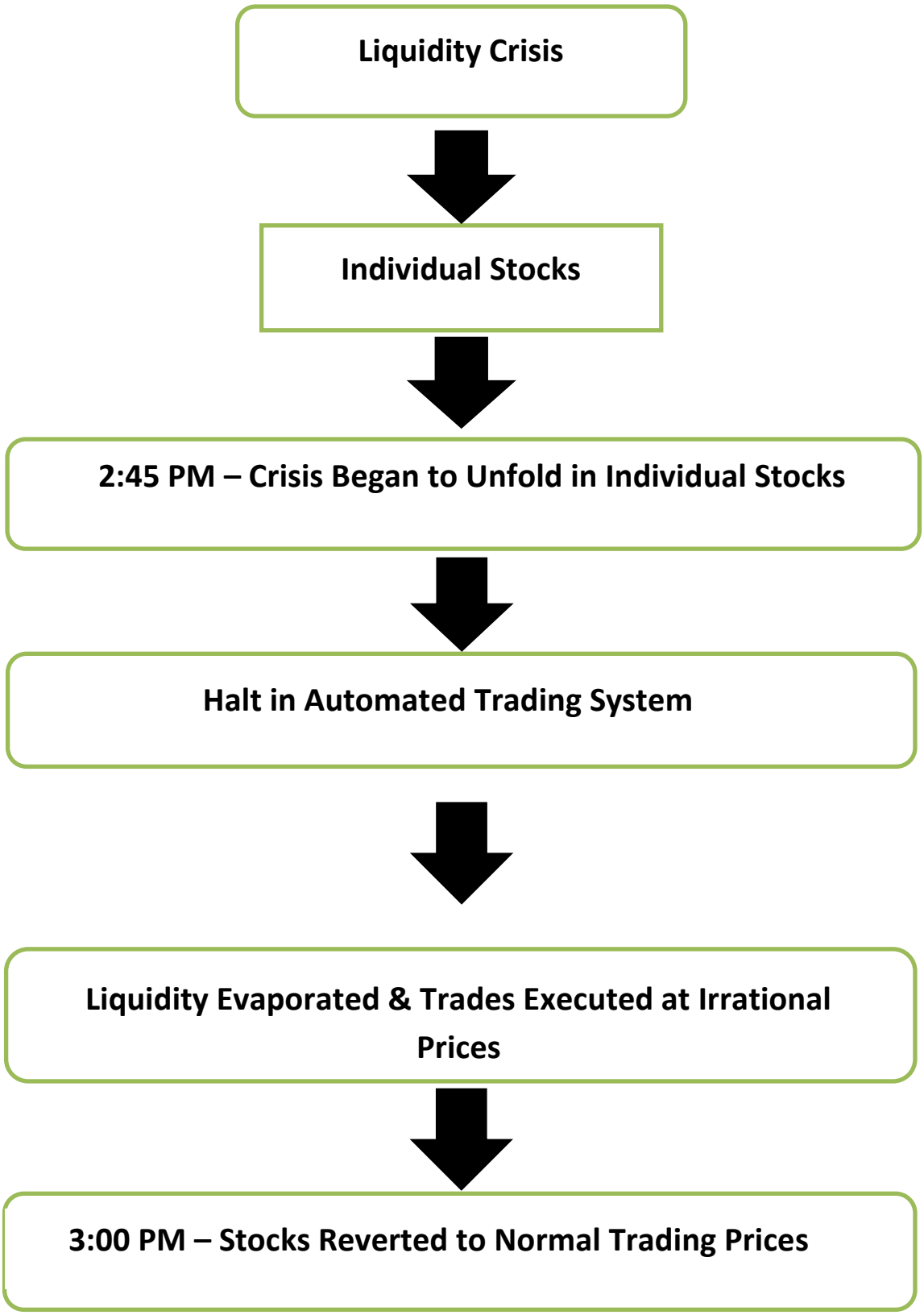

Figure 3: Liquidity Crisis in Individual Stock during the Flash Crash on May 06, 2010 Source: SEC/CFTC report (report 2010)

Figure 1 provides us insights using a time line scenario on the happening of the event of the flash crash on May 06, 2010. From the information provided by SEC/CFTC report (report 2010) indicated the market deteriorating from 1 PM onwards due to the Greek Debt Crisis and fall in Euro against two major currencies. The volatility index "VIX" had a major rise in its value to 22.5 % while the S&P 500 dropped by 2.5 %. In such stressful conditions a large sell order from a mutual fund complex using a complex algorithm software caused a chain of events led by high frequency traders ultimately resulting in liquidity crisis.

Figure 2 provides us with a time line for the liquidity crisis that occurred in the index of E-Mini futures as reported in the SEC/CFTC report (report 2010). The crisis began at 2:41 pm. The crash in E-mini was contributed primarily to the sell algorithm and HFT players. The impact was also felt in SPY and it was mainly contributed to the cross market arbitrageurs. The E-mini and SPY fell substantially during 2:45:13-2:45:27, during the same time the rapid decline also led to the fall in liquidity as none of the liquidity providers were willing to provide liquidity. The halt in the E-mini for 5 seconds due to the Stop Logic Functionality brought some relief as prices began to recover

Figure 3 covers the liquidity crisis for the individual stocks. According to SEC/CFTC report (2010) the liquidity crisis in individual stocks begins to unfold at 2:45 PM. The report gives a description of the aftermath of the trading halt and has mentioned that traders had to reconsider their situation. This reassessment done by the traders give an indication that it could be the reason for the liquidity crisis in individual stocks. This is based on the conclusion that when E-Mini was recovering buying interest had considerably reduced in individual stocks. This fall in liquidity led to trade executions at erroneous prices. At 3 PM price finally returned to their normal levels.

3.3 Structure of Algorithm Trading

Technology has developed rapidly in the recent decade. Most of the exchanges have already switched to computer based trading from the traditional open outcry system. With vast improvements in technology there has developed a growing need among traders to use software's that are fast and can execute complicated strategies with ease. Algorithm trading has been able to provide most traders low latency in executing complex strategies thus giving an extra edge over traditional traders. Hendershott, Jones

and Menkveld (2010) has suggested in their paper that in 2009 approximately 73% of the trades in the US markets were done through algorithm trading.

A flash crash generally occurs due to various reasons. The most common being fat finger trades where trades generally occur due to errors done by a trader while punching orders in to the system. This kind of trade was visible during the flash crash that hit Indian markets in 2012. Fat finger trades is very common in trading circles but does not cause huge impact on the market if the volumes traded is very low and by using better risk management system. The significant cause of flash crash can be pointed towards algorithm trading.

Algorithm trading is trading by computer system with minimum interference by humans. Various algorithms are programmed to execute complex strategies. These strategies are very difficult and time consuming if it was to be executed by a trader manually. It was also implemented so that it could enable avoiding of errors done by human while trading manually. Retail investors usually do not trade using algorithms and find it hard to compete with the institutional investors. Kelejian & Mukerji (2015) analyzed 110 most traded companies from S&P 500 and studied the variance of return volatility for 35 industries. The result indicated that HFT resulted in the increase of volatility having a huge effect on the income of non-algorithm traders. There could also be a possibility of non-algorithm traders losing confidence which may result in avoiding the market completely.

