How One Trade Could Change theWorld

High Frequency Trading and the Flash Crash of 2010

The Honors Program
Senior Capstone Project
Student's Name: Sarah Perlman
Faculty Sponsor: Dr. AsliAscioglu
April 2012

Table of Contents

ACKNOWLEDGEMENTS

First, I would like to thank my Faculty Sponsor, Dr. AsliAscioglu for her time, effort and dedication to the successful completion to this project. I credit her with the success of this project and the learning opportunities that have come with it.

Next, I would like to thank Professor Michael Roberto for being the Editorial Reviewer for this paper. The inputs and perspectives he brought to this project were instrumental crafting this manuscript.

I would like to thank the Honors Program and the whole Bryant University community for the opportunity, support and guidance to complete this project. From beginning to end, the program and the university have created incredible opportunities for me to learn and grow as an individual.

Finally, I would like to thank my friends and family for their endless support and encouragement. Without them, this project would not have been possible.

ABSTRACT

Financial markets are controlled directly by a small population of people, but have direct effects on almost every aspect of the global community. Financial markets are now flooded with computerized algorithms that have drastically changed the face of trading. As with any advances in technology, there are always unforeseen events that create new challenges, and adjustments that need to be made. In our increasingly global and technological world, one wrong click of the mouse in New York could affect the stock markets in London, Tokyo, and Brazil. On May 6th, 2010, such a situation occurred and caused the Dow Jones Industrial Average to drop 9.8 percent in a matter of minutes.

The "Flash Crash",as it has become known,is a perfect example of how removing the human element from trading can cause problems that ripple through the economy. This event brought to light the major impact that High Frequency Trading (HFT) has on financial markets, when such a large majority of trades occur without even a human click of the mouse. The value of the Dow Jones Industrial Average multiplied by over 47 times and the volume grew about 2975 times from 1928 to 2011. Therefore, the spike in volume and stock price in recent years is definitely a correlation to note due to the introduction of technology. A widely cited statistic by the TABB Group is that high frequency trading accounts for 65% of volume on the United States market (Russolillo, 2011). The study that is conducted in this research will examine statistical hypothesis tests of the data from May 6th, as well as five other days to demonstrate thenegative effects that high frequency trading can have on the financial markets.

INTRODUCTION

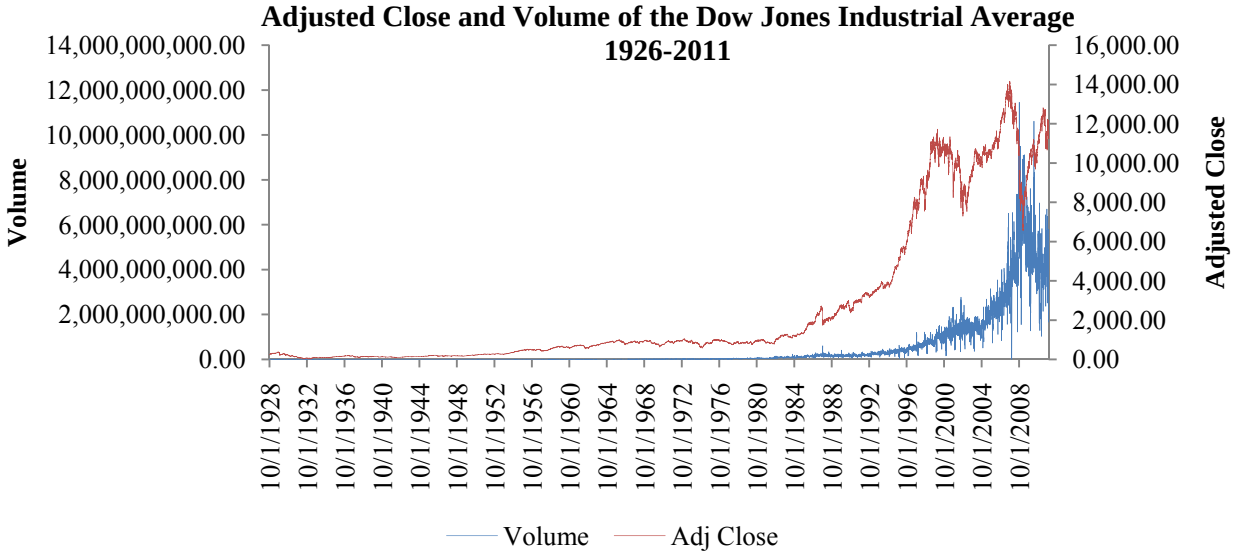
> *"A person watching the tide coming in, and who wishes to know the spot which marks the high tide, sets a stick in the sand … The average of [stock prices] is the peg which marks the height of the waves. The price-waves, like those of the sea, do not recede all at once from the top. The force which moves them checks the inflow gradually, and time elapses before it can be told with certainty whether high tide has been seen or not."*
>
> — Charles Dow, creator of the Dow Jones Industrial Average, in the January 31, 1901, edition of The Wall Street Journal (CME Group Index Services LLC, 2010).

Today's financial market environment seems very far from Dow's calm waves rolling on the shore. However, Charles Dow's metaphordemonstrates the simple, yet methodical, origins of what has become one of the most referenced market indexes across the world. Starting with only 12 stocks, and expanding to 30 holdings, the Dow Jones Industrial Average (DJIA) is a price weighted measure of the United States marketplace (Dow Jones, 2012). The DJIA representsthe performance of large and well-known U.S. companies' stocks. It covers all industries with the exception of Transportation and Utilities. Commonly known as 'the Dow', the average still represents the largest US companies' performance, albeit in a much more complicated trading environment. Throughout history, globalization, communication and technology have altered the market landscape. We currently operate in an environment with more participants from across the globe trading shares at lightning speeds, creating a completely different market space from as little as 20 years ago.

Only a few weeks after increasing the number of companies inthe Dow to 30 back in 1928, it reached a milestone of 300 points. The all-time high of 14,164 points was on October 9th, 2007. Similarly, the volume of the Dow has ranged from 130,000 shares in 1940 to around 11.5 billion shares in 2010 (CME Group Index Services LLC, 2011). An interesting piece of history that correlates with the sudden rise in price and volume of the Dow is the introduction of the "human free network", or computerized trading,in 1996 (Mehta, 2010). As can be seen in Figure 1, both price and volume havebegun an upward surge in 1996 , and still has the same

trend in 2011.Over time, this correlation seems to show an inflationary environment that has pervaded all indices, especially the Dow Jones Industrial Average.

Figure 1 (Yahoo, 2011)



Automation of the marketplace has led to several different types of market participation. Some of the most controversial market players today are High Frequency Traders (HFT*). Market Event Findings*, published by the Securities and Exchange Commission (SEC) and the U.S. Commodity Futures Trading Commission (CFTC),classify high frequency traders as "proprietary trading firms that use high speed systems to monitor market data and submit large numbers of orders to the markets...HFTs use quantitative and algorithmic methodologies to maximize the speed of their market access and trading strategies" (U.S. Commodity Futures Trading Commisision and U.S. Securities and Exchange Commission, 2010). By using advanced technologies, HFTs trade on spreads as small as pennies to turn profits. A widely cited 2011 statistic by markets research firm TABB Group, says that high frequency trading accounts for an average of 65% of trading volume in the United States (Strasburg, 2011). This has completely changed the landscape of financial marketplaces. Where trades were once run across floors, they can now be executed without any human intervention. Conflict arises when there is no human intervention in the event of a malfunction; which is exactly what happened on May 6th, 2010. However, this does not mean that high frequency trading can be touted as all bad, considering it

has technically increased liquidity in the market and decreased many commission costs for the average investor.

The following is an overview of the Securities and Exchange Commission's highlights of what is now known as "The Flash Crash". A detailed description of the events of May 6th can be found in an excerpt of the CFTC and SEC's publication of *May 6, 2010 Market Event Findings* in **Appendix G**. On May 6th, 2010 at 2:30 pm, the S&P 500 volatility index was up 22.5% and the Dow was down 2.5%. Likewise, two of the most active index vehicles, E-Mini S&P 500 futures contracts and S&P 500 SPDR exchange traded fund, had posted a 55% and 20% decline respectively by that point in the day. At 2:32, a large mutual fund complex realized the high volatility and loss of liquidity in the marketplace and sold approximately $4.1 billion worth of E-Mini contracts(U.S. Commodity Futures Trading Commisision and U.S. Securities and Exchange Commission, 2010). E-minis are small futures contracts traded electronically on the Chicago Mercantile Exchange, based on the S&P 500 index (What is E-mini, 2012). These contracts were intended to be sold via an automated algorithm at a rate of 9% of the average trading volume. Since the only parameter of this algorithm was trading volume, and the markets were not operating efficiently, the program executed all 75,000 contracts in 20 minutes. Between 2:40 pm and 3:00 pm, 2 billion shares had traded exceeding $56 billion. While 98% of shares were executed within 10% of the value, over 20,000 shares across 300 securities had been executed 60% or more away from the price they had been at 2:40 pm (U.S. Commodity Futures Trading Commisision and U.S. Securities and Exchange Commission, 2010).This research will examine the events of May 6th to determine the severity and extent that high frequency trading had on the Dow Jones Industrial Average on the day of the flash crash.

There is a definite need for clarification surrounding the practice of high frequency trading. The arbitrary labels of 'good' and 'bad' fail to capture the complexity of high frequency trading. At this point in the development of the trading world, stocks are changing hands, just in a different means than they were years ago. At this stage, what is left to be examined are the nuances around this relatively new trading practice to determine its effects on the broader marketplace. The world has already seen the effects of a faulty algorithmic trade and the ripple

through the economy, and therefore it is crucial that the research community provides a quantitative background for this relatively new technology.

LITERATURE REVIEW

What Does High Frequency Trading Mean?

In recent years, the term"high frequency trading" (HFT) has been disputed on several levels; starting with the definition and increasing in complexity through industry practices, norms and regulations. The introduction of technology that allows trades to occur in milliseconds, with no human interaction, has changed the landscape of the financial markets. One of the complexities that has arisen from this technology is that while efficiency has never been higher, there are hidden costs that have the potential to take a toll on the market.

Since high frequency trading a relatively new practice in the financial industry, there are several arguments over how to define it. In order to come to a concise conclusion, many turn to the Securities Exchange Commission (SEC) for a more concrete definition. For example, Stephen Barnes, a Juris Doctor Candidate at J. Ruben Clark Law School cites the SEC in stating, "[high frequency trading] typically is used to refer to professional traders acting in a proprietary capacity that engage in a number of strategies that generate a large number of trades on a daily basis" (Barnes, 2010). On the other hand, Mike O'Hara has taken another approach to defining HFT by asking industry professionals the question,"What is HFT?". In his article in Futures Magazine, Steve Zwick summarizes O'Hara's interviews with a linkage of commonalities rather than a clear-cut definition. He defines HFT as "…computer driven; it generates a large number of orders in a short space of time: it's dependent on low-latency, fast access to execution venues; its positions are held for short periods of time; it ends the day flat and its characterized by a high order-to-trade ratio" (Zwick, 2011). Zwick's definition of HFT exemplifies the many different components of this process, from the medium of trade, to the speed of execution, and the duration of the positions. As a summary from industry professionals, Zwick's definition provides insight into the most crucial characteristics of high frequency trading. Adding to this definition, Thomas Watson quotes Martin Wheatley, the CEO of the Securities and Futures Commission in Hong Kong, in his article "Rise of theMachines" which appeared in Canadian Business, " [Wheatley] defines [HFT] as the use of supersonic trading algorithms 'to capture

opportunities that may be small or exist for a very short period of time'"(Watson, 2011). This is a crucial component to add to the definition because it provides an explanation for the prime motivation of traders engaging in High Frequency Trading. Trading in the financial markets is about uncovering value, and being the first to do so generates the highest revenues. High frequency trading creates this opportunity by exposing small windows of opportunity that would be impossible to recognize without the aid of lighting fast computers and networking systems.

In a speech given to the International Economic Association's Sixteenth World Congress, Andrew G. Haldane, an Executive Director of Financial Stabilityand a member of the interim Financial Policy Committee at the Bank of England, goes yet a different route by depicting the three key effects that high frequency trading has on markets: "First, [HFT] has meant ever-larger volumes of trading have been compressed into ever-smaller chunks of time. Second, it has meant strategic behavior among traders is occurring at ever-higher frequencies. Third, it is not just that the speed of strategic interaction has changed but also its nature. Yesterday interaction was human –to-human. Today it is machine-to-machine" (Haldane, 2011). Haldane highlights the fact that the behavior in the financial markets has changed drastically, and the three key changes he notes demonstrates key characteristics of high frequency trading as it has evolved today. Therefore, these key market effects could be considered in the definition of high frequency trading. When talking about the flash crash, Haldane says "…only one clear explanation emerges: that there is no clear explanation" (Haldane, 2011). This is often the way high frequency trading is regarded across the industry. Based off of these examples, the following descriptionof high frequency trading can be deduced: High frequency trading has created the opportunity for traders to intensify the opportunities available in the market through computerized algorithms and proprietary strategies. It has created an environment in which human-less interactions initiate large numbers of low-latency transactions trades in what has become an incredibly high volume market.

Influence of Technology in the Markets

The flash crash of May 6th, 2010 has caught the attention of many journalists, researchers and industry professionals, in part because of how rare and abnormal an event it truly was. All of the attention that May 6th has gotten has created many diverse views of how high frequency

trading. In Thomas Watson's article in Canadian Business "Journalists vs. High Frequency Traders", the author addresses the idea that high frequency trading has been vilified across the industry due to the assumed turmoil that the computer generated trading has created. The authorcalls attention to a response to a New York Times article issued by ManojNarang, CEO of the HFT trading firm Tradeworks. Narang had said "markets react to news, and since 2007, there has been an abundance of news which has caused investors to panic…Computers don't panic, humans do" (Cited in Watson, 2011). Narang is putting pressure on journalists for reporting news that causes investor panic. Watson takes great offense to this comment due to the fact that Narang classifies volatility as only being caused by panic, and not incorporating the "dramatic changes in bid and ask market orders" (Watson, 2011), which tend to be present in today's market due to high frequency trades.