3.3.1 Liquidity

Liquidity is considered an important aspect in financial markets. Market participant always prefer a highly liquid market as it leads to swift execution of orders. The role of algorithm trading in providing liquidity is still very crucial. CFTC report on the flash crash has clearly indicated that a liquidity crisis emerged in the market due to the selling pressure from sell algorithm and HFT. Institutional investors always have their trading strategies build around highly liquid markets. The role of algorithm trading in providing liquidity is still quite controversial as there is still no consensus as to whether algorithm trading is responsible for providing or sucking out liquidity from within the market.

Carrion (2013) analyzed the participation of high frequency traders on 120 stocks of the NASDAQ stock exchange. The result suggested that HFT works in both ways when it comes to providing liquidity. It injects liquidity when it is scarce but is also responsible

for withdrawing liquidity when it is in excess. Brogaard, Hendershott and Riordan (2014) have similar view in terms of liquidity while studying the impact of HFT on price efficiency. More evidence is provided by Hendershott, Jones and Menkveld (2011) to prove that algorithm trading does help in improving liquidity. The study uses autoquoting as an instrumental variable approach to demonstrate the impact of AT on liquidity. The result indicate that algorithm trading activity has been constantly increasing over the years and also increased liquidity within the market.

3.3.2 Market Quality

There are various factors considered when an investor decides to invest in a particular instrument. These factors may vary based on investors risk and return. The market quality could prove to be an important deciding factor for an investor when selecting a particular avenue for investment. Market quality can be judged on various parameters such as liquidity, low bid-ask spread and high volumes. The impact of HFT on market quality has been debated in a lot of research papers.

Market efficiency is used as a parameter by Carrion (2013) to study the impact of HFT on market quality. The result indicate a positive relation between HFT and price efficient. However the result does not justify that an increase in price efficiency is due to HFT. Scholtus, Dijk and Frijns (2014) have used liquidity and volatility as a main parameter for market quality to study the impact of algorithm trading on market quality around macroeconomic news announcement. The results suggest that liquidity and volumes both increase immediately after the news announcement due to high algorithmic trading activity.

3.3.3 Volatility

The volatility of a stock is one of the parameters considered by most investors before investing. Empirical evidence from previous literature have suggested that there could be positive and negative correlation between stock market return and volatility. However the role of HFT is reducing volatility could be of prime importance. Most of the research papers suggest HFT has been able to curb high volatility. Hagströmer and Norden (2013) have done an event study to study the effect of HFT on volatility. They have used minimum tick size as a medium to study volatility. Their findings indicate that HFT does lead to reduction in short term volatility.

3.3.4 High Frequency Trading Strategies

Algorithm trading are being used to cater to specific demands of the investor community. Various strategies are developed to suit investors need. Profitability may not be the only reason for migrating into algorithm trading. Some investors also use it to sell huge quantity of shares in a systematic way while other could use it to get an advantage over time due to low latency available in algorithm trading. Statistical arbitrage is the most widely used HFT strategy. Serbera and Paumard (2016) throws light on various HFT strategies such as mean reversion and pair trading while analyzing the fall of HFT due to intense competition and fall in profitability.

The impact of algorithm trading on non-algorithm trading investors has been studied by Kelejian and Mukerji (2016). They use spatial econometric modelling to focus on the impact of statistical arbitrage strategy to measure the transfer of volatility across different stocks. The result indicate that after the introduction of HFT there has been an overall decrease in volatility spill over across various industries. Hagströmer and Nordén (2013) have differentiated HFT strategies into two main categories market-making strategies and opportunistic trading to study the diversity among HFT traders. Through their study they analyze the different characteristics of HFT and also study their impact on short term volatility. Their findings reveal that majority of the market participants utilize market-making strategies. The result also suggest that market making strategies dominate over opportunistic strategies as they are beneficial in terms of reducing volatility and prove to be far more inexpensive.

3.3.5 Speed

Algorithm trading could not have played a vital role without taking into the account the aspect of speed. Trading speed has considerably increased over the years due to technological advancement. But algorithm trading have been responsible to speed up trades even further. This poses a problem to non-algorithm traders as they find it hard to compete with speeds used by computer driven algorithmic software. Due to high speeds the trading time have also reduce greatly bringing in extreme low latency. Serbera and Paumard (2016) have noted in their paper that there are various factors involved to achieve speeds of low latency and that trade executions timing are reducing considerably and will be reduced to nanoseconds. They have also suggested that in the future speeds could hit the speed of light which would be the maximum speed possible

after which there could be no more technological advancement to reach any higher speeds limits.

Scholtus, Dijk and Frijns (2014) have taken into consideration the speed aspect of HFT around macroeconomic news announcement. They use Wilcoxon signed rank test to determine returns between trades that executed instantly and trades with small delays. The results indicate that there is a significant decrease in returns for delays in executions versus executions instantaneously. Slower speeds of 10 milliseconds, 300 milliseconds or even a second can cause returns to reduce by 0.19%, 1.94% or 3.90% annually. They also analyze the impact of speed on various scenarios such as days of high and low volatility, time of news arrival and the level of the news announcement. The analysis conclude that on high volatile days delays of 400 milliseconds and more lead to a loss for event-based trading strategies. The result for high impact news announcements is 2.87% annually for a one second delay while a large news surprise lead to decrease of 2.23 bps in comparison to 0.83 for a small surprise for the same time frame.

3.3.6 Profitability

Most HFT investors are working towards gaining an upper hand in trading. But the most important reason to migrate to HFT is to have an increase in profitability. The role of profitability still has a lot of concerns as to how much excess returns do HFT actually make over non HFT traders. Switching to HFT may not be the key to higher profits as it also requires the strategies to work. Profitability may also get reduced as the competition around HFT increases. With increase in HFT players it has become difficult to gain an edge as each trader tries to gain competitive advantage over one another.

Carrion (2013) has focused on distinguishing the source of profits for HFT. The need for getting a clear understanding of the source of profitability was to rule out the possibility of earning profits from spreads instead of gaining profits from market timing. VWAP difference is used to calculate profits from HFT. The findings reveal that HFT traders earn $2,623.84 on daily basis. The profits earned are from liquidity-demanding and liquidity-supplying trades. The estimations draws a conclusion that profits are earned of $3,292.61 when HFT supply liquidity while losses are made of $691.54 when HFT demand liquidity. The paper also deals with profitability through market timing. Intraday return was calculated by using two different time duration called short-term timing performance and intraday market timing performance. The result suggest that

between the two different time frames the performance for intraday market timing is better when it is compared against the previous.

The source of HFT profitability is extremely important to actually differentiate whether profits are earned through HFT as the results could also suggest that profits are earned through other sources which could clearly indicate that migrating to HFT alone could not lead to higher profitability. Menkveld (2013) also has tried to analyze the source of profitability by considering various factors. The study classifies HFT into two different parameters and associates them with a friendly approach and a hostile approach. The friendly approach takes into consideration HFT trying to form new market makers while the hostile approach considers HFT taking a very aggressive approach. The parameters are classified into positioning profit and net spread. Their findings reveals most of the trades turn out to be passive. The traders tend to earn on spreads but lose out on position. The duration aspect is also considered and the findings favors positions that last less than five seconds.