Many comparisons have been made between the flash crash and the stock market crash that happened in 1987. In 1987, high frequency trading did not exist as we knew it in 2010. In the article "How the 'Flash Crash' Echoes Black Monday" published in the *Wall Street Journal*, author Scott Patterson highlights that in 1987,the crash continued on into the next day, the Dow fell 20% and over 600 million shares were traded. Conversely, in 2010, the worst of the day lasted only 10 minutes, the decline was 9.8% and trading reached 19 billion shares (Patterson, 2010). In October of 1987, over 600 million shares of NYSE stocks changed hands, compared to May 6th, where over 10.3 billion shares were traded (Betancourt, 2011). While the numbers the two events produced were drastically different, some of the market conditions that the two events played out in were very similar.

The crash of 1987 was predicated by rising interest rates, a growing U.S. trade deficit and the decline of the value of the dollar led to concern in the marketplace. Likewise, the financial markets had recently been introduced to program trading. Program trading, specifically a strategy known as 'portfolio insurance' was when a computer model optimized stock-to-cash ratios at various market prices to suggest when to increase and decrease exposure to the market (Carlson, 2007). The week prior to the crash, the market began declining and resulted in one of the largest one-week declines in decades, and program trader's models were indicating that traders should sell stocks and futures contracts (Carlson, 2007) . Record trading volume on October 19th overwhelmed systems causing some trades to execute over an hour late, creating a significant

amount of uncertainty in the market. The top ten sellers accounted for 50 percent of non-market-maker volume, and one large institution sold thirteen installments of about $100 million each to total $1.1 billion throughout the day. The NYSE put trade restrictions on using the designated order turnaround (DOT) system which created unusual patterns in program trading (Carlson, 2007). Program trading was cited by the SEC as "both to the inability of non-portfolio insuring investors to accurately gauge the amount of selling suggested by the portfolio insurance models, which could reduce their buying interest and to an increase in the concentration and velocity of selling, which may distort prices and have a negative impact of the capital position of stock specialists" (Carlson, 2007). Program trading, margin calls and difficulty obtaining information have all been associated with the causes of the market crash of 1987. In response to this event, the Federal Reserve issued a public statement indicating their actions towards meeting needs for market liquidity, lowered the federal funds rate to increase liquidity, liberalized rules regarding lending securities from system accounts and encouraged banks lending to brokers and dealers to work cooperatively with their customers (Carlson, 2007).

Therefore, some have claimed that HFT magnified the effects of the flash crash when compared to Black Monday. However, the decline in 2010 was less than half of that in 1987. Another difference Patterson points out is that in 2010, there was a heavy sell off of exchange traded funds (ETFs), which are linked to other markets, thereby causing those markets to decline (Patterson, 2010). Since ETFs were not prevalent in the 1980's, this was one less factor that needed to be thought about while the markets were plummeting. In his article "Rise of the Machines", Watson echoes these views pointing out that in 1987, prices did not instantly rebound as they did during the flash crash. "So if you want to blame part of the flash crash on HFT," Watson claims,"then the robo-traders also deserve credit for the quick recovery" (Watson, 2011). Watson also quotes Mike Bignell, the president of a Canadian alternative trading system, who points out that the world of trading is evolving, "They don't play football the way we played it in the '30s, and they don't trade stocks like they did years ago" (Cited in Watson, 2011). Another analysis of the flash crash and high frequency trading that takes a similar viewpoint to Bignell,can be found in the Bloomberg Businessweek article "The Machines That Ate the

Market". The authors, Mehta et. al, also emphasize some of the benefits of high frequency trading.

> Wall Street's extreme makeover has achieved its main goals: greater efficiency and much lower commissions for pension and mutual funds, insurance companies, and endowment managers that invest in equities. Reduced transaction costs benefit teachers, office workers, corporate executive and retirees coast to coast.(Mehta, 2011)

While much of the industry criticizes high frequency trading as a drain of profits from traditional investors, these authors do a good job in bringing the perspective of all of the other beneficiaries to the financial markets that can get lost in a sea of trades. This is most definitely a major fact to consider when determining the ultimate question of whether high frequency trading is positive or negative. Another benefit that high frequency trading brings is the reduction of human biases in the financial markets. "Computer systems are now becoming powerful enough, and subtle enough, to help us reduce human biases from our decision-making. And this is the key: They can do it in real-time…Neither we nor the computers are perfect, but in tandem, we might neutralize our biased, intuitive failings…"(Berman, 2012). This is a very important key to note, because while there is no control over the human bias, supplementing human ideas with algorithmic data analysis can help to reduce investor bias, and in the future could be a major contributor to shifts in trading practices. Financial markets are one of the quintessential foundations of world economies there many believe should be evolving with the rest of the technological world.

<u>How to Suit Everyone In the Market</u>

Betancourt, VanDemburgh and Harmelink, the authors of "Understanding the Flash Crash", published in *CPA Journal,* point out that a fundamental changeoccurred in market structure and technology over the past decade, most importantly the Regulation National Market System (Reg NMS). This structure was supposed to increase market competition by lowering costs, which has a greater benefit to the market system. However, it tended to do the contrary. The author states that the Reg NMS created conditions to attract high frequency traders, brought liquidity into dark pools, and did not allow markets to slow during times of panic because there were so many stock trading platforms (Betancourt, 2011). The article continues to say that this

new market environment created by much of the new regulations has diminished investor confidence in equities and thus threatened capital formation (Betancourt, 2011).

Similarly, when reflecting on the flash crash, Craig Rothfeld, the executive director of WJB Capital Group, looks to dark pools and HFT as a major source of the panic. He says "There's no liquidity anymore…We're also kept in the dark about what's being traded. Its not a safe and secure market" (Rehfeld, 2010). Many industry professionals feel similarly to Rothfeld, and thus the quest for afair and efficient form of regulation is on. One of the biggest problems is that there is the distinct possibility for a crash like the flash crash to occur again. In the article *A Day to Remember,* the author cites the example of Patrick Fay, the head of equity trading at D.A. Davidson & Co.:

> [Fay] doesn't think Wall Street is equipped for debacles like this one-and he got a look into the abyss. He was one of the traders who had his biggest losses reversed…Next time-and no one doubts there could be one- he and the rest of Wall Street might not be so lucky (Rehfeld, 2010).

Eric Hunsader, of Nanex shares the same sentiments with Fay, but adds in the component that the next flash crash may be done deliberately. In a 2011 article forthe *Journal of Business & Economics Research,* Hundsader says that traders are using large volumes to intentionally slow down the market, and skim profits from competitors. He feels that the last crash was caused on purpose, in a situation where one trader tried to overload the NYSE to add latency. Likewise, Hundsaderpoints to the fact that mini flash crashes have happened before, citing April 28th where Wal-Mart and Procter and Gamble fell 50 cents for less than a second. Hundsader's final argument is that the system has shown delays more than once since the flash crash, "With dark pools[3], flash trading[4], quote stuffing[5] and sub-penny pricing all being included in the tricks of HFTs, it is no wonder that the market can be manipulated. No one knows then the next flash crash will happen, but it is reasonable to assume that another one will happen." (Rose, 2011).There is currently a cloudy understanding of exactly what happened on May 6th, but there

[3] A type of trading platform that allows large blocks of shares traded without prices being revealed publicly until after the trades are completed (Dark pools definition n.d.).
[4] Flash trading is where orders are shown to members of an exchange for a split second before being passed onto the wider market (Flash trading definition n.d.).
[5] Quote stuffing is an attempt to overwhelm the market with excessive numbers of quotes by traders. This is done by placing and almost immediately cancelling large numbers of rapid-fire orders to buy or sell stocks (Quote stuffing definition, n.d.)

is no doubt in many minds across the industry that this same type of crash could happen again. Thus, many in the industry are searching for solutions as to how to best operate the marketplace in order to mitigate the risk of a similar crash happening again.

On the panel "What Makes and Exchange a Unique Institution", at the Baruch College Conference "The Economic Function of a Stock Exchange", the panelists discussed how to serve everyone in the marketwhile still making sure that the markets are a fair trading environment with the addition of high frequency trading. Alfred Berkley of Pipeline Trading Systems, brought up the point that in the blink of an eye, five trades are executed. Berkley feels that you need to let the rules of engagement in the market evolve and not overregulate, but ask for more innovation (Berkeley, 2011). Gary Katz of the International Securities Exchange agreed, saying that the marketplace today is a completely different world than it was ten years ago and we need to keep moving forward. William O'Brien of DirectEdge and AsaniSarkar, of the Federal Reserve Bank of New York both came to the conclusion that more education on the subject of high frequency trading is crucial. William O'Brien statedthat high frequency trading is generally poorly portrayed, and it needs to be communicated to America that this technology creates a mechanism to share insight and knowledge in a productive and collaborative way (Berkeley, 2011). AsaniSarkarbrought up the point that high frequency trading creates a huge network effect that few people are familiar with. Sarkar feels that we need more education and research in the field to demonstrate the way high frequency trading affects other aspects of trading and the overall current market place (Berkeley, 2011). Due to the fact that nothing in the financial world is static, you need to be constantly reevaluating the way that your firm trades and operates. Greg Tusar, the head of Goldman Sachs Electronic Trading business in the Americas, points out the fact that remaining competitive in high frequency trading involves a constant commitment to improve infrastructure. He then discussed the opportunities that Goldman offers for their clients to execute large orders across many pools, while managing risk, all over the course of milliseconds (Ramage, 2010). As technology develops, it is crucial that there are developments in infrastructure in order to stay competitive in the high frequency trading marketplace. New technology develops everyday, so it will be crucial for big firms to make strategic decisions when updating and adapting HFT infrastructure. While these are very costly improvements, it will prove to be a cornerstone of the marketplace in the future.

The flash crash did not take everyone by surprise. In an article published in the January/February 2010 edition of Technology Review, Paul Wilmott spotted the trend early and cautioned the need for the movement within the financial industry to be studied. "High – frequency trading is the latest bandwagon, and everyone is jumping on board…Wall Street always piles on to the next thing, and it always blows up…The potential is there for a crash to happen quite quickly" (Urstadt, 2010). Wilmott's seeming premonition demonstrates that HFT was a concern for investors well before the actual flash crash occurred. In a survey conducted by Liquidnet, a dark-pool operator, over 300 asset management firms with control over $13 trillion of assets were polled on their feelings towards high-frequency trading. The results exposed that approximately two thirds of industry participants were concerned about the impacts that HFT has on market structures (Russolillo, 2011). The founder and chief executive of Liquidnet, Seth Merrin explains, "It's not the high frequency traders that are catalysts for the volatility. But they're simply exacerbating the moves" (Russolillo, 2011). This is a key point because similar to the market crash of 1987, where program trading did not cause the market crash, it enhanced the movements. At the top five firms surveyed, results revealed that 73% of traders felt HFT was a "high priority market-structure issue" (Russolillio, 2011). While the article submitting the results of the findings was short, Merrinhad a few very insightful quotes demonstrating the need to look at HFT at a closer level:

> "Investors are clearly concerned that their long-term investment styles are at odds with the speculative, nanosecond profit-taking approach utilized by high-frequency traders….The fundamentals simply don't change on a daily percentage basis that we've been seeing, especially with these 400- and 500- point days" (Russolillo, 2011).

Russolillo summarizes Merrin's views saying "the survey results exemplify how traditional investors are vastly opposed to high-frequency traders, whose quick-fire moves raise the costs of trading for traditional players" (Russolillio, 2011).This brings light to the fact that while the industry opinions of HFT run a broad spectrum of acceptance, traditional traders are highly opposed to HFT because they feel it puts the traditional traders at a disadvantage, and increases the perceived risks in the market.

Despite the risks that are presented from high frequency trading, many of the larger firms have realized the potential it holds for their firm. Not all firms have built up their HFT

infrastructure, so there is a tremendous opportunity for these bulge bracket banks to createa competitive HFT platform, so customerscan combine HFT with all of the offerings of a full service prime brokerage. This combination will allow high frequency traders to borrow more stock and make better usage of their leverage and capital. John Goeller, managing director within Bank of America/Merrill Lynch's global execution services described the process as "an arms race of sorts" (Armstrong, 2011). Firms can also leverage the research and development that goes into HFT to help their buy-side clients. Due to the constant evolution of technology, it is important to provide these technological advantages to all aspects of the banking business.

The Introduction of Regulation

The recentness of these events, and the ever changing nature of the current financial market landscape, makes high frequency trading and the flash crash a crucial component to understanding and improving our current financial market system. The sole fact that the definition of high frequency trading is so cloudy shows that there is a lot of research to be done in this field. The financial market system is at the crux of economies across the world, and thus it is crucial that it develops with the technology of the modern world. Moving forward, research needs to address the long term effects that market crashes can have on the financial markets, regulations that can help curb market crashes and technology that will be changing the industry over the course of the next few years.