3.4 Regulatory Requirement

Regulation forms a core aspects of any financial system. The financial system has to be sound and should function without any hindrances from any kind of manipulative practices. The regulatory authority have to safeguard the interest of the investors and make sure every financial institution have to comply with the rules and regulation set by them for the smooth functioning of the financial markets. Investor's confidence is the key for smooth functioning of the financial markets. Manipulative practices, scams, financial crisis and events like flash crash lower investor's confidence who are then become very hesitant to enter the markets again. The regulations set by the regulatory authority are quite stringent but there are times when they fail to provide safety to the investors either because of regulation being outdated, loopholes in the system and new technological advancement making the need to keep updating the rules and regulation a high priority. Strong governing bodies forcing the companies to adopt to ethical practices could help in building a robust financial system. The event of flash crash led to various debated across the investor community questioning the failure of the regulatory authority to prevent such an event.

Brewer, Cvitanic and Plott (2013) focus on the role of regulatory authority in getting the situation under control immediately after the flash crash. They use a stimulated

approach to study the impact of alternative policies in bringing about stability to the market. The stimulated approach is a direct replication of the actual flash which allows them to study various factors. They considered various factors that could help in getting liquidity back to the markets and maintaining the prices back to normal levels and helping to restore stability in the market. After considering various alternatives they have provided detailed analysis of the factors that could work best in getting the market to normal level during the event of a flash crash. The regulatory intervention could help provide the necessary support the market needs in bringing about overall stability and give a direction to the market.

The event of flash crash clearly pointed out the need for better regulation to prevent such events from reoccurring again. Immediately after the flash crash the SEC/CFTC report (2010) suggests a lot of new implementation were brought in the counter such a crash in the future. The individual security halt was brought in if the stock experiences high volatility this could help in isolating only that particular stock from the overall market. The rule was focused on stalling the entire market now is extended to individual stocks. In the initial phrase only a few stocks were used for the purpose of testing but now it is extended to wider range of stocks that trade on various indexes. Another important issue of concern is that of broken trades. The report suggests that only those trades were cancelled that were executed at a price limit exceeding 60% making the process unfair. To bring about a change in the system the SEC have defined a new set of standard procedure that has to be followed in case of a broken trades. Thus making it clear across the investor's community about the trades that can qualify to be considered broken. Other measures are also being tested one such measure is limit up/limit/down that defines a specific parameter and trading outside those parameters is not accessible. The upside of the flash crash event has been the implementation of new regulatory procedures and the steps taken to bring about SEC in countering such an event to take place again.

3.5 Circuit Breaking Mechanism

Circuit breakers have become very important in the stock markets. Circuit breakers halt trading if the index or stocks have reached a certain level. It is generally used if there is extreme movement in any direction. It is a technique generally used to reduce volatility and stabilize the markets. Circuit breakers are placed at different levels by the stock exchange. Generally trading is halted for a specific time period and then trading is

resumed back. But there is a possibility that if the circuit breakers are pressed in the latter half of the day the markets could be shut for the remainder of the day. Every stock exchange has its own regulation in regard to circuit breakers. Mostly it's the regulator who decides the level for the circuit breaker and exchanges have to adhere to the regulation. The role of circuit breakers during the flash crash has been studies in various previous literature.

After the flash crash event Brewer, Cvitanic and Plott (2013) have studied and suggested various alternatives techniques that could lead to stability in the market. They analyze different type of circuit breakers but find them only as a temporary measure in contrast to bringing a complete change in market structure. They suggest intervention is helpful only if it's a temporary spike in prices but in case of fundamental change of market structure it could lead to hindrance to the overall transitioning.

Chakrabaty, Corwin and Panayides (2011) try to concentrate on finding the advantages associated with trading on alternative avenues during a trading halt. Their analysis concentrated on trading halts that took place on NYSE. They give insights into the benefits of resuming trading on other avenues during halts on the NYSE. Even though there are advantages the cost and volatility are significantly high as compared to non-halted trading days.

Rule 80A has been closely monitored by Goldstein (2015) to study the reduction of volatility in the stock market. He gives a brief description of Rule 80A and 80B that is related to circuit breaking mechanism on the NYSE that could enable delinking of the futures and equities market. He analyses intraday data and studies the impact of volatility before and after rule 80A has been implemented. Due to various issues caused by possible smoothing and no proper convergence to the data used, GARCH model is not implemented but instead a different approach is estimated. The research paper does find evidence of reduction as well as some effect on volatility due to delinking of the equities and futures market. The market crash of 27-28 October was covered briefly by Goldstein and Kavajecz (2004) by drawing an event timeline. While 80A was imposed only on 28 October both rules came into effect on October 27.

Extreme market movements are generally beyond the investor's control. If circuit breakers come into effect it becomes extremely challenging for investors to find better alternatives. During a flash crash there is a high tendency of stocks or index's being hit by circuit breaker so it is always beneficial to find a concrete solutions to counter such

problems. Goldstein and Kavajecz (2004) have studied various trading strategies when circuit breaker are implemented by the exchanges and during high volatile market movements. The analysis is focused on the actions of the investor during the high volatile days of 27-28 October, 1997 and is compared with non-volatile days. The three main parameters considered was trading platform, order type and the time of investor's reaction. These parameters played a vital role for investors while they form key strategies. The trading floor was found more preferred by the traders over trading through electronic form. They suggested that market participants alter their strategies while prices came close to the circuit breakers and their decisions are mostly based on flexibility.

A different set of research that also deal with trading strategies was done by Cho, Russell, Tiao and Tsay (2003) and have concentrated their study on daily price limits and their effects which also covers the magnet effect. For their study they consider data from Taiwan Stock Exchange as the exchange has high volatility and low price limits. They have used GMM methodology to study the magnet effect. The magnet effect is visible on the ceiling price but not on the floor price. For finding a concrete conclusion that the magnet effect is not due to momentum further analysis was done and the results suggest weak evidence of momentum effect. In their study they have formulated various strategies to benefit from the magnet effect but also found the transaction cost to be very high. In order to prevent from profits lowering due to high transaction cost they devised a combination of a threshold limit and the number of stock to invest to come up with a strategy that could beat all other benchmark combinations.

The first use of circuit breakers and the various levels at which they are implemented are mentioned by Ackert, Church and Jayaraman (2001). The initial use of circuit breakers came in the October 1988 and was based on threshold limit of 250 and 400 points. This was soon changed to 350 and 550 on January 1997. On February 1998 a new circuit breaking system was implemented that would come into effect if the price would cross a certain percentage limit. The percentage limits were set a 10%, 20% and 30% and these limit had certain implication if they were hit at certain time of the day. They focused their study on circuit breaking mechanism and their effect on the three main components namely price, volume and profitability by using the experimental market setting. Analyzing volumes gives a clear indication whether circuit breakers do affect trading and the findings suggest it does significantly. Profitability remains unaffected by trading but traders tend to trade at a faster pace if they feel a circuit breaker will be hit.

Circuit breakers are quite common when the whole market is shut down for a specific period of time. But a rule on NYSE also permits shutting down of a single stock while trading can continue seamlessly on other stock and indexes. Jiang, McInish and Upson (2009) have concentrated their study on stocks that are related through parameters such as return, volatility, volume and spreads that continue trading during a halt on a particular stock. They found evidence of liquidity and price being affected on informationally related stocks that continue trading while trading is halted in a particular stock. Also the halt brought an increase in transaction costs.

Transaction costs were also considered by Christie, Corwin and Harris (2002) while studying trading halts on the NASDAQ stock exchange. The focus their research on trading halts caused due news events while considering their impact on stock prices, cost of transaction and trading activity. They have used signed-rank test to analyze the change in volatility, transaction cost and trading activity caused due to trading halts and delayed opening. They have mentioned about the trading mechanism used by NASDAQ that initiates trades after a 90 minutes quotation period in case the halt has been lifted later than 4.00 pm for the previous day. This method differentiates itself from opening days where NASDAQ open after a 5 minute quotation period. The analysis indicate that trades after a 5 minute quotation period tend to have higher volatility and transaction costs as compared to reopening after a 90 minute quotation period. On volumes front higher volumes were noticed after a 90 minute quotation period than a 5 minute quotation period.

The effectiveness of circuit breakers has been quite debatable as some studies have proven it to be very effective by lowering volatility and giving opportunity to investor to understand the situation more closely while others believe it hampers stock movement and causes price inefficiency. These arguments have been studied very closely by Corwin and Lipson (2000) while concentrating on the effects of trading halts on the liquidity and order flow of the NYSE market. They have categorized their analysis based on two different types of halts namely news halt and order imbalance. An important trend noticed during the analysis suggest an increase in the order submission even if the trading has been halted which gives a clear indication of the eagerness of entering the market immediately when the market restarts normal trading. They have also done a thorough analysis of the limit order book to find evidence of variation in liquidity and volatility. Signed-rank test have been used to study trading activity during halts and determine their impact on liquidity. Another important aspect that they have

considered in their study is the connection between volatility and liquidity during halts by using the Wilcoxon rank-sum test.

A study having a focus on volume and volatility is covered by Lee, Ready and Seguin (1994). They study trading halts on the New York Stock Exchange and their impact on stock volatility and volumes. They have stressed on differentiating between trading cessation and the process of price discovery and whether their combination does lead to reducing volatility and volumes. In their paper they take into consideration news events and categorize them into six different categories as most of the previous literature have suggested a relation between news events and trading halts. The intention of a trading halt is to reduce the panic in the market but they find this does not serve the purpose as there is an increase in volumes and volatility immediately after trading is resumed.

The results obtained by Lee, Ready and Seguin are quite similar to the finding from Subrahmanyam (1994) who concentrates more on the relation between Circuit breakers and volatility. He suggests that even though it is a common notion that circuit breakers usually calm the market down and give investors time to take stock of the situation his results prove it could tend to be more a costly affair as it could lead to price discrepancies and transition in volumes into other markets. The resulting action is from analyzing a situation between two different markets one from the more dominant market with high liquidity and the other called the satellite market.

4. Data and Methodology

4.1 Data

The need to find impact of flash crash makes it critical to understand the returns of different stocks for an indepth analysis. Since flash crash is an event we can study the effect it has on market structure before, during and after the crash. Doing an event study will help to find a clear picture and a wider perspective of the aftermath of the flash crash. For this study the methodology aspect is adopted from Boulton, Braga-Alves and Kulchania (2014). For their study they have considered two set for stocks each set consisting of 29 stocks and have divided them into base sample and match sample. The base sample consist of stocks that had trades executed but eventually led to the cancellation while the match sample did not have any cancelled executions. The stocks were matched on the basis of certain criteria. The next step involved them using three-factor model documented by Fama and French (1993) to find the abnormal returns. The data used by them consists of 255 trading days that ended 46 days before the flash crash.

The data in the thesis contains two sets of 21 stocks that are similar to the stock selection of Boulton, Braga-Alves and Kulchania (2014) with the exception of 8 stocks due to data unavailability. The data consists of daily data before, after and on the day of the flash crash. The data has taken into account two stock indices that includes Dow Jones Industrial Average that was highly affected on the day of the flash crash. Similarly S&P 500 and the volatility index "VIX" was also considered with a similar time frame. The data is taken over a wider time frame consisting from March 2009 until December 2011.

Table 1: Descriptive Statistics

	Mean			Median		
	Base sample	Matched sample	Difference	Base sample	Matched sample	Difference
Market Capitalization (mUSD)	34,573.79	37,888.84	-3,315.05	5,663.73	5,447.48	216.25
Price	34.94	31.12	3.82	31.87	27.06	4.81
Turnover*	5,993.15	8,682.64	-2,689.49	3,773.10	5,280.40	-1,507.30
Volatility (%)	1.63	1.69	-0.05	1.26	1.28	-0.03

* Number of shares, millions.

Table 1 reports the descriptive statistics for the base sample and the matched sample. The market capitalization for base sample is over $34 million with a share price of 34.94 and return on volatility is 1.63%.

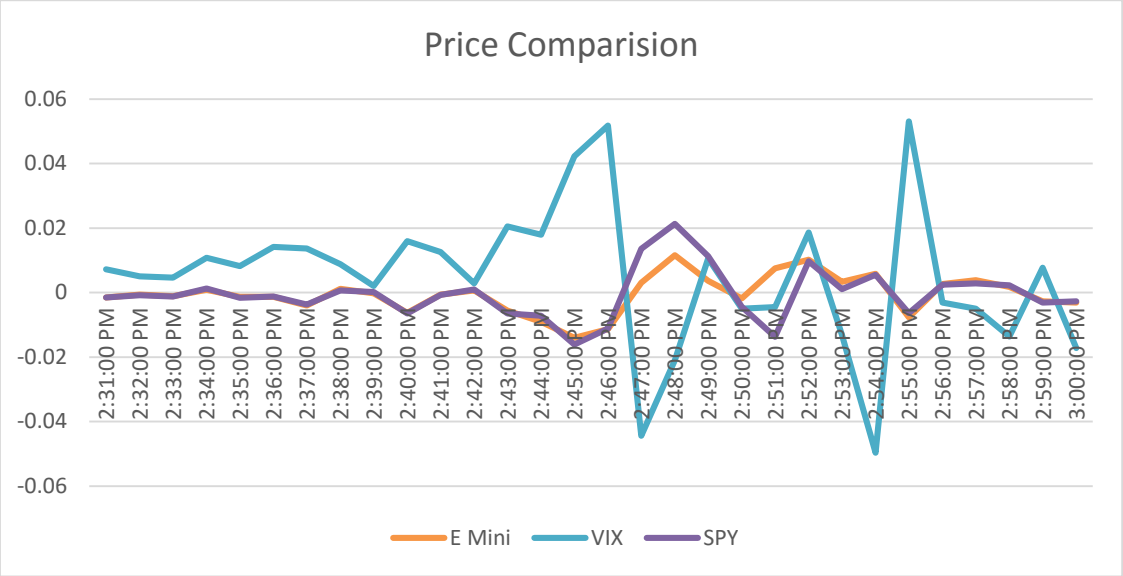

Figure 4: Intraday return for E-Mini,VIX and SPY during the Flash Crash on May 06,2010.