Ironically, high frequency trading was actually created from a set of regulations, and many industry publications have pointed to items that high frequency traders deem necessary to be addressed. Author Edgar Perez explains that SEC regulation, and the assistance of computers and technology, helped create many jobs focused around quants and traders looking to make profits on spreads. However, Perez feels that more forced regulation would tighten margins and discourage trading (Perez, 2012). From an international perspective, France is one of the leaders in high frequency trading reform, and EdouardVieillefond, managing director at French regulator AMF explained, "To understand this debate we should separate surveillance of the technology and surveillance of the strategy. High frequency trading (HFT) is not a strategy, it is a new technology" (Becker, 2011). Chris Sparrow took this idea one step further explaining, "Put simply, HFT is not a trading strategy. It's a business model" (Sparrow, 2011). These two inputs

explain that high frequency trading is no longer simply one type of trade used in the market.It has evolved into a series of strategies, from latency arbitrage to pattern recognition, which all need to be fully understood before regulation can be put forward. John Cartlidge of the University of Bristol explained that "Economic theory has always lagged behind economic reality, but now the speed of technology change is widening that gap at an exponential rate. The scary result of this is that we now live in a world dominated by a global financial market of which we have virtually no sound theoretical understanding" (Keim, 2012). It is therefore the challenge of the current generation to not only further grow technology, but also keep markets efficient and fair.

One of the problems with a constantly evolving and rapidly moving trading environment is that, while there is a widespread agreement some components of the industry needs to change, the high complexity of high frequency trading make regulators largely ignorant to the nature of the practice. In his article in Bloomberg BusinessWeek, Matthew Philips explained "High-frequency trading remains today as it was two years ago: an opaque, misunderstood, and almost totally unregulated industry worth billions of dollars "(Philips, 2012). Later in the article, Philips continues, explaining that the problem is that regulators lack both the expertise and the technology to monitor high frequency traders effectively. He cites SEC Chairwoman Schapiro who admitted that the regulators still did not understand the industry enough. The analogy Philips made was "It's as if regulators are on horseback while the traders are in Ferraris" (Philips, 2012). Therefore, the high frequency trading industry is at an incredibly interesting point in time. There are many steps that can be taken; however, technology advances so rapidly that it is difficult to comprehend and invest in a regulation that could become outdated before it is even enacted.

While it has proven difficult to grasp a definition of high frequency trading, there has been a universal consensus that there needs to be an examination of regulation. Immediately following the event, the Subcommittee on Securities, Insurance and Investment of the Committee on Banking, Housing and Urban Affairs of the United States Senate held a hearing "examining the causes and implications of the May 6, 2010 market plunge and identifying what policy changes may be necessary to prevent such events from occurring again"(U.S. Senate, 2010). In the two years since then, there has been ample discussion on the best way to keep the markets a

fair and efficient place for people to raise capital. As Mary Schapiro, Chairman of the Securities and Exchange Commission stated "At the end of the day, our goal has got to be that our markets operate fairly and efficiently and effectively for all the constituencies… our markets have to be about investors and the ability to raise capital. So that is how we are going forward on these issues" (U.S. Senate, 2010). The Securities Industry and Financial Markets Associations (SIFMA) echoes Schapiro's sentiments in saying "In general, SIFMA believes that the business of trading should never take precedence over the business of investing" (SIFMA, 2011). This holistic view of regulation takes into account the evolution of technology in the marketplace and acknowledges the end goal to create a fair and equitable financial markets system. However, with the constant evolution of technology, creating a fair and equitable financial marketplace is proving to be an increasingly difficult task.

In the time since the flash crash, several regulatory steps have already been taken. Key items that SIFMA distinguishes include: the SEC's Market Access Rule, the Single Stock Circuit Breaker Program, Limit Up/Limit Down Mechanism, Revisions to Market-Wide Circuit Breakers, Large Trader Reporting Systems and Consolidated Audit Trails (SIFMA, 2011). The Market Access Rule was implemented in November of 2010 to further implement risk controls for broker-dealer clients in the market. In a press release by the SEC, they explain that the rule was intended to focus on 'unfiltered' or 'naked' access, in which broker-dealers provide customers with sponsored access to markets. It requires broker-dealers "to put in place risk management controls and supervisory procedures to help prevent erroneous orders, ensure compliance with regulatory requirements, and enforce pre-set credit or capital thresholds" (US Securities and Exchange Commission , 2010). Spurred by an effort to increase transparency in the marketplace, this regulation will help to bring more accountability in the monitoring and controlling of risk on the part of the broker –dealer.

The single stock circuit breaker program created a five minute pause in a stock across all US equity markets if there is a 10% change in the stock price. Already having been pushed back four separate dates, it was extended to July of 2012 (Securities and Exchange Commission, 2012). This program is a very crucial component to creating market regulation on high frequency trading because on days such as the flash crash, stock prices were incredibly volatile, with many moving in swings greater than 10%. Further investigation of this circuit breaker program is

crucial because while there is an existing market wide circuit breaker, the influence of high frequency trading has altered the way these circuit breakers operate. In his statements before the Senate, Gary Gensler, the Chairman of the Commodity Futures Trading Commission explained "A lot these algorithms, just because it is [an] algorithm, don't think smart…And so giving the 30-minute pause in the inter-market circuit breaker or even overnight if it is a 30 percent decline, for instance, today gives humans a chance and information to come in" (U.S. Senate, 2010). Algorithms have created an environment where computers execute what they are told to execute, which in turn has created a system that can lack human logic and reasoning. Single stock circuit breakers provide the market with that opportunity to recover and respond logically and appropriately to major market situations, such as the flash crash.

One of the problems with the existing circuit breaker approach is that the circuit breakers can be triggered by single inaccurate trades. The Limit Up/Limit Down mechanism would be a complementary piece of regulation to ensure the most efficient and transparent market. This mechanism would not allow trades to occur outside of a specified price band above or below the average price of the stock for the preceding five minutes. These bands, which are set as a percentage, would be adjusted to accommodate fundamental price shifts, and the opening and closing of the market (Securities and Exchange Commission, 2011). With high frequency trading, stocks can move intensely up or down based on many different signals that a human would not necessarily trade from. Therefore, there the limit up/limit down mechanism was put in place to attempt to curb the extreme volatility that high frequency trading has brought to the market.

Another regulation that has been implemented is the Large Trader Reporting Regime. Large traders will be required to identify themselves to the SEC, who will in turn give them a unique identification number. Broker-dealers will be required to keep all transaction records for their traders and be able to provide that information to the SEC should they deem it necessary. Acknowledging the need to enhance the ability to analyze events quickly and accurately, Chairman Schapiro said in a press release "This new rule will enable us to promptly and efficiently identify significant market participants and collect data on their trading activity so that we can reconstruct market events, conduct investigations, and bring enforcement actions as appropriate" ("SEC adopts", 2011). This piece of regulation is good because it creates more

transparency and accountability among large traders in the marketplace. Since the SEC is has more oversight on large traders, it will also be a crucial component to studying market structure in the future.

The final major pieceof regulation that has been enacted since the flash crash is the introduction of a consolidated audit trail. This rule would require self-regulatory agencies (SROs) to create a system that would allow regulators to track information about the way trading orders are received and executed across markets. Currently, there is no single database, so to track suspicious activity requires copious amounts of data ("SEC proposes consolidated", 2010). While this would help to create a more fair and efficient market, this system would cost $4.1 billion to build and $2.1 billion annually to maintain and would most likely not be operational until 2014 (D'Antonia, 2012). In an article in *Traders Magazine*, JohnD'Antonia Jr. explains "The thinking behind the audit trail was to give regulators a central database of trade information to help them reconstruct trades during a destabilizing market event, so they could figure out what happened and possibly create safeguards to prevent future occurrences" (D'Antonia, 2012). As of March 2012, this regulation was still being debated. However, in light of the fact that the flash crash is still being investigated two years later, it could be an indication that regulators do need to be able to reconstruct market activity quickly and easily.

With such a controversial topic, there are many approaches that can be taken. Europe has begun to establish initiatives aimed at high frequency trading, not only providing definitions of high frequency trading and algorithmic trading, but also outlining provisions for providing liquidity and maintaining a ratio of orders to transactions executed, as well as risk controls and filters (Seitz, 2010). Likewise, the Intercontinental Exchange (ICE) has successfully implemented an HFT policy for over a year. President and COO Chuck Vice explained, "These traders [HFT] represent the natural evolution of the long-standing market-making role as trading overwhelmingly shifted to electronic venues in the last two decades. ICE believes that it is incumbent upon exchanges to adopt rules and design controls that effectively address the existence of high frequency trading within the context of market structure" (IntercontinentalExchange, 2012). ICE's High Frequency Messaging Policy was implemented on its most heavily traded futures and OTC contracts to discourage inefficient and excessive messaging using a Weighted Volume Ratio (WVR). The results were that the WVR declined

63% in ICE Futures US markets, 19% in ICE Futures Europe markets and 53% in ICE's OTC markets. The number of violations of the policy's highest thresholds dropped 93% after the implementation of the policy (IntercontinentalExchange, 2012). While this is only one year's worth of data, studies such as this one will be crucial in determining appropriate regulatory measures for high frequency trading in the United States.

The success of ICE's policy indicates that there are regulatory alternatives available that could have a major impact on preventing future flash crashes. SIFMA believes that other potential alternatives that are being evaluated are putting throttles or disincentives on excessive market data inputs, steps to ensure market data quality, studying the impact of maker-taker pricing/rebates and access fees, adapting incentives and obligations for new market makers, and conducting more empirical studies on factors causing increased market volatility (SIFMA, 2011). All of these items should be explored in order to keep up with the constantly changing marketplace. Regulation can take months or even years to be implemented, and as we have seen with the flash crash, it can take even longer for a situation to be understood. Therefore, firms have shown that it is possible to implement successful regulation and many others are sharing their view for alternatives to help bring the regulatory component of high frequency trading up to speed with the technology that is quickly outpacing it.

HYPOTHESES

To determine the effects that high frequency trading may have had on the events of May 6th, 2010, this paper will examine five hypotheses. These hypotheses compare data from the day of the flash crash with four other randomly selected days in 2010 that had little or no news that would have a drastic impact on the market. These dates were February 4th, May 3rd, May 19th, and October 11th. It was important to select dates both within close proximity to the event date as well as further throughout the year to see if there were any other underlying occurrences in market around the time of the event. February 4th was chosen as a day with little market news months before the actual flash crash. May 3rd was chosen as a day with little market news the same week was the flash crash to show if there were any other events occurring that week that could have influenced the flash crash. May 19th was chosen as a little news day two weeks after the flash crash to determine if there were any residual implications that the flash crash left in the

marketplace, and October 11th was chosen as a little news day months after the flash crash as a post-flash crash control date. The trading day was broken into 26 fifteen minute intervals to create a clear picture of the small timeframe in which these events occurred. T-Tests and Sign Rank Tests were conducted comparing the control dates with the event dates. Since the Dow Jones Industrial Average consists of 30 securities, it was on the limit of the number appropriate for a T-Test and for a Sign Rank test. So to ensure accuracy, both tests were conducted. Alphas of less than 10% were considered significant. From the Trades and Quotes data, five key variables appeared important to analyze and present as hypotheses.

Hypothesis 1a: The returns during the flash crash of May 6th were lower than those on the other four days when measured in fifteen minute periods.

Hypothesis 1b: The returns during the recovery of the flash crash on May 6th were greater than on the other four test days when measured in fifteen minute periods.

Average returns reflect the increase or decrease of the average return calculated over the course of the 15 minute period. Due to the rapid and frequent price changes on the day of the flash crash, this hypothesis estimates that the average returns across the 30 components of the Dow would be lower than a normal market day during the flash crash, but higher than a normal market day .

Hypothesis 2: The number of trades executed after 1:30 pm on May 6th were greater than on other four test days.

Due to the technology of high frequency trading platforms, algorithms can be programmed to trade on price changes. This leads to the hypothesis that there were more trades executed on May 6th than the other test dates because stock prices fluctuated so drastically, it caused algorithms to buy and sell with no regards to the other market conditions.

Hypothesis 3: The average volatility of the Dow Jones Industrial Average will be higher after 1:30 pm on May 6th than on the other four test days.

The average volatility was calculated by finding the standard deviation of returns based on every trade, calculated based on tick by tick trading prices. This demonstrates the average amount that a price could go up or down within short period of time. Most importantly measures the amount of risk that is present in the market. With the uncertainty of the market events on that day, this hypothesis predicts that there will be higher average volatility on May 6th.

Hypothesis 4: The average trade size on the Dow Jones Industrial Average will be larger after 1:30 pm on May 6th than on the other four test days.

The influence of high frequency trading algorithms has led to a change in the way that trading occurs. Many algorithms are programmed to trade in small blocks of 100 or 200 shares so that when they execute trades, it does not tip off other traders that they are buying or selling. However, this hypothesis argues that on the day of the flash crash, larger trades were executed because algorithms were programmed to either rapidly buy or sell stocks at a certain price. With the price fluctuations in the market, this would have led to larger trades.

Hypothesis 5: The average volume of trades on the Dow Jones Industrial Average will be higher after 1:30 pm on May 6th than the other four test days.

This hypothesis estimates that the average number of trades that occur in each period will be higher on the day of the flash crash than on any other day. This is because on May 6th, investors would have wanted to either capitalize on pricing by buying or remove themselves from riskier situations by selling. Similarly, many algorithms are programmed to trade on price changes and other market fundamentals that could have been triggered with the abnormal market conditions, therefore creating more trades. This was measured by determining the cumulative size of trades on the DJIA and taking the average across the periods.

METHODOLOGY

This study uses a compilation of New York Stock Exchange (NYSE) data to examine the effects that high frequency trading has on financial markets and the role it played in the flash crash. In this study, only the thirty stocks from the Dow Jones Industrial Average will be

examined. The Dow 30 was selected in order to provide a complete market picture, while still maintaining a manageable amount of trades to observe. Other indices, such as the S&P 500 would have had too many components to analyze effectively. The 30 stocks in the Dow are all industry leading corporations and are widely held by investors, making this index an accurate representation of market activity.

Using the Trades and Quotes system from the New York Stock Exchange, and retrieved data for May 6th, the day of the flash crash, as well as February 4th, May 3rd, May 19th and October 11th, as randomly selected days will little to no news that could greatly affect the market. The list of the thirty holdings that were examined in this study can be found in **Appendix H.** The information retrieved from the quotes included the following: the exchanges on while the trades occurred (AMEX, Boston, NSX, NASD ADF and TRF, Philadelphia, Chicago, NYSE, ARCA, NASDAQ, ISE, CBOE, BATS), the time the trades were executed, the bid, the bid size, the offer, the offer size, any quote conditions, as well as the market maker identification. The information retrieved for the trades included: the exchange, the time, the trade price, the trade size, any conditions on the trade, any corrections made to the trades, as the stopped stock trade indicator.

Once this data was retrieved, it was filtered in order to provide accurate representations of market activity. The trades that were included were regular trades , without any stated conditions. This includes trades that were executed on NYSE Direct + and BSE Instant Liquidity which are both high speed automatic order execution platforms, and trades that were made without checking for trade throughs making the broker responsible for the best execution. The trades were also filtered for any corrections made to them, showing only regular trades that were not corrected, changed or cancelled, original trades that were later corrected in which the record displays the original time but corrected data for the trade, and any symbol corrections that were made. NYSE TAQ qualifies all of the above correction codes as 'Good Trades'. In terms of time, the data only included trades during normal market hours, 9:30 am to 4:00 pm.

The trading day was divided into 26, 15 minute periods in order to display the frequent and abrupt changes that occur in the marketplace. From this point, the mean, median, standard deviation and sum of the returns, trade size, and price for the trades were calculated for each day. In order to conduct Match T-Tests, this data was combined into a database and the differences in

the data between the event dates for each of the five variables that were studied were calculated. The variables being studied were trade size, number of trades, volatility, cumulative return, and volume.

In order to determine the statistical significance of the relationship between May 6th and the control dates, both parametric and non-parametric statistical tests were used. The parametric test that was conducted is known as a matched t test. The null and alternative hypotheses for this test are:

$$H_0 : \mu_d = 0$$

$$H_1 : \mu_d \neq 0$$

μ_d is the mean difference between the values for two samples. From there, we find the mean and sample standard deviation for the difference values.

$$\bar{d} = \frac{\Sigma d_i}{n}$$

$$s_d = \sqrt{\frac{\Sigma (d_i - \bar{d})^2}{n-1}}$$

The final test statistic for hypothesis tests using matched samples is:

$$t = \frac{\bar{d} - \mu_d}{s_d / \sqrt{n}}$$

If the *p* value is less than 10%, then the value is deemed statistically significant. (Anderson, 2011)

The second set of tests that was run was a Wilcoxon Signed Rank Test. This is a non-parametric test that does not require the differences between the paired observations to be normally distributed. The populations must be symmetrical when the shapes of the two populations are the same to determine if there is a difference between the median of the two populations. In this test, the hypotheses are:

H_0: Median for method A- Median for method B ≤ 0

H_1: Median for method A- Median for method B > 0

First,difference of zero are eliminated, and then the absolute value of the remaining difference are calculated. Next, the absolute differences are ranked from lowest to highest, beginning with 1. Each rank is then given the appropriate sign (positive or negative) based on the original difference. T^+denotes the sum of the positive signed ranks and used as the test statistic. The next step is to determine the mean and standard deviation of the population respectively:

$$Mean: \mu_{T^+} = \frac{n(n+1)}{4}$$

$$Standard\ Deviation: \sigma_{T^+} = \sqrt{\frac{n(n+1)(2n+1)}{24}}$$

Then the *p* value is computed.If it is less than .10, this test will consider it statistically significant. The results of these tests will demonstrate if there is a statistical significance between the event day and the control day, thereby providing grounds to accept or reject the hypothesis (Anderson, 2011).

RESULTS

Hypothesis 1

As can be seen in **Appendix A**, around 2 pm, returns started tobecomenegative, taking a sharp turn down at about 2:20pm. Theyreach the low of -0.0439, or -4.3%. The average returns rebound around 2:40, reaching a peak of .0835, or 8.35%, before returning to average levels and closing the day at almost 0, .0027, or -.27% returns. The T-Test shows statistical significance at 10%. When evaluating the statistical analysis we do not observe a statistically significant difference between return on May 6th and return on the control days. When looking at the Sign Rank test, the values follow the same pattern, showing statistical significance. When examining the alphas of both of these tests, from1:30 pm to 3:00 pm, the values are at or around 0.000, meaning that these are very statistically significant. In a paper by Jialin Yu of Columbia Business School, he presents the argument that stocks with better past returns crashed more on May 6th than other stocks. Yu suggests this is because these stocks are unattractive to contrarian

buyers(Yu, 2011). Contrarian traders are traders that buy or sell against market trends. In this study, this phenomenon was found hold true when examining cumulative returns. In **Appendix F,** it is evident that the flash crash produced wild swings for Procter and Gamble (PG), in terms of both price and return. In the first chart of the appendix, it shows the constant price appreciation PG has enjoyed over the past three years, and the following charts depict the volatility in returns that PG experienced during the flash crash. In Yu's conclusion, he explains "…the glass is half full because the study simultaneously find a group of stocks a contrarian buyer is unlikely interested in stabilizing, even with big crash sizes" (Yu, 2011). Therefore, while contrarian stabilization is certainly not what led to drastic cumulative returns of securities like PG during the flash crash, it could be one step closer to examining swings in cumulative return that happened across major companies such as PG, ExxonMobil (XOM), and Alcoa (AA).

The results of this study differ from many widely reported industry statistics for two possible reasons. The first reason is that when calculating the average return the first and last price for the period of each security so many of the larger price swings of securities were not included in the calculations. Secondly, this study only included trades designated as 'good' by the New York Stock Exchange, which could eliminate some of the trades which were included in the other industry studies.

Hypothesis 2

As can be seen in **Appendix B** on May 6th the average number of trades on the Dow Jones Industrial Average began increasing around 2:00 and remained at above average levels throughout the rest of the day. The interesting point to note about **Appendix B** is that on all days, the number of trades appears to follow the U shaped curve indicating that there were more trades made at the opening and close of the market. In August of 2010, the first and last hour of trading generated almost 58% of New York Stock Exchange primary volume, in increase from 45% in August of 2005 (Peterson, 2010). On May 6th, after the number of trades spiked and then retreated, the levels still increased again for the close of the market. The t-test and sign rank tests show statistical significance at 10% after 2:00 pm. Since number of trades rose before the flash crash occurred, it could be an indication that there were smaller earlier market events that triggered the flash crash that algorithms were picking up on and began buying and selling stock.

Many argue that quote stuffing, in which trades are placed and then cancelled, is a major problem that is associated with high frequency trading. However, as Adam Sussman of the TABB Group points out in his discussion of "What Isn't in the Flash Crash Report", he says "There is no evidence that quote stuffing played a part in the Flash Crash. Indeed, the report implies the opposite, namely that quote volume dramatically increased because folks were exiting the market en mass, replacing their tightly quoted spreads with stub quotes, for example" (Sussman, 2010). When examining the average daily volume (ADV) of the VIX (volatility index of the S&P 500), it shows that during times of uncertainty, volumes increase significantly. Matthew Simon, also of the TABB Group, states "Case in point: Post the May 6 Flash Crash, the VIX increased significantly above its five-year average of 23, and busier trading days followed. Also, figures published by major exchanges show that equity market volumes increased to their highest levels over the last 10 years during the 2008/2009 credit crisis" (Simon, 2011). The concepts of trading under uncertain market conditions confirms the results of the event study that shows a large increase in the number of trades on the day of the Flash Crash and the high statistical significance between May 6th and the control dates. The event study has shown that with more uncertainty in the market comes more trades in the marketplace.

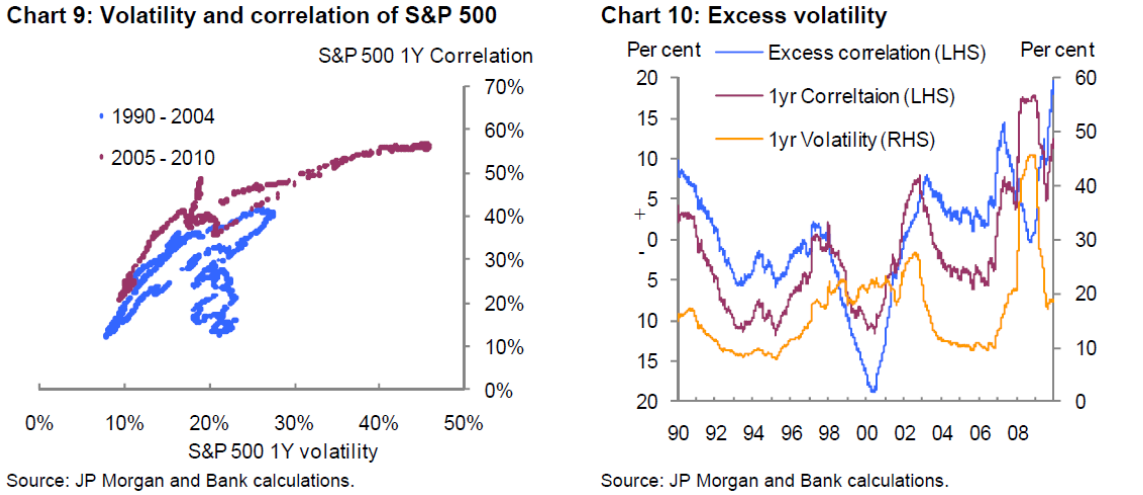
Hypothesis 3

This event study found that average volatility peaked in the 2:45 period, where it reached a level of .00532, which is significantly higher than levels on the other days, most of which remain close to 0. Statistically, at 2:00 the Sign Rank values become both positive and much larger, and the alphas for the sign ranks are very low demonstrating the statistical significance of therelationship between May 6th and the other test days. Likewise, the T-Test values also increase and remain positive, and the alphas fall to below 10%, confirming the significance of the increase in volatility on May 6th. This shows that during the flash crash, there was a much larger amount of risk in the market. In his speech at the International Economic Association Sixteenth World Congress, Andrew Haldane of the Bank of England highlights the relationship between market volatility and correlation. **Figure 2** demonstrates the volatility correlation between the components of the S&P 500 and showing that since the introduction of trading platform

fragmentation and HFT in 2005, there has been an increase in volatility and correlation 10 and 8 percent respectively. In **Figure 2**, Haldane also points to excess correlation which is measured market correlation in excess volatility on the S&P 500, which in July of 2011 was at all-time highs (Haldane, 2011).

> "Taken together, this evidence points towards market volatility being both higher and propagating further than in the past…Coincidence does not of course imply causality. Factors other than HFT may explain these patterns. Event studies provide one way of untangling this knitting…The official report on the flash crash, while not blaming HFT firms for starting the cascade, assigns them an important role in propagating it. (Haldane, 2011)

Figure 2: Volatility and Correlation and Excess Volatility



(Haldane, 2011).

While, Haldane's evidence uses the S&P 500, similar conclusions can be drawn with this event study of the Dow. In **Appendix C**, it is evident that the average volatility increases five-fold on the day of the flash crash, and the alphas of the Sign Rank tests drop to zero, which proves the statistical significance of the event. This further demonstrates Haldane's point that "Taken together, this evidence suggests something important. Far from solving the liquidity problem in situations of stress, HFT firms appear to have added to it. And far from mitigating market stress, HFT appears to have amplified it" (Haldane, 2011). The Flash Crash is an event that is directly connected to high frequency trading, and this event study directly demonstrates the great effect that high frequency trading can have on volatility in the marketplace.

Hypothesis 4

This hypothesis was rejected because during the flash crash, the average trade size on the Dow Jones Industrial Average remained in the 200 to 250 shares per trade range, as can be seen in **Appendix D**. The Sign Rank tests show statistical significance at 10% in the relationship between May 6th and February 4th; however, in comparison, October 14th only showed statistical significance at 10% after 3:00 pm which was after the flash crash occurred. . The T-tests confirmed these findings with similarly negative values and high alphas. This brings light to the prevalence of algorithms in the market because the algorithms are frequently programmed to trade in small blocks. With all of the uncertainty, many human traders could have stopped trading or not traded large positions during the flash crash. Another factor that should be considered is that there were many trades that were cancelled that had been executed within the period the flash crash occurred in. These could have been larger trades with traders trying to capitalize on low prices or get out of securities before prices dropped too far. In a transcript of an interview with Joe Saluzzi, Partner at Themis Trading and member of the CTFC Subcommittee on Automated and High Frequency Trading, Saluzzi says "The type of trades that are out there now used to be dominated by institutional volume and the block trade was a big deal. When you sold a block, the stock would move accordingly. Well the blocks are miniscule now compared to overall volume. Most of the volume is 100-share prints to an average trade size of 5200 shares. That's because the type of trades have changed" (The Equity Market, 2011). This means that the firm could be selling a total of 5200 shares; however, they split the transaction into several smaller ones to further high frequency trader's strategies. This would allow for example , the trade would go undetected by other firms. Therefore, Saluzzi's point of view confirms that there has been a major shift in the types of trades made in the equity markets. The electronic markets have opened the investing world up to new players who are trading faster, and in smaller blocks in order to stay competitive. This further demonstrates the changing face of the financial marketplace, because where there was once few and larger blocks of shares being traded, there

are now more, smaller trades being placed which has implications on liquidity and infrastructure in terms of firms remaining competitive in the market.