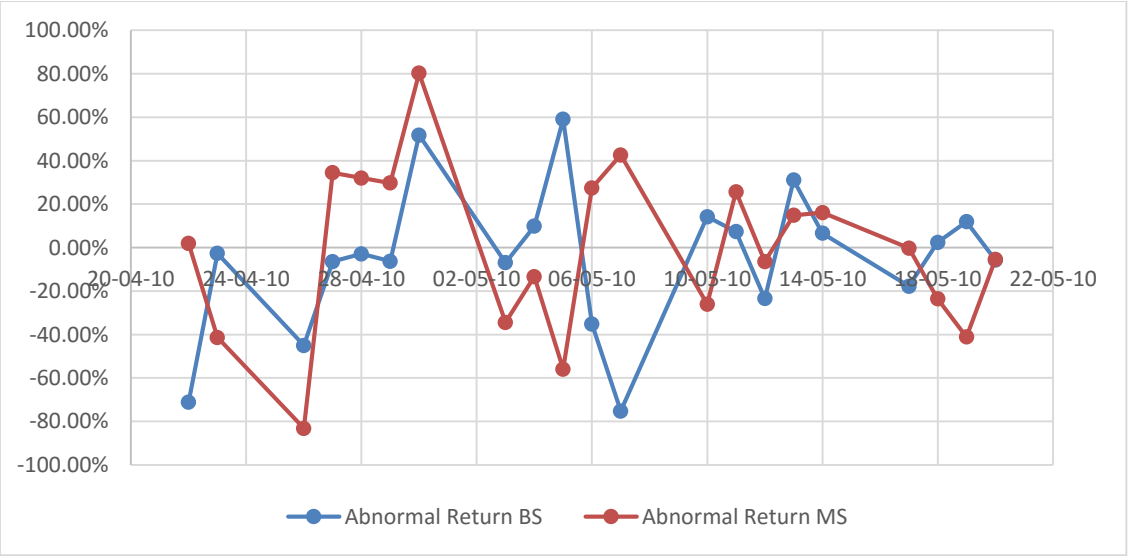

Figure 5: Abnormal return for S&P 500 index for 22-04-10 – 20-05-10.

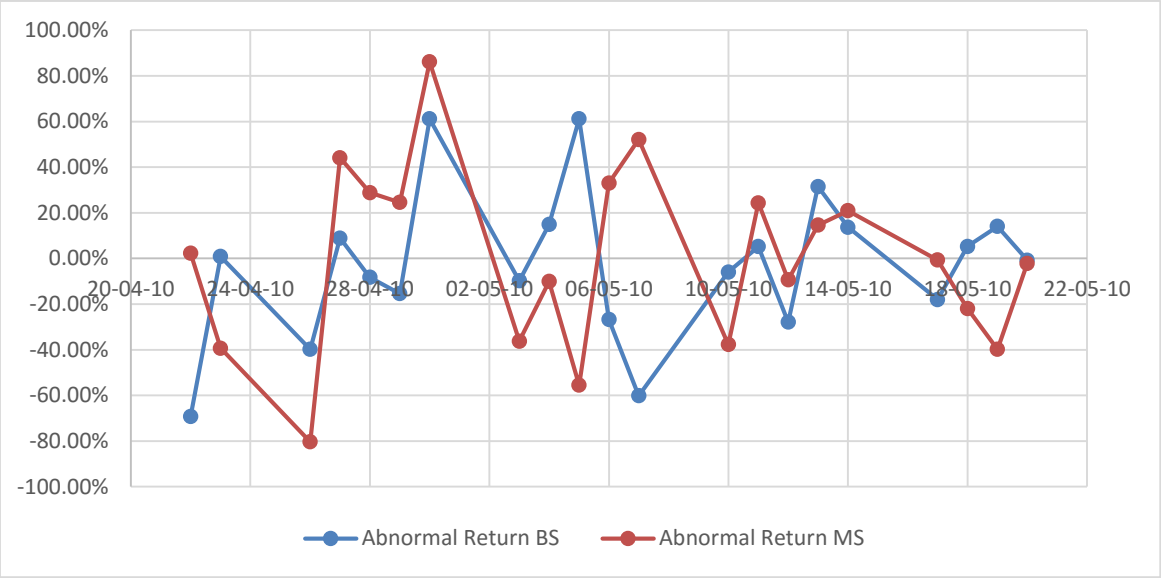

Figure 6: Abnormal return for S&P 500 index inclusive of VIX for 22-04-10 – 20-05-10.

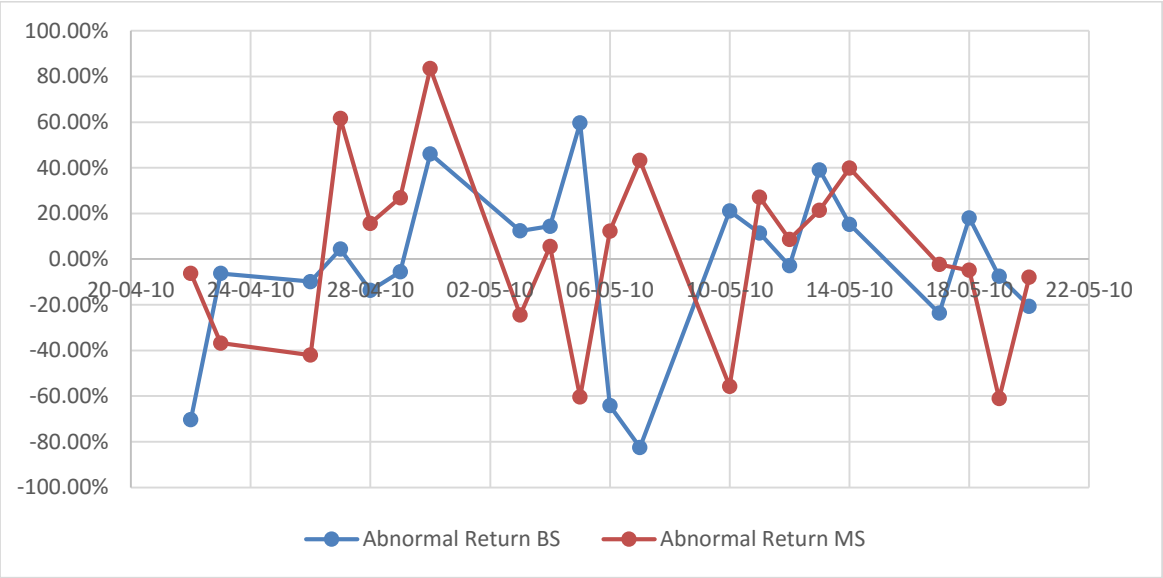

Figure 7: Abnormal return for Dow Jones Industrial Average for 22-04-10 – 20-05-10.