Hypothesis 5

According to **Appendix E**the volume of trades on the DJIA peaked in the 2:30 period and remained high through the 2:45 period, retreated and then rose during the end of day trading. This shows that trading volume was much higher than it usually is on the control days. The statistical analysis confirms this, because after 1:30, the alphas demonstrate the statistically significant relationships between May 6th and the control dates. This rise in trading volume can be attributed to high frequency trading because with the introduction of computer and algorithms, trades can take place so rapidly and are programmed to execute on many different bases. Therefore, many of the abnormal trading conditions that the flash crash brought could have triggered more trades than would have occurred on a normal day. According to industry estimates, HFT accounts for about two thirds of US stock market volume (Patterson, 2010 June), and this was evidenced on the day of the flash crash. However, the flow of volume is the crucial component to examine in this case. In an article in *Securities Technology Monitor*, Tom Steinert-Threlkeld brings together portions of SEC chairman Schapiro's statements on the one-year anniversary of the flash crash, pointing to structural problems in the market that are attributed to high frequency trading. "Fundamental investors, in fact, she said, would have been strong buyers in the decline, when prices plunged 600 points in five minutes. But high-frequency traders did not act like fundamental investors—or market makers…The specialists, who accounted for 17% for the volume, were net buyers in the decline. The crash took out 6.3% of the value of stocks, at its max" (Steinert-Threlkeld, 2011). Therefore, this evidences the concept that volume and liquidity, which are supposed to be made by high frequency traders, can often greatly fluctuate, especially when HFT traders turn their computers off and get out of the market when there is all of a sudden a downturn.

CONCLUSION

By conducting this event study of the flash crash, it further demonstrates the impact that this market event had on the overall marketThe introduction of technology in the stock markets has led to an increase in both adjusted close and volume to the Dow Jones Industrial Average over the past fifteen years. The influx in volume and prices have created a more high stakes environment in which both traders and regulators are trying to keep up with the developments in the market landscape. With the introduction and increased popularity of high frequency trading, the financial markets are operating in uncharted waters. The lack of a common definition of high frequency trading contributes to the investor uncertainty that exists. Likewise, the fact that algorithms execute on command without the traditional logic that goes into trading has changed the face of the market place.

This however is not saying it has changed for the worse, as can be seen in the comparison to the crash of 1987, it can prove to minimize some of the implications of market crashes. High frequency trading has led to decreased transaction costs for some investors, yet has created a liquidity crisis for others with the introduction of trade practices such as dark pools and quote stuffing. Regulation is a part of this industry that needs to be further developed and moving forward, concise and decisive action will needed to be taken by the appropriate regulatory agencies. High frequency trading has evolved from a type of trade to a business strategy and thus must be regulated as such. At the end of the day, it is most important that the financial markets remain a fair and efficient place to do business.

The data analysis in the paper show that crashes such as the flash crash can have major effects on the market and are statistically significant event . Four out of five hypotheses were proven to be valid and all demonstrated drastic statistical significance, evidencing the gravity of the flash crash. These studies have certainly proved that with an increase in technology comes an increased risk, and with that must come a heightened understanding of the world in which we live. Since this study used the 30 stocks that make up the Dow Jones Industrial Average, one of the limitations to this study is that it does only incorporate 30 securities. With additional resources and time, it would be interesting to study other indices as well and compare the results, because companies such as Accenture had some of the larger price changes during the flash crash. Due to the fact that it is not included in the Dow 30, this was not incorporated in the data

and thus the results for the same study done on a different index may yield different results. Likewise, due to the complexity of the way trades were cancelled during the flash crash, some of the data was yielding outlier results and thus average return had to be calculated using the quotes from the beginning and end of the period. With more concrete data on prices for that day it could yield a different result for the average return numbers.

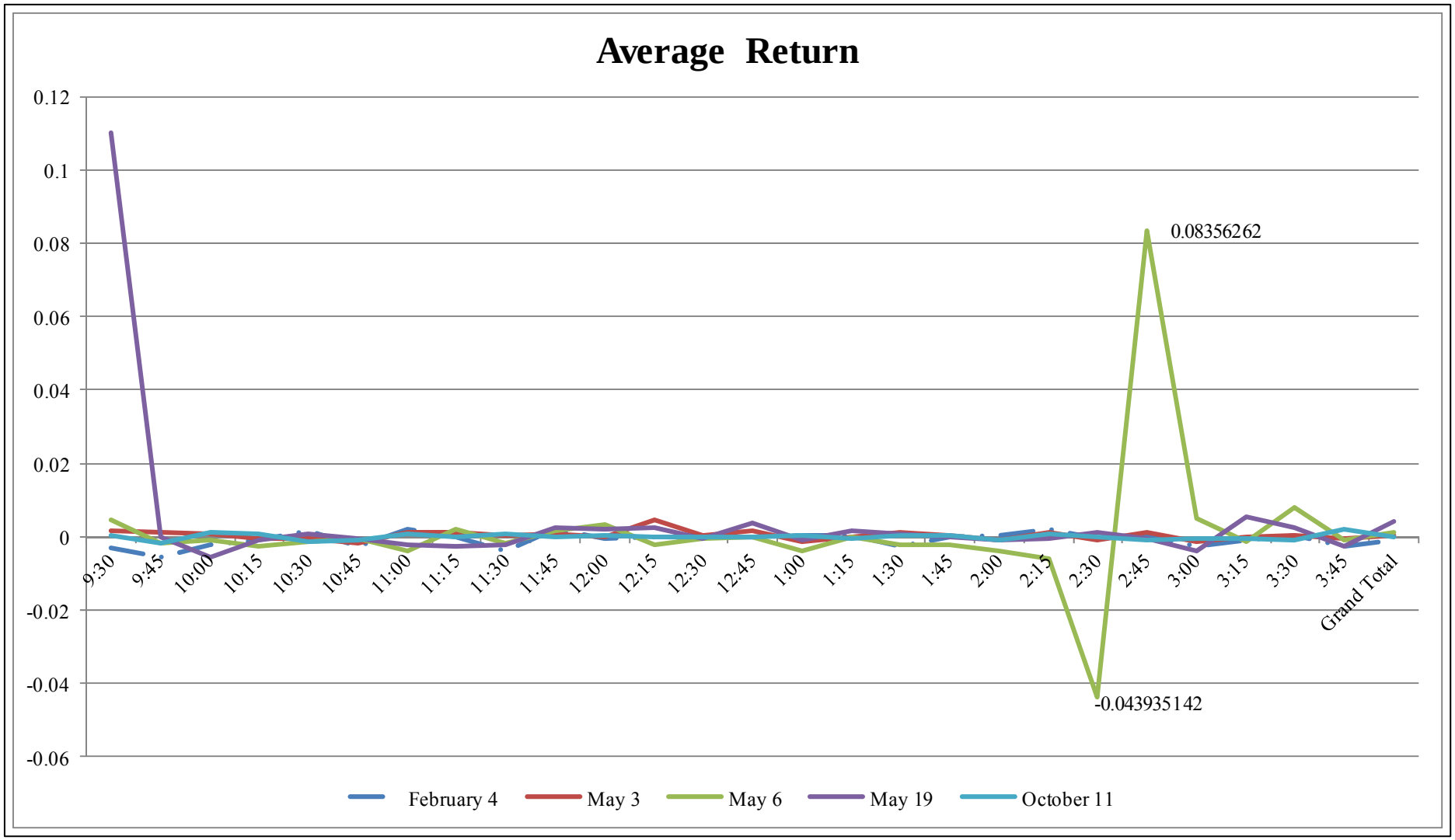
MOVING FORWARD

Within a month of this paper being written, high frequency trading was brought into the limelight again. After operating for years, BATS went public on March 23rd, only to be forced to withdraw its IPO after a technical glitch caused erroneous trades. Explaining their company in their initial public filing, they explain "…we are a technology company at our core. We developed, own and operate the BATS trading platform, which we designed to optimize reliability, speed, scalability and versatility" (Benoit, 2012). According to the Wall Street Journal, over the course of nine seconds, BATS went from $15.25, already below their expected IPO price, dropping to $0.0002cents before climbing back to 4 cents, where trading was halted (Benoit, 2012). This glitch apparently caused Apple to have a brief crash itself, with shares falling 9.4% and hitting a low of $542.80. However, Nasdaq cancelled the erroneous trades and APPL resumed trading as usual (Russolillo, 2012). This mishap, which in hindsight was a software error on the part of BATS, and which in hindsight was not actually related to high frequency trading per se, just further demonstrates the need for accountability, transparency and most importantly, clarification of terminology. Errors and confusion with technology is not a problem that will be going away any time soon, and for the safety, security and transparency of our markets, it is crucial that there more understanding of this high speed world that changes every second. The culmination of market events since May 6th, 2010 has truly shown how one single trade can truly change the world.