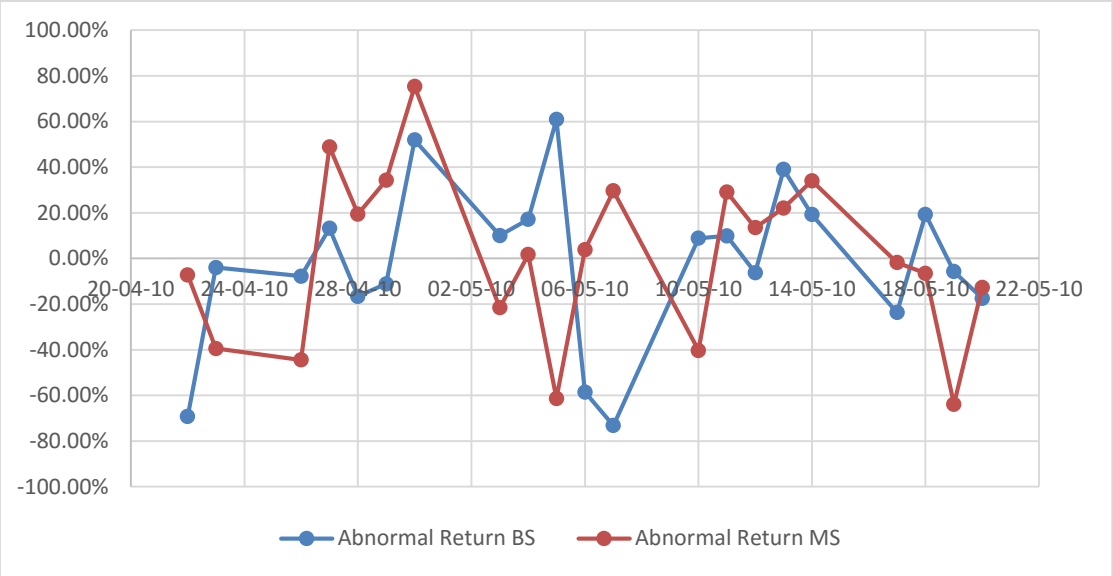

Figure 8: Abnormal return for Dow Jones inclusive of VIX for 22-04-10 – 20-05-10.

Figure 4 provides us a graph of the intraday return for E-mini, SPY and VIX. Figure 5, 6, 7 and 8 gives a graphical representation of the abnormal returns for the base sample & matched sample for S&P 500, S&P 500 inclusive of VIX, DJIA and DJIA inclusive of VIX. The figures provides a clear indication that the abnormal returns for the base sample and matched sample moved in the same direction till a certain extend before the flash crash. After the crash the scenario changed as the movement between the base sample and the matched sample started to move in the opposite direction. On the day of the flash crash and the immediate next day we could see the deflection towards the opposite direction the maximum. This deflection could be attributed mainly due to the cancellations of trades undertaken by Nasdaq and NYSE Arca.

4.2 Methodology

In order to analyze the impact of the flash crash on the stock prices this paper follows Boulton, Braga-Alves and Kulchania (2014) methodology. The entire sample consists of US stocks from the NYSE. The paper divides the sample of stocks into two groups: base sample (stocks which consists of executed trades on May 06, 2010 and respectively cancelled by either Nasdaq or NYSE Arca) and matched sample (stocks which are matched with the base sample based on the price, turnover measure the volume of daily traded shares, market capitalization and volatility. The sample contains 21 for base sample and 21 stocks for matched samples as indicated in the below table.

Table 2: List of companies in base sample and matched sample

Base sample		Matched sample	
Company	Ticker	Company	Ticker
3M Co.	MMM	McDonald's Corp.	MCD
American Tower Corporation	AMT	St. Jude Medical Inc.	STJ
B & G Foods Inc.	BGS	Comfort Systems USA Inc.	FIX
Brown & Brown Inc.	BRO	Ingram Micro Inc.	IM
CenterPoint Energy, Inc.	CNP	NiSource Inc.	N
CenturyTel, Inc.	CTL	FirstEnergy Corp.	FE
Cenveo Inc.	CVO	The E.W. Scripps Company	SSP
Clearwater Paper Corporation	CLW	Piper Jaffray Companies	PJC
Eagle Materials Inc.	EXP	GATX Corp.	GMT
Exelon Corporation	EXC	Walgreen Co.	WAG
Health Net, Inc.	HNT	Superior Energy Services, Inc.	SPN
Hewlett-Packard Company	HPQ	The Coca-Cola Company	KO
The Interpublic Group of Companies, Inc.	IPG	PulteGroup, Inc.	PHM
Merck & Co. Inc.	MRK	Wells Fargo & Company	WFC
ONEOK Inc.	OKE	Hormel Foods Corp.	HRL
Oxford Industries Inc.	OXM	Trex Co. Inc.	TREX
Philip Morris International, Inc.	PM	Abbot Laboratories	ABT
Procter & Gamble Co.	PG	Johnson & Johnson	JNJ
Quest Diagnostics Inc.	DGX	ITT Corporation	ITT
Sotheby's	BID	Tempur Pedic International	TPX
United Technologies Corp.	UTX	Occidental Petroleum Corporation	OXY

The period under analysis is 242 trading days ending 50 days prior to the flash crash in order to avoid any biases which may be caused by the flash crash. In order to calculate the returns of each individual stock the below mentioned formula has been used:

(1) $$R_{j,t}=P_{i,t}/P_{i,t-1}$$

where :

$R_{j,t}$ is the return of stock j on the t day;

$P_{j,t}$ is the price of stock j on the t day;

$P_{j,t-1}$ is the price of stock j on the t-1 (previous) day;

Moving forward the analysis of the abnormal returns is based on the Fama-French (1993) three-factor model and Cahart's (1997) momentum factor. The model used for calculating abnormal returns takes the following form:

(2) $$R_{jt} = \alpha_j + \beta_j R_{mt} + s_j SMB_t + h_j HML_t + u_j UMD_t + \varepsilon_{jt}$$

where R_{jt} is the stock return for j^{th} stock on the day t, return on market index on day t is denoted by R_{mt}, SMB_t indicates the average return on small-firm stocks minus the average return on large-firm stocks on day t, HML indicates the average return on high book-to-market stocks minus the average return on low book to market-to –market stocks on day t, and UMD_t is the average return on high prior return portfolios minus the average return on low prior return portfolios. β_j, s_j, h_j, u_j measure a stock's sensitivity to the market, size, book-to-market, and momentum factors, respectively.

In order to calculate daily abnormal returns for a stock j on day t the analysis is based on the below formula;

(3) $$AR_{jt} = R_{jt} - (\widehat{\alpha_j} + \widehat{\beta_j} R_{mt} + \widehat{s_j} SMB_t + \widehat{h_j} HML_t + \widehat{u_j} UMD_t)$$

Where $\widehat{\alpha_j}, \widehat{\beta_j}, \widehat{s_j}, \widehat{h_j}$, and $\widehat{u_j}$ are the Ordinary Least Squares estimated from equation 2.

5. RESULTS

The paper by Boulton, Braga-Alves and Kulchania (2014) give us a broad perspective of the change in shareholders wealth due to the flash crash. The flash crash that occurred on May 06, 2010 did crash and recover in a span of few minutes but it manage to erode the shareholders wealth substantially. The paper created a distinction between two different set of samples one with trades that have been executed but cancelled by Nasdaq or NYSE Arca while the other group is matched with companies based on similar criteria who's trades have not been cancelled. The analysis done works on similar ground by finding the abnormal returns and taking a closer look at impact of shareholders wealth days after the impact of the flash crash. To get a better understanding of the impact of the flash crash on investor's capital the paper takes into consideration the abnormal returns for the base sample and the matched sample. Four cases have been studied in this research that includes Dow Jones Industrial Average and S&P 500. Dow Jones Industrial Average was one of the most affected indexes in the crash so it was eminent for its consideration into the analysis. The research also takes into account the role of the volatility index during the crash by adding VIX as an explanatory variable to the regression. As we have noted in Figure 1 that VIX was up by 22.5%. So apart from the DJIA and S&P 500 the analysis also concentrates on DJIA and S&P 500 with the inclusion of VIX.