APPENDICES

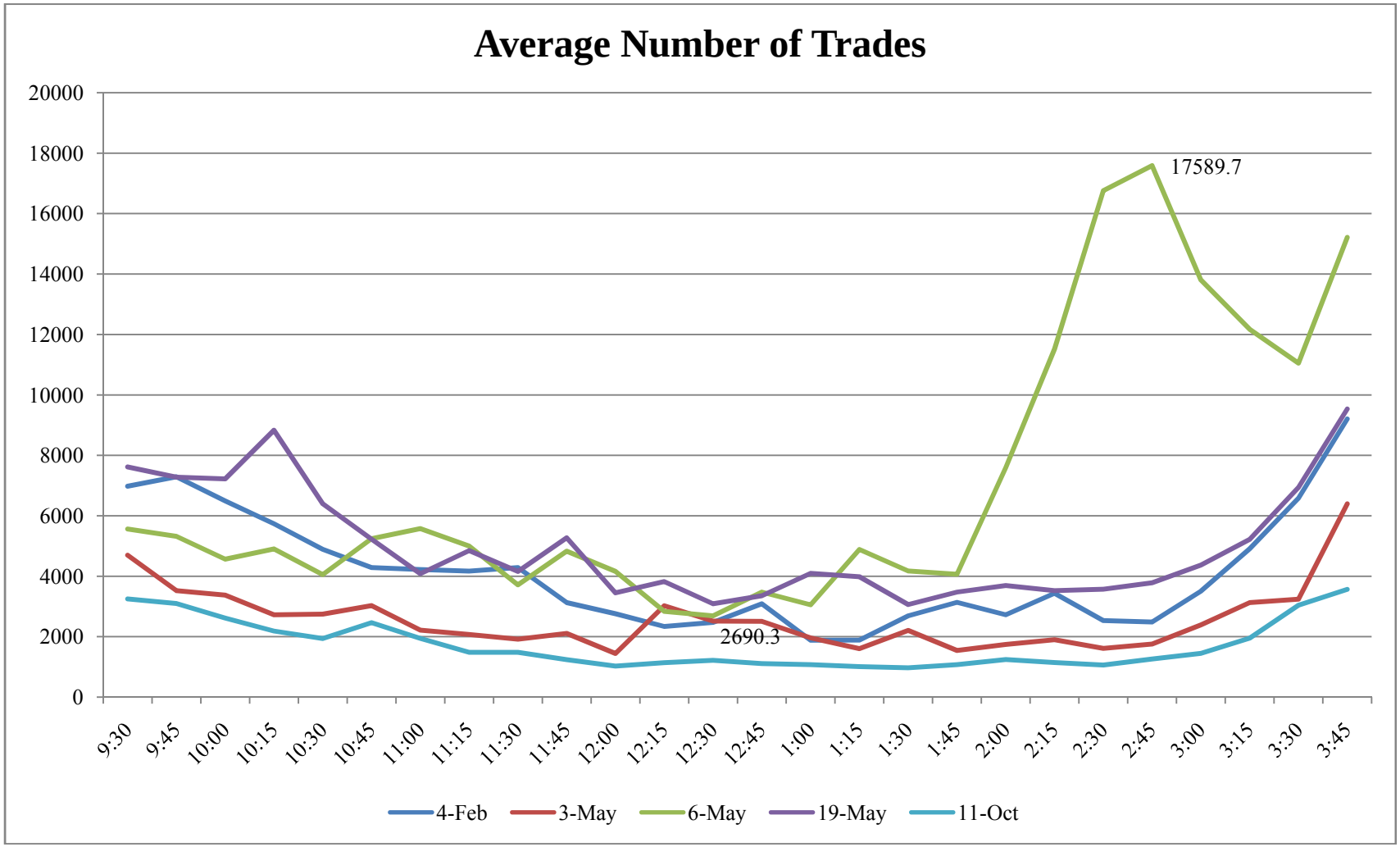
Appendix A –Average Return

	T Values				Alphas				Sign Rank Values				Alphas			
Time	4-Feb	3-May	19-May	11-Oct	4-Feb	3-May	19-May	11-Oct	4-Feb	3-May	19-May	11-Oct	4-Feb	3-May	19-May	11-Oct
9:30	4.4450	2.7021	-0.9907	3.9962	0.0001	0.0114	0.3300	0.0004	178.5000	116.5000	26.5000	159.5000	0.0000	0.0138	0.5943	0.0004
9:45	3.4442	-4.1926	-1.3268	-0.3741	0.0018	0.0002	0.1949	0.7111	146.5000	-181.5000	-58.5000	-14.5000	0.0013	0.0000	0.2351	0.7711
10:00	1.9656	-1.3405	6.2536	-2.5394	0.0590	0.1905	0.0000	0.0167	110.5000	-37.5000	210.5000	-95.5000	0.0203	0.4499	0.0000	0.0476
10:15	-1.7670	-2.5466	-1.8872	-5.1513	0.0878	0.0164	0.0692	0.0000	-47.5000	-107.5000	-89.5000	-187.5000	0.3370	0.0243	0.0645	0.0000
10:30	-4.2774	-2.4256	-4.5870	-0.3076	0.0002	0.0217	0.0001	0.7606	-171.5000	-101.5000	-189.5000	-15.5000	0.0001	0.0344	0.0000	0.7558
10:45	3.5458	1.9491	0.2857	0.9525	0.0014	0.0610	0.7771	0.3487	136.5000	90.5000	14.5000	63.5000	0.0032	0.0614	0.7711	0.1964
11:00	-8.5048	-7.6809	-4.0324	-7.2105	0.0000	0.0000	0.0004	0.0000	-230.5000	-228.5000	-150.5000	-224.5000	0.0000	0.0000	0.0009	0.0000
11:15	3.1484	1.6353	5.1913	4.5100	0.0038	0.1128	0.0000	0.0001	142.5000	69.5000	205.5000	192.5000	0.0019	0.1562	0.0000	0.0000
11:30	4.5392	-3.7616	0.9171	-4.5227	0.0001	0.0008	0.3667	0.0001	173.5000	-150.5000	66.5000	-186.5000	0.0001	0.0009	0.1755	0.0000
11:45	-0.6304	1.5666	-1.2826	4.4272	0.5334	0.1281	0.2098	0.0001	-42.5000	62.5000	-54.5000	164.5000	0.3911	0.2038	0.2694	0.0002
12:00	8.8658	10.4064	3.3820	8.0123	0.0000	0.0000	0.0021	0.0000	225.5000	231.5000	159.5000	224.5000	0.0000	0.0000	0.0004	0.0000
12:15	-4.7463	-16.9624	-8.5638	-4.9632	0.0001	0.0000	0.0000	0.0000	-191.5000	-232.5000	-232.5000	-194.5000	0.0000	0.0000	0.0000	0.0000
12:30	-1.0713	-3.0575	-0.4773	-2.3520	0.2929	0.0048	0.6367	0.0257	-48.5000	-127.5000	-35.5000	-107.5000	0.3268	0.0064	0.4746	0.0243
12:45	0.0197	-4.0262	-7.3714	0.3340	0.9845	0.0004	0.0000	0.7408	7.5000	-155.5000	-224.5000	13.5000	0.8805	0.0006	0.0000	0.7865
1:00	-8.2327	-6.1568	-5.0313	-10.0789	0.0000	0.0000	0.0000	0.0000	-229.5000	-204.5000	-183.5000	-232.5000	0.0000	0.0000	0.0000	0.0000
1:15	-1.2023	-0.3469	-3.7251	0.8389	0.2390	0.7312	0.0008	0.4084	-44.5000	-11.5000	-151.5000	45.5000	0.3689	0.8176	0.0008	0.3581
1:30	0.9545	-7.2865	-5.6517	-5.8692	0.3477	0.0000	0.0000	0.0000	56.5000	-215.5000	-209.5000	-201.5000	0.2518	0.0000	0.0000	0.0000
1:45	-4.4771	-4.4521	-3.7392	-4.8586	0.0001	0.0001	0.0008	0.0000	-174.5000	-182.5000	-146.5000	-184.5000	0.0001	0.0000	0.0013	0.0000
2:00	-6.6406	-5.5019	-4.9003	-6.3438	0.0000	0.0000	0.0000	0.0000	-232.5000	-194.5000	-187.5000	-213.5000	0.0000	0.0000	0.0000	0.0000
2:15	-10.7278	-9.4517	-6.0521	-8.9602	0.0000	0.0000	0.0000	0.0000	-232.5000	-230.5000	-208.5000	-229.5000	0.0000	0.0000	0.0000	0.0000
2:30	-16.6988	-16.6120	-17.6846	-17.0254	0.0000	0.0000	0.0000	0.0000	-232.5000	-232.5000	-232.5000	-232.5000	0.0000	0.0000	0.0000	0.0000
2:45	8.8740	8.4623	9.1310	8.9484	0.0000	0.0000	0.0000	0.0000	230.5000	229.5000	230.5000	229.5000	0.0000	0.0000	0.0000	0.0000
3:00	5.0952	4.5812	6.4645	3.6294	0.0000	0.0001	0.0000	0.0011	197.5000	185.5000	216.5000	158.5000	0.0000	0.0000	0.0000	0.0004
3:15	-0.8454	-1.2367	-6.5663	-0.8719	0.4048	0.2261	0.0000	0.3904	-46.5000	-51.5000	-212.5000	-44.5000	0.3475	0.2972	0.0000	0.3689
3:30	8.1384	8.2941	6.0829	9.4354	0.0000	0.0000	0.0000	0.0000	223.5000	224.5000	200.5000	228.5000	0.0000	0.0000	0.0000	0.0000
3:45	2.3047	-0.9365	2.2234	-4.1479	0.0285	0.3567	0.0341	0.0003	95.5000	-66.5000	94.5000	-162.5000	0.0476	0.1755	0.0501	0.0003


Average Return
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
0.08356262
-0.043935142
9:30
9:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
3:00
3:15
3:30
3:45
Grand Total
February 4
May 3
May 6
May 19
October 11

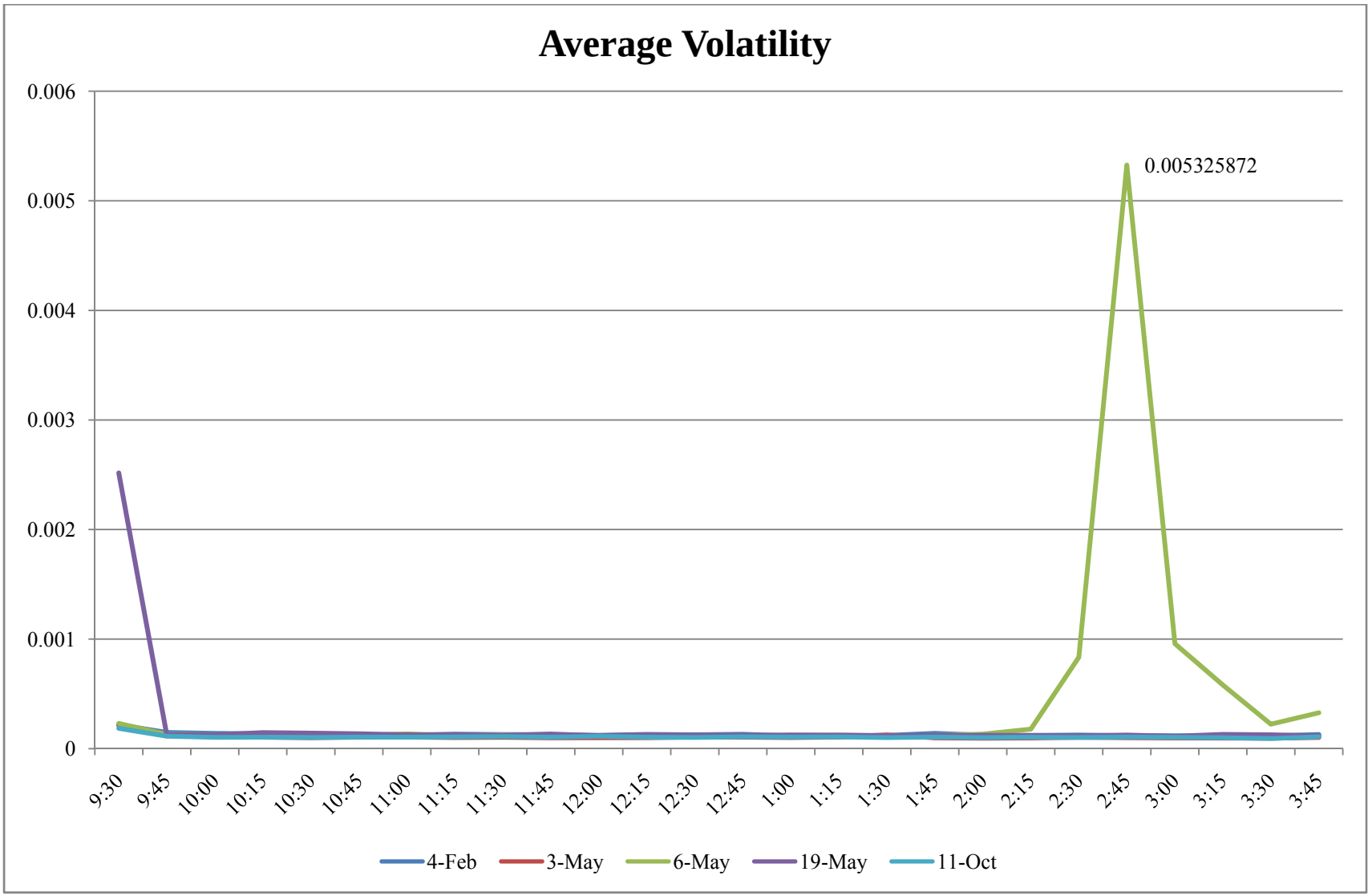
Appendix B- Average Number of Trades

	T-Values				Alphas				Sign Rank				Alphas			
Time	4-Feb	3-May	19-May	14-Oct	4-Feb	3-May	19-May	14-Oct	4-Feb	3-May	19-May	14-Oct	4-Feb	3-May	19-May	14-Oct
9:30	-1.3182	2.0892	-2.5267	5.3906	0.1978	0.0456	0.0172	0.0000	-105.5000	81.5000	-136.5000	231.5000	0.0274	0.0940	0.0032	0.0000
9:45	-2.3602	4.9083	-3.3589	6.1457	0.0252	0.0000	0.0022	0.0000	-104.5000	187.5000	-142.5000	217.5000	0.0290	0.0000	0.0019	0.0000
10:00	-2.4414	3.9652	-5.4593	4.4564	0.0210	0.0004	0.0000	0.0001	-145.5000	205.0000	-224.5000	223.5000	0.0015	0.0000	0.0000	0.0000
10:15	-1.8823	4.6932	-5.7813	5.2168	0.0699	0.0001	0.0000	0.0000	-85.5000	213.5000	-232.5000	228.5000	0.0782	0.0000	0.0000	0.0000
10:30	-1.5983	2.8529	-6.7514	5.4109	0.1208	0.0079	0.0000	0.0000	-113.5000	184.5000	-219.5000	231.5000	0.0168	0.0000	0.0000	0.0000
10:45	2.8354	5.3372	0.0606	5.6546	0.0083	0.0000	0.9521	0.0000	124.5000	215.5000	-24.5000	231.5000	0.0080	0.0000	0.6225	0.0000
11:00	3.3227	6.0412	3.9015	5.7746	0.0024	0.0000	0.0005	0.0000	172.5000	232.5000	193.5000	232.5000	0.0001	0.0000	0.0000	0.0000
11:15	2.4951	5.2743	0.3270	5.5331	0.0185	0.0000	0.7460	0.0000	116.5000	232.5000	85.5000	232.5000	0.0138	0.0000	0.0782	0.0000
11:30	-1.6755	5.1272	-0.8914	5.6314	0.1046	0.0000	0.3801	0.0000	-85.5000	231.5000	-16.5000	232.5000	0.0782	0.0000	0.7405	0.0000
11:45	5.2929	6.6295	-1.0919	6.5326	0.0000	0.0000	0.2839	0.0000	197.5000	232.5000	-71.5000	232.5000	0.0000	0.0000	0.1442	0.0000
12:00	3.2335	4.9288	2.7201	5.3544	0.0030	0.0000	0.0109	0.0000	208.5000	232.5000	144.5000	232.5000	0.0000	0.0000	0.0016	0.0000
12:15	1.8878	-0.7876	-3.8559	5.8362	0.0691	0.4373	0.0006	0.0000	106.5000	-42.5000	-193.5000	232.5000	0.0258	0.3911	0.0000	0.0000
12:30	0.7330	0.9761	-1.8209	6.7180	0.4695	0.3371	0.0790	0.0000	77.5000	94.5000	-80.5000	232.5000	0.1122	0.0501	0.0984	0.0000
12:45	1.0858	2.9288	0.3836	5.0655	0.2865	0.0066	0.7040	0.0000	24.5000	174.5000	48.5000	232.5000	0.6225	0.0001	0.3268	0.0000
1:00	3.6859	4.2627	-5.0346	5.2506	0.0009	0.0002	0.0000	0.0000	193.5000	206.5000	-194.5000	232.5000	0.0000	0.0000	0.0000	0.0000
1:15	4.3095	4.5799	2.0810	5.2077	0.0002	0.0001	0.0464	0.0000	232.5000	232.5000	100.5000	232.5000	0.0000	0.0000	0.0363	0.0000
1:30	3.7966	4.5378	3.1727	5.7759	0.0007	0.0001	0.0036	0.0000	215.5000	230.5000	157.5000	232.5000	0.0000	0.0000	0.0005	0.0000
1:45	2.2965	5.2194	2.2438	6.1399	0.0291	0.0000	0.0326	0.0000	135.5000	231.5000	94.5000	231.5000	0.0035	0.0000	0.0501	0.0000
2:00	4.9423	5.1638	4.7228	5.2580	0.0000	0.0000	0.0001	0.0000	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
2:15	7.3159	7.2467	7.3060	7.2883	0.0000	0.0000	0.0000	0.0000	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
2:30	6.9839	7.0726	7.0808	7.1171	0.0000	0.0000	0.0000	0.0000	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
2:45	6.0404	6.0985	5.8167	6.0946	0.0000	0.0000	0.0000	0.0000	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
3:00	6.2331	6.1951	6.0507	6.3271	0.0000	0.0000	0.0000	0.0000	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
3:15	5.6858	6.2636	5.5343	6.3825	0.0000	0.0000	0.0000	0.0000	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
3:30	4.7775	6.7201	4.4523	6.1861	0.0000	0.0000	0.0001	0.0000	213.5000	232.5000	230.5000	232.5000	0.0000	0.0000	0.0000	0.0000
3:45	5.8436	6.9769	6.2154	7.2573	0.0000	0.0000	0.0000	0.0000	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000


Average Number of Trades
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
17589.7
2690.3
9:30
9:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
3:00
3:15
3:30
3:45
4-Feb
3-May
6-May
19-May
11-Oct

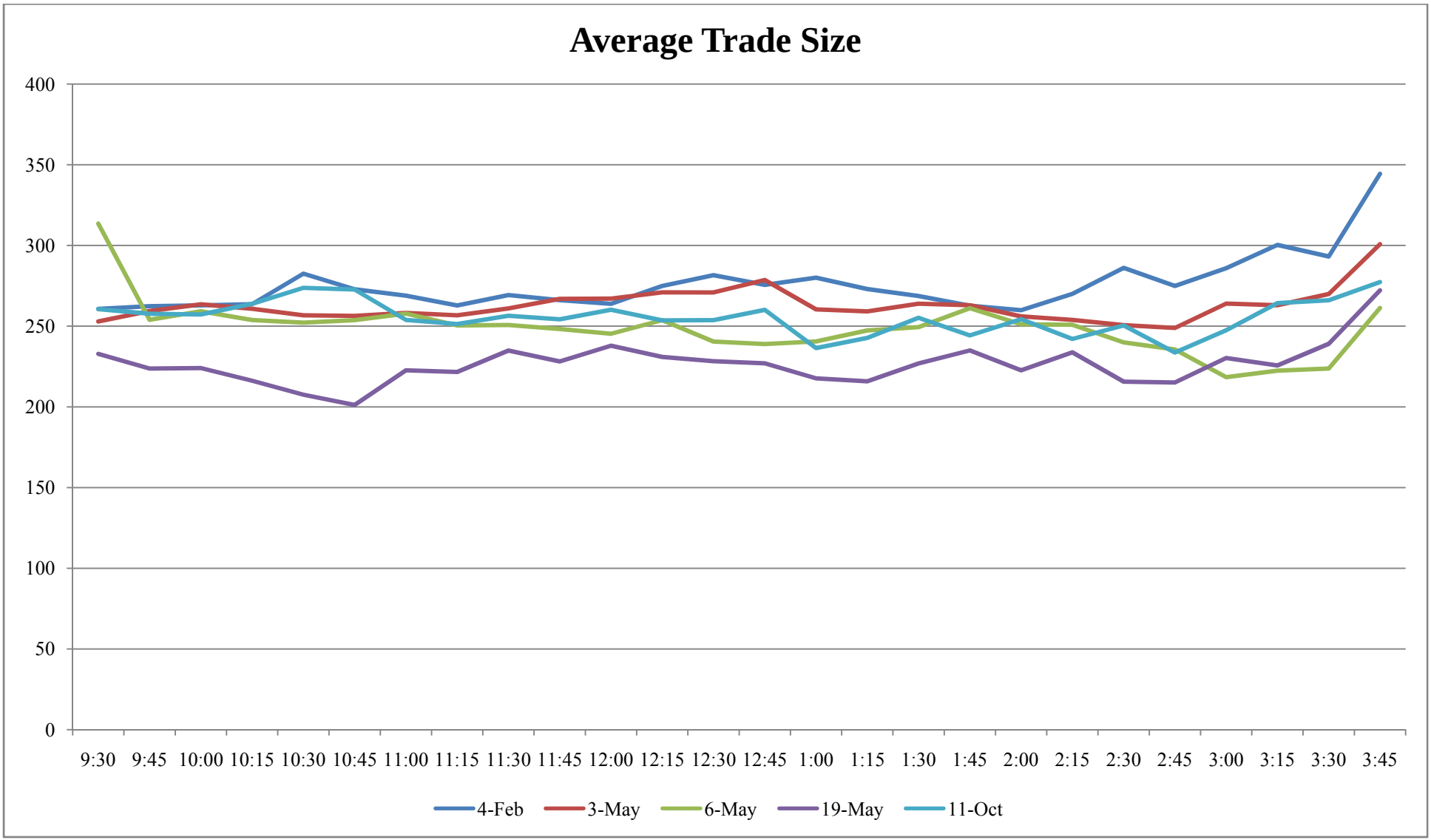
Appendix C- Average Volatility

Time	4-Feb	3-May	19-May	11-Oct	4-Feb	3-May	19-May	11-Oct	4-Feb	3-May	19-May	11-Oct	4-Feb	3-May	19-May	11-Oct
9:30	0.6393	1.1791	-0.9897	2.1921	0.5276	0.2479	0.3305	0.0365	43.5000	49.5000	61.5000	167.5000	0.3799	0.3167	0.2113	0.0002
9:45	-2.7383	3.1348	1.1587	4.2166	0.0104	0.0039	0.2560	0.0002	-123.5000	172.5000	45.5000	170.5000	0.0086	0.0001	0.3581	0.0001
10:00	-1.5766	3.9458	0.2235	4.7542	0.1257	0.0005	0.8247	0.0001	-47.5000	160.5000	7.5000	188.5000	0.3370	0.0003	0.8805	0.0000
10:15	-2.9356	4.1493	-5.2388	3.4683	0.0065	0.0003	0.0000	0.0017	-133.5000	174.5000	-189.5000	148.5000	0.0041	0.0001	0.0000	0.0011
10:30	-2.4090	5.8952	-3.3809	4.3798	0.0226	0.0000	0.0021	0.0001	-102.5000	215.5000	-138.5000	174.5000	0.0325	0.0000	0.0027	0.0001
10:45	-1.1246	3.0582	-3.5052	3.8235	0.2700	0.0048	0.0015	0.0006	-41.5000	176.5000	-139.5000	154.5000	0.4025	0.0000	0.0025	0.0006
11:00	1.1002	2.9504	1.0504	2.6767	0.2803	0.0062	0.3022	0.0121	10.5000	156.5000	3.5000	131.5000	0.8332	0.0005	0.9441	0.0048
11:15	-2.0752	3.8370	-1.4136	2.1814	0.0469	0.0006	0.1681	0.0374	-77.5000	157.5000	-69.5000	100.5000	0.1122	0.0005	0.1562	0.0363
11:30	-0.5551	1.9977	0.3951	1.3733	0.5831	0.0552	0.6957	0.1802	-110.5000	130.5000	-52.5000	45.5000	0.0203	0.0051	0.2878	0.3581
11:45	-1.8451	4.4141	-3.7166	2.6212	0.0753	0.0001	0.0009	0.0138	-87.5000	184.5000	-164.5000	118.5000	0.0711	0.0000	0.0002	0.0121
12:00	-0.4008	3.9786	0.3496	1.2153	0.6915	0.0004	0.7292	0.2340	-21.5000	170.5000	8.5000	49.5000	0.6659	0.0001	0.8646	0.3167
12:15	-1.3744	3.7086	-2.2912	1.6065	0.1798	0.0009	0.0294	0.1190	-85.5000	166.5000	-141.5000	89.5000	0.0782	0.0002	0.0021	0.0645
12:30	-2.2068	2.0534	-2.4673	2.2228	0.0354	0.0491	0.0198	0.0342	-104.5000	114.5000	-112.5000	132.5000	0.0290	0.0158	0.0179	0.0044
12:45	-3.8311	2.6975	-1.7020	0.8575	0.0006	0.0115	0.0994	0.3982	-161.5000	113.5000	-80.5000	88.5000	0.0003	0.0168	0.0984	0.0678
1:00	0.6199	3.6894	-0.8890	1.5445	0.5401	0.0009	0.3813	0.1333	-10.5000	167.5000	-88.5000	74.5000	0.8332	0.0002	0.0678	0.1274
1:15	0.3247	2.2986	-0.1358	1.3832	0.7477	0.0289	0.8929	0.1771	-16.5000	146.5000	-43.5000	103.5000	0.7405	0.0013	0.3799	0.0307
1:30	-0.8592	-1.2156	-0.1945	2.2597	0.3973	0.2340	0.8471	0.0315	-79.5000	-69.5000	-29.5000	116.5000	0.1028	0.1562	0.5530	0.0138
1:45	-1.9130	4.7819	-0.2940	2.0981	0.0657	0.0000	0.7709	0.0447	-121.5000	196.5000	-14.5000	98.5000	0.0099	0.0000	0.7711	0.0405
2:00	2.2596	7.5891	2.4641	5.1239	0.0315	0.0000	0.0199	0.0000	89.5000	227.5000	105.5000	184.5000	0.0645	0.0000	0.0274	0.0000
2:15	11.7853	12.0917	11.8402	7.6256	0.0000	0.0000	0.0000	0.0000	232.5000	232.5000	229.5000	220.5000	0.0000	0.0000	0.0000	0.0000
2:30	10.6150	11.2526	11.1840	11.0577	0.0000	0.0000	0.0000	0.0000	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
2:45	5.5280	5.5456	5.5186	5.5326	0.0000	0.0000	0.0000	0.0000	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
3:00	3.9655	4.0459	3.9822	3.9967	0.0004	0.0004	0.0004	0.0004	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
3:15	1.7319	1.8009	1.6722	1.7822	0.0939	0.0821	0.1052	0.0852	232.5000	232.5000	232.5000	229.5000	0.0000	0.0000	0.0000	0.0000
3:30	10.4752	13.9076	11.2624	11.5375	0.0000	0.0000	0.0000	0.0000	231.5000	232.5000	231.5000	232.5000	0.0000	0.0000	0.0000	0.0000
3:45	15.8474	14.2938	13.8438	13.0856	0.0000	0.0000	0.0000	0.0000	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000


Average Volatility
0.006
0.005
0.004
0.003
0.002
0.001
0
0.005325872
9:30
9:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
3:00
3:15
3:30
3:45
4-Feb
3-May
6-May
19-May
11-Oct