Table 3 provides us the abnormal returns for S&P 500 index. The mean abnormal return and the percentage of positive returns for a period of 21 days have been noted below. To the bottom we have the cumulative abnormal return over eight window period starting from 10 days before the event of the flash crash to 10 days after the crash. The results for S&P 500 Index on the day of the flash crash indicate negative returns of -0.35% for the base sample. The negative return continues on the next day and is also statically significant which could also possibly indicate low investor sentiments. Most of the stocks on the base sample have negative abnormal returns for the window period of [0, +1]. The cumulative abnormal return for the window period [0, +1] is -1.10%. The results for matched samples does not provide any significant results.

Table 4 provides us the abnormal returns for S&P 500 including VIX. The results on the day of the flash crash indicate negative returns of -0.27% for the base sample. The negative return continues on the next day and the day after. Most of the stocks on the base sample have negative abnormal returns for the window period of [0, +1]. The

cumulative abnormal return for the window period [0, +1] is -0.87%. The results for matched samples does not provide any significant results.

Table 3: Abnormal returns for S&P 500 index

	Base sample		Matched sample		Difference
	Abnormal Returns	% Positive	Abnormal Returns	% Positive	
22-04-10	-0.711	57.143	0.019	52.381	0.730*
23-04-10	-0.027	52.381	-0.414	57.143	-0.387
26-04-10	-0.450 *	66.667	-0.832***	80.952	-0.382
27-04-10	-0.064	61.905	0.344	47.619	0.409
28-04-10	-0.029	52.381	0.320	38.095	0.349
29-04-10	-0.063	47.619	0.297	38.095	0.360
30-04-10	0.518	23.810	0.803	47.619	0.285
03-05-10	-0.069	47.619	-0.344	52.381	-0.275
04-05-10	0.099	38.095	-0.134	47.619	-0.232
05-05-10	0.591*	38.095	-0.560	42.857	-1.150
06-05-10	-0.352	61.905	0.275	38.095	0.626
07-05-10	-0.753*	71.429	0.427	47.619	1.179**
10-05-10	0.142	57.143	-0.260	61.905	-0.402
11-05-10	0.074	42.857	0.257	42.857	0.183
12-05-10	-0.235	52.381	-0.064	57.143	0.170
13-05-10	0.311	28.571	0.148	47.619	-0.162
14-05-10	0.066	42.857	0.162	47.619	0.095
17-05-10	-0.178	57.143	-0.002	52.381	0.175
18-05-10	0.024	47.619	-0.236	61.905	-0.260
19-05-10	0.119	47.619	-0.411*	71.429	-0.531**
20-05-10	-0.057	52.381	-0.055	52.381	0.002
CAR					
[0,-10]	-0.557	50.216	-0.225	50.649	-0.333
[0,-5]	0.724	57.143	0.338	55.556	0.386
[0,-3]	0.269	53.571	-0.763	54.762	1.032
[0,-1]	0.239	50.000	-0.285	59.524	0.524
[0,1]	-1.104	33.333	0.701	57.143	-1.805*
[0,3]	-0.889	41.667	0.698	52.381	-1.587
[0,5]	-0.812	47.619	0.782	50.794	-1.595
[0,10]	-0.838	48.918	0.239	47.186	-1.076

*** Statistically significant at 1%

** Statistically significant at 5%

* Statistically significant at 10%

Table 4: Abnormal returns for S&P 500 index inclusive of VIX

	Base sample		Matched sample		Difference
	Abnormal Returns	% Positive	Abnormal Returns	% Positive	
22-04-10	-0.692	42.857	0.023	47.619	0.716*
23-04-10	0.008	52.381	-0.393	42.857	-0.402
26-04-10	-0.398	33.333	-0.803***	23.810	-0.405
27-04-10	0.089	47.619	0.441	61.905	0.352
28-04-10	-0.083	42.857	0.288	61.905	0.371
29-04-10	-0.154	47.619	0.246	61.905	0.400
30-04-10	0.612*	76.190	0.861	57.143	0.250
03-05-10	-0.098	52.381	-0.362	47.619	-0.264
04-05-10	0.149	61.905	-0.101	57.143	-0.250
05-05-10	0.612	61.905	-0.555	52.381	-1.167
06-05-10	-0.268	38.095	0.330	57.143	0.598
07-05-10	-0.601	42.857	0.521	71.429	1.123**
10-05-10	-0.059	42.857	-0.377	33.333	-0.318
11-05-10	0.052	57.143	0.244	57.143	0.191
12-05-10	-0.279	42.857	-0.093	42.857	0.186
13-05-10	0.315	71.429	0.146	47.619	-0.169
14-05-10	0.137	61.905	0.209	52.381	0.072
17-05-10	-0.180	42.857	-0.007	52.381	0.173
18-05-10	0.053	52.381	-0.219	33.333	-0.273
19-05-10	0.140	52.381	-0.398*	33.333	-0.538**
20-05-10	-0.007	38.095	-0.021	47.619	-0.014
CAR					
[0,-10]	-0.223	50.649	-0.024	51.948	-0.198
[0,-5]	0.853	56.349	0.419	55.556	0.434
[0,-3]	0.395	53.571	-0.688	53.571	1.083
[0,-1]	0.344	50.000	-0.225	54.762	0.569
[0,1]	-0.869	40.476	0.851	64.286	-1.721*
[0,3]	-0.876	45.238	0.718	54.762	-1.594
[0,5]	-0.840	49.206	0.770	51.587	-1.610
[0,10]	-0.696	49.351	0.335	48.052	-1.031

*** Statistically significant at 1%

** Statistically significant at 5%

* Statistically significant at 10%

Table 5: Abnormal returns for Dow Jones Industrial Average

	Base sample		Matched sample		Difference
	Abnormal Returns	% Positive	Abnormal Returns	% Positive	
22-04-10	-0.703	42.857	-0.062	47.619	0.641*
23-04-10	-0.063	47.619	-0.368	42.857	-0.305
26-04-10	-0.098	47.619	-0.420	42.857	-0.322
27-04-10	0.044	38.095	0.616*	61.905	0.572
28-04-10	-0.137	47.619	0.156	52.381	0.294
29-04-10	-0.056	52.381	0.269	57.143	0.325
30-04-10	0.461	71.429	0.836	52.381	0.375
03-05-10	0.124	66.667	-0.245	47.619	-0.369
04-05-10	0.144	61.905	0.055	57.143	-0.088
05-05-10	0.596	61.905	-0.604	52.381	-1.201
06-05-10	-0.642	33.333	0.123	47.619	0.765
07-05-10	-0.825	28.571	0.432	52.381	1.257**
10-05-10	0.210	42.857	-0.557	38.095	-0.768
11-05-10	0.114	57.143	0.271	57.143	0.157
12-05-10	-0.029	61.905	0.086	52.381	0.115
13-05-10	0.391*	76.190	0.214	57.143	-0.177
14-05-10	0.152	61.905	0.399**	80.952	0.246
17-05-10	-0.237	38.095	-0.024	47.619	0.213
18-05-10	0.181	57.143	-0.049	52.381	-0.230
19-05-10	-0.076	52.381	-0.611***	28.571	-0.535**
20-05-10	-0.206	38.095	-0.079	52.381	0.127
CAR					
[0,-10]	-0.331	51.948	0.355	51.082	-0.686
[0,-5]	0.626	57.937	0.433	52.381	0.193
[0,-3]	0.221	55.952	-0.671	51.190	0.893
[0,-1]	-0.046	47.619	-0.481	50.000	0.435
[0,1]	-1.467*	30.952	0.555	50.000	-2.023**
[0,3]	-1.143	40.476	0.269	48.810	-1.412
[0,5]	-0.781	50.000	0.570	50.794	-1.351
[0,10]	-0.966	49.784	0.205	51.515	-1.172

*** Statistically significant at 1%

** Statistically significant at 5%

* Statistically significant at 10%

Table 6: Abnormal returns for Dow Jones Industrial Average inclusive of VIX

	Base sample		Matched sample		Difference
	Abnormal Returns	% Positive	Abnormal Returns	% Positive	
22-04-10	-0.693	42.857	-0.072	47.619	0.621*
23-04-10	-0.040	47.619	-0.395	42.857	-0.355
26-04-10	-0.078	47.619	-0.445	42.857	-0.367
27-04-10	0.132	47.619	0.489	61.905	0.357
28-04-10	-0.166	38.095	0.195	57.143	0.361
29-04-10	-0.111	47.619	0.342	61.905	0.453
30-04-10	0.519	76.190	0.753	57.143	0.234
03-05-10	0.100	66.667	-0.216	47.619	-0.316
04-05-10	0.172	61.905	0.017	57.143	-0.155
05-05-10	0.609*	61.905	-0.613	52.381	-1.222
06-05-10	-0.585	28.571	0.038	38.095	0.624
07-05-10	-0.732*	38.095	0.296	57.143	1.028**
10-05-10	0.089	52.381	-0.403	28.571	-0.492
11-05-10	0.099	57.143	0.291	61.905	0.192
12-05-10	-0.062	57.143	0.135	57.143	0.196
13-05-10	0.390*	76.190	0.221	57.143	-0.169
14-05-10	0.192	61.905	0.340*	71.429	0.148
17-05-10	-0.236	38.095	-0.018	52.381	0.218
18-05-10	0.193	52.381	-0.065	52.381	-0.258
19-05-10	-0.057	52.381	-0.639***	28.571	-0.582**
20-05-10	-0.174	38.095	-0.127	42.857	0.047
CAR					
[0,-10]	-0.140	51.515	0.095	51.515	-0.235
[0,-5]	0.704	57.143	0.322	52.381	0.382
[0,-3]	0.295	54.762	-0.774	48.810	1.069
[0,-1]	0.023	45.238	-0.575	45.238	0.598
[0,1]	-1.317*	33.333	0.335	47.619	-1.652
[0,3]	-1.129	44.048	0.223	46.429	-1.352
[0,5]	-0.801	51.587	0.578	50.000	-1.379
[0,10]	-0.884	50.216	0.070	49.784	-0.954

*** Statistically significant at 1%

** Statistically significant at 5%

* Statistically significant at 10%

Table 5 provides us the abnormal returns for Dow Jones Industrial Average. The results for Dow Jones Industrial Average on the day of the flash crash indicate negative returns of -0.64% for the base sample. The negative return continues on the next day. Most of the stocks on the base sample have negative abnormal returns for the window period of [0, +1]. The cumulative abnormal return for the window period [0, +1] is -1.47% and is statistically significant. The results for matched samples does not provide any significant results.

Table 6 provides us the abnormal returns for Dow Jones Industrial Average including VIX. The results on the day of the flash crash indicate negative returns of -0.58% for the base sample. The negative return continues on the next day and is also statistically significant. Most of the stocks on the base sample have negative abnormal returns for the window period of [0, +1]. The cumulative abnormal return for the window period [0, +1] is -1.32% and is statistically significant. The results for matched samples does not provide any significant results.

The results gives us a strong indication of the negative impact of flash crash on the market structure. The negative impact is only seen in the base sample where trades were executed and then subsequently cancelled. The inclusion of the volatility index 'VIX' does not provide any substantial difference from the original results. Lee, Cheng and Koh (2011) had suggested in their paper that they were not very convinced with the cancellation of trades as it was an unfair to some market participants. The findings of the non-negative effect seen in the matched sample during the period of flash crash would support their understanding in respect to cancellation of trades to a certain extent.

6. CONCLUSION

This thesis concentrates on the role of flash crash and its negative impact it brought about on May 06,2010 in the US markets. The influence of the crash is compared over a given time frame thus focusing not only on the event date but also before and after the crash. Distinction has been made between trades that got executed and were later cancelled by Nasdaq or NYSE Arca and those that were not cancelled.

The findings do suggest that share holders wealth did deteriorate after the flash crash. Negative returns were found on the day of the flash crash and in some case even two days after the crash. The distinction between trades of those that were executed and cancelled and those that were not cancelled gives us an understanding of the impact it has on the returns between the two samples. The result suggest that the base sample stocks had consistently negative return on the day immediately after the crash and was responsible for eroding more of investors wealth as compared to those for the matched samples.The maximum impact was felt on Dow Jones Industrial Average with negative abnormal returns close to -0.83% for the day after the crash. The cumulative abnormal returns for all the four cases for the window period of [0,+1] is also negative for the base sample. It could also be seen from the results that the negative return is only persisten on the very next day or maximum on the day after it. This implies that the impact of the crash does not last for longer time span.

The analysis done gives a clear indication that investors did incur losses on their investment and the whole scenairo could be attributed to being artifically created. This has raised various concerns regarding the ethical aspect of trading. Recent developments on manipulation has clearly suggested that a lot of regulations were compromised to benefit few selected people. Such practice should not be accepted and stringent measures should be taken to make sure events like this do not happen again. Focus should also be set on defining the regulations well so no loopholes can be used to manipulate the system. The regulators should ensure better framework for algorithm traders and should only allow strategies that would not create any kind of interference in the dynamics of trading. Similarly trading companies that take advantage of complex algorithms in their trading strategies should make sure they are done in compliance with the regulations set by the regulatory authority. Similary robust risk management system should be in place to ensure avoidance of undesirable incidences or errors. Trading systems and complex strategies should be well tested before engaging in any kind of

high volume trading. This could elminate the possibility of liquidity crisis that could arise due to trading errors. Circuit breakers should also be implemented to give investors a fair opportunity to reasscess the situation and avoid further movement of stocks due to panic.

For further research it would be interesting to take into consideration the volumes and analyze the impact it could probably have on days after the flash crash. This would give a clear picture on the understanding of the negative sentiment and its persisance. Studying the effect of volumes could also help in understanding the issue of liquidity crisis and further measures could be taken to avoid such situations in the near future. Further extension of the research could be brought about by studing other international markets and analyzing how events like this in the US could affect markets of other countries especially those of emerging economies.

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