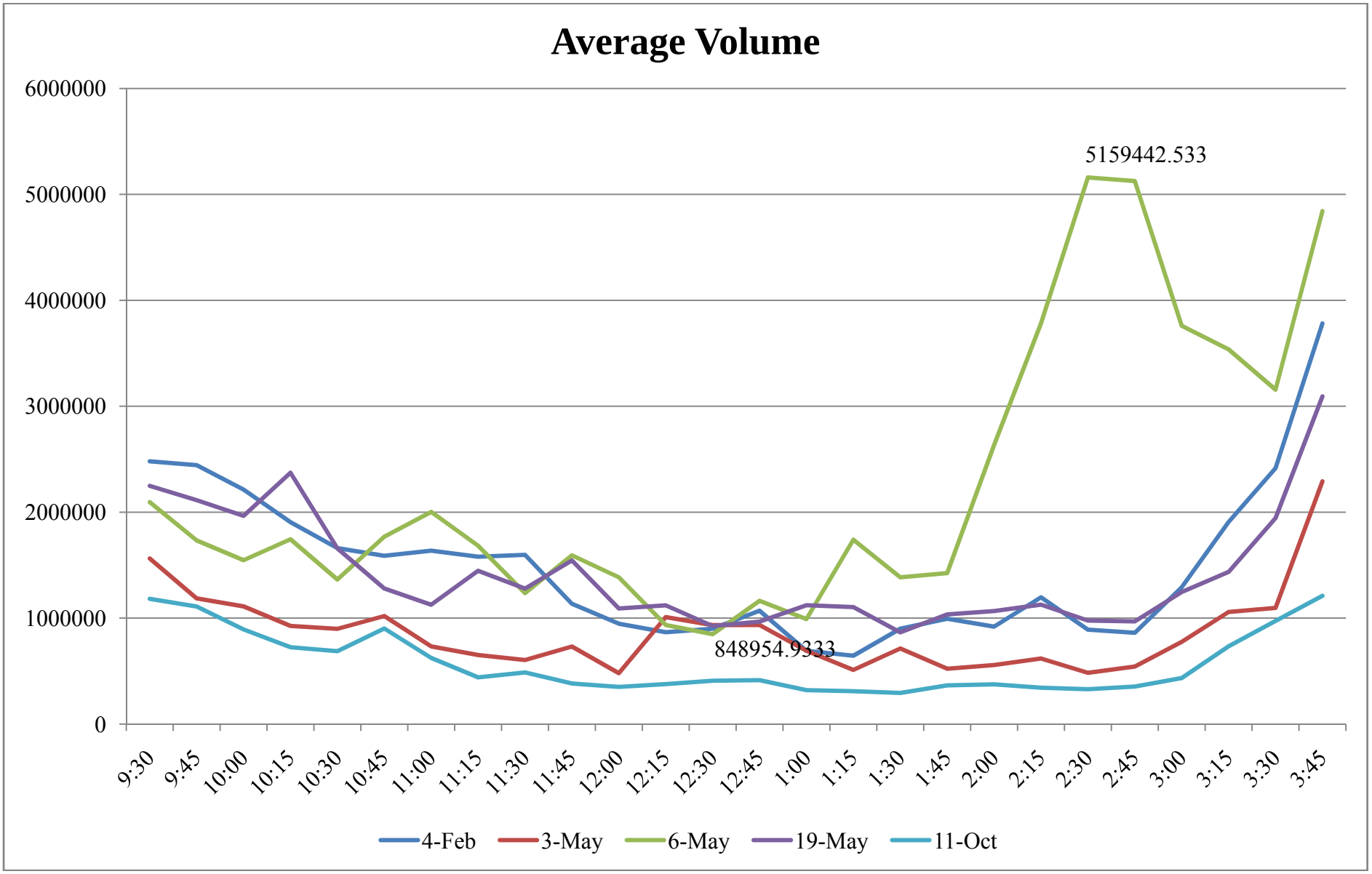
Appendix D- Average Trade Size

	T-Values				Alphas				Sign Rank				Alphas			
Time	4-Feb	3-May	19-May	14-Oct	4-Feb	3-May	19-May	14-Oct	4-Feb	3-May	19-May	14-Oct	4-Feb	3-May	19-May	14-Oct
9:30	0.8257	0.9625	1.2594	0.8070	0.4157	0.3438	0.2179	0.4263	0.5000	29.5000	123.5000	-2.5000	0.9920	0.5530	0.0086	0.9600
9:45	-0.6805	-0.5359	2.5740	-0.2550	0.5016	0.5961	0.0154	0.8005	-53.5000	-42.5000	140.5000	-17.5000	0.2785	0.3911	0.0023	0.7254
10:00	-0.2458	-0.3791	4.4281	0.1711	0.8075	0.7074	0.0001	0.8654	74.5000	1.5000	187.5000	27.5000	0.1274	0.9760	0.0000	0.5804
10:15	-0.7423	-0.6691	3.0922	-0.9294	0.4639	0.5087	0.0044	0.3604	-36.5000	-51.5000	155.5000	-47.5000	0.4622	0.2972	0.0006	0.3370
10:30	-2.6988	-0.4323	3.5117	-1.7096	0.0115	0.6687	0.0015	0.0980	-151.5000	-48.5000	174.5000	-79.5000	0.0008	0.3268	0.0001	0.1028
10:45	-1.6663	-0.2667	4.2828	-1.4553	0.1064	0.7916	0.0002	0.1563	-89.5000	-41.5000	171.5000	-53.5000	0.0645	0.4025	0.0001	0.2785
11:00	-1.0315	-0.0329	3.1490	0.4146	0.3108	0.9740	0.0038	0.6815	-83.5000	9.5000	162.5000	33.5000	0.0858	0.8489	0.0003	0.5001
11:15	-1.3945	-0.6015	3.1572	-0.0884	0.1738	0.5522	0.0037	0.9302	-69.5000	-29.5000	131.5000	-20.5000	0.1562	0.5530	0.0048	0.6806
11:30	-1.8290	-1.0015	1.6693	-0.4508	0.0777	0.3249	0.1058	0.6555	-93.5000	-35.5000	101.5000	23.5000	0.0528	0.4746	0.0344	0.6369
11:45	-1.7385	-1.6695	2.6146	-0.5174	0.0927	0.1058	0.0140	0.6088	-66.5000	-58.5000	109.5000	10.5000	0.1755	0.2351	0.0216	0.8332
12:00	-1.8541	-1.5410	0.9634	-0.7575	0.0739	0.1342	0.3433	0.4549	-60.5000	-23.5000	60.5000	9.5000	0.2190	0.6369	0.2190	0.8489
12:15	-1.5956	-1.4971	2.6056	0.0087	0.1214	0.1452	0.0143	0.9931	-57.5000	-83.5000	99.5000	32.5000	0.2434	0.0858	0.0384	0.5131
12:30	-3.5732	-2.6855	1.3958	-1.5786	0.0013	0.0119	0.1734	0.1253	-175.5000	-144.5000	78.5000	-64.5000	0.0001	0.0016	0.1074	0.1892
12:45	-4.5365	-3.3768	1.8747	-1.3029	0.0001	0.0021	0.0709	0.2029	-196.5000	-163.5000	88.5000	-20.5000	0.0000	0.0002	0.0678	0.6806
1:00	-3.0299	-1.6754	3.0014	0.4892	0.0051	0.1046	0.0055	0.6284	-138.5000	-70.5000	126.5000	14.5000	0.0027	0.1501	0.0069	0.7711
1:15	-2.7094	-1.3617	3.2140	0.4355	0.0112	0.1838	0.0032	0.6664	-105.5000	-67.5000	139.5000	-32.5000	0.0274	0.1688	0.0025	0.5131
1:30	-1.5963	-1.8740	1.8813	-0.5331	0.1213	0.0710	0.0700	0.5980	-78.5000	-107.5000	86.5000	-41.5000	0.1074	0.0243	0.0746	0.4025
1:45	-0.0997	-0.1584	2.0729	1.4257	0.9213	0.8752	0.0472	0.1646	-6.5000	-15.5000	92.5000	85.5000	0.8963	0.7558	0.0555	0.0782
2:00	-0.9755	-0.5030	3.9186	-0.3462	0.3374	0.6188	0.0005	0.7317	-21.5000	23.5000	198.5000	6.5000	0.6659	0.6369	0.0000	0.8963
2:15	-1.7896	-0.3472	1.2583	0.7342	0.0840	0.7310	0.2183	0.4687	-108.5000	-2.5000	90.5000	9.5000	0.0229	0.9600	0.0614	0.8489
2:30	-5.4897	-1.3829	3.5979	-1.0100	0.0000	0.1773	0.0012	0.3209	-201.5000	-63.5000	184.5000	-20.5000	0.0000	0.1964	0.0000	0.6806
2:45	-3.2621	-0.8491	2.1831	0.1638	0.0028	0.4028	0.0373	0.8710	-142.5000	22.5000	124.5000	51.5000	0.0019	0.6513	0.0080	0.2972
3:00	-4.5349	-3.2196	-1.3688	-1.8350	0.0001	0.0032	0.1816	0.0768	-200.5000	-157.5000	-48.5000	-82.5000	0.0000	0.0005	0.3268	0.0899
3:15	-4.3703	-4.4862	-0.5708	-2.1022	0.0001	0.0001	0.5725	0.0443	-198.5000	-199.5000	-63.5000	-109.5000	0.0000	0.0000	0.1964	0.0216
3:30	-4.7704	-4.9447	-2.0212	-3.4718	0.0000	0.0000	0.0526	0.0016	-215.5000	-214.5000	-127.5000	-173.5000	0.0000	0.0000	0.0064	0.0001
3:45	-5.1950	-5.7195	-2.2677	-2.0381	0.0000	0.0000	0.0310	0.0508	-228.5000	-204.5000	-104.5000	-71.5000	0.0000	0.0000	0.0290	0.1442

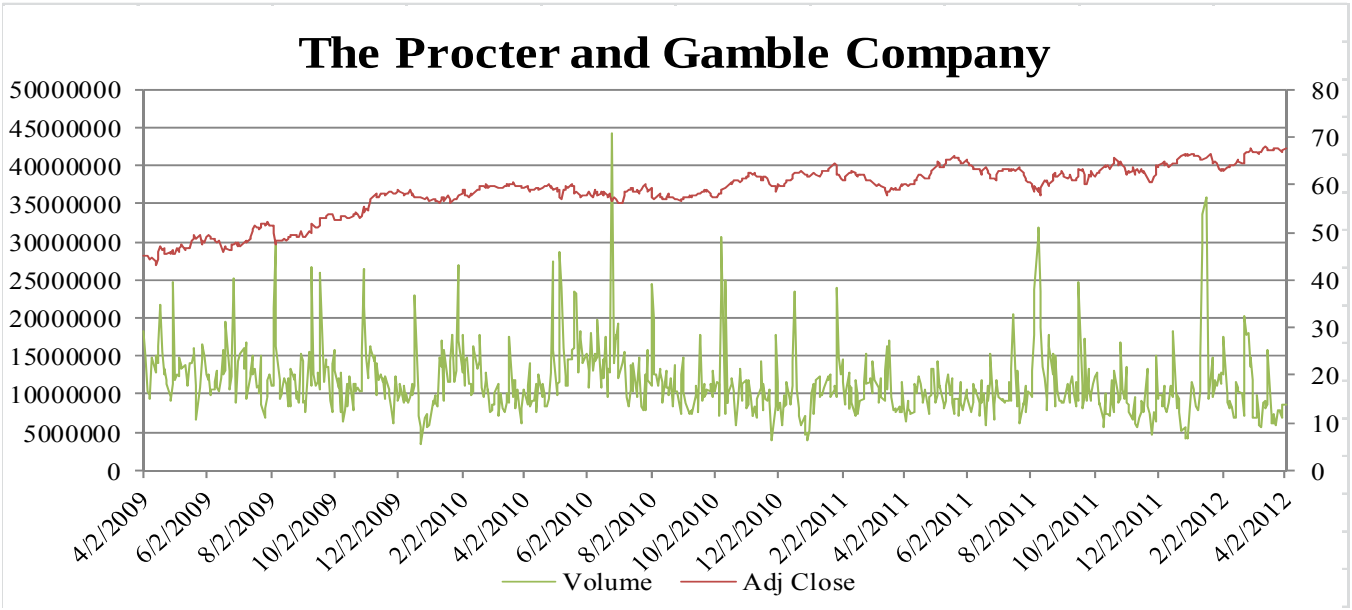

Average Trade Size
400
350
300
250
200
150
100
50
0
9:30
9:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
3:00
3:15
3:30
3:45
4-Feb
3-May
6-May
19-May
11-Oct

Appendix E- Average Volume

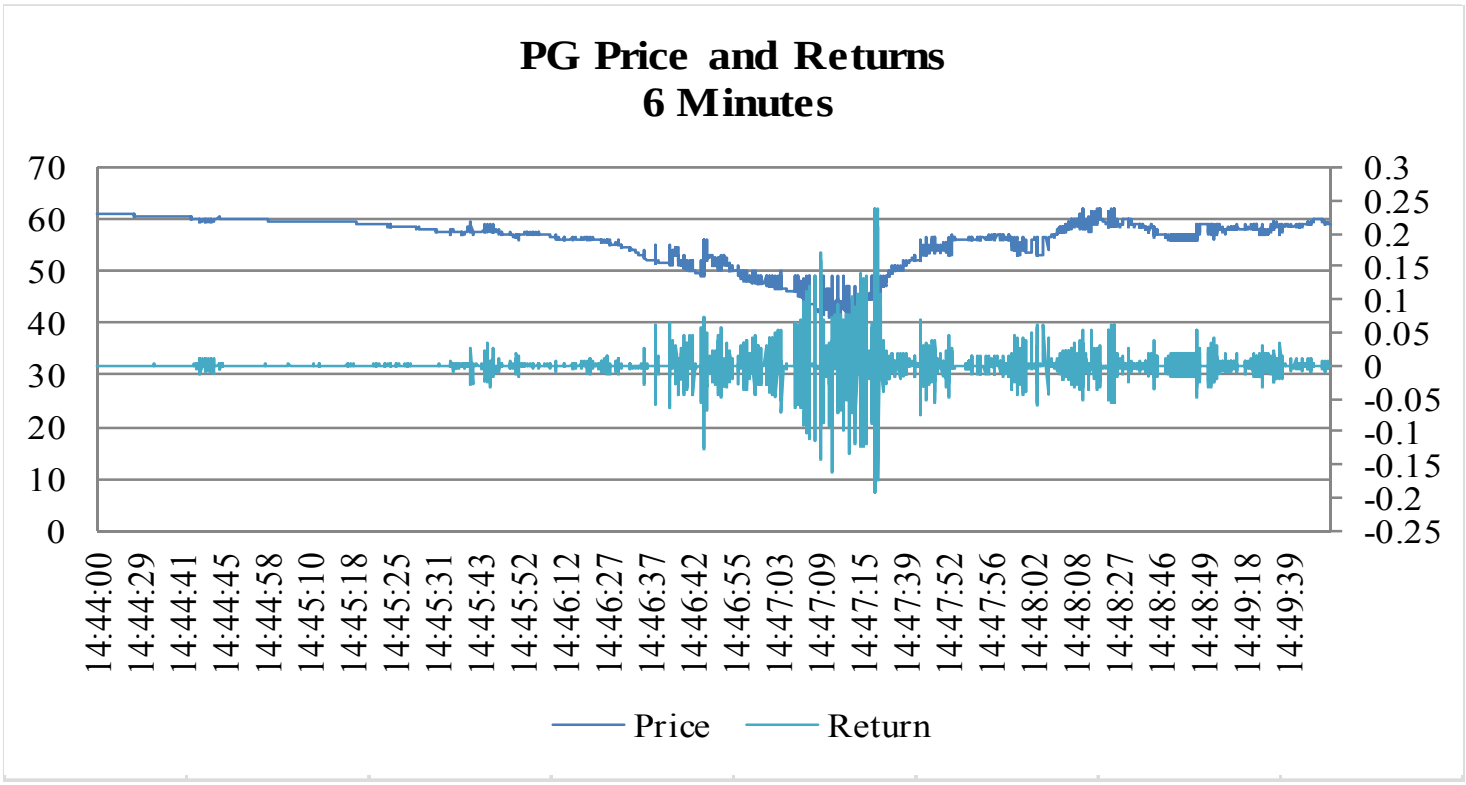
	T-Test Values				T-Test Alphas				Sign Rank Test Values				Sign Rank Test Alphas			
Period	4-Feb	3-May	19-May	11-Oct	4-Feb	3-May	19-May	11-Oct	4-Feb	3-May	19-May	11-Oct	4-Feb	3-May	19-May	11-Oct
9:30	-1.3175	1.7925	-1.5539	5.1094	0.1980	0.0835	0.1311	0.0000	-94.5000	91.5000	-92.5000	221.5000	0.0501	0.0584	0.0555	0.0000
9:45	-1.9573	3.3796	-2.0511	4.1981	0.0600	0.0021	0.0494	0.0002	-96.5000	182.5000	-91.5000	176.5000	0.0451	0.0000	0.0584	0.0000
10:00	-1.9349	2.4989	-2.9721	3.0053	0.0628	0.0184	0.0059	0.0054	-125.5000	158.5000	-172.5000	182.5000	0.0074	0.0004	0.0001	0.0000
10:15	-1.2381	3.2571	-3.3906	3.0128	0.2256	0.0029	0.0020	0.0053	-92.5000	209.5000	-196.5000	219.5000	0.0555	0.0000	0.0000	0.0000
10:30	-1.0063	2.2301	-3.3337	2.7852	0.3226	0.0336	0.0024	0.0093	-123.5000	170.5000	-170.5000	223.5000	0.0086	0.0001	0.0001	0.0000
10:45	2.4292	2.9991	1.6830	3.3313	0.0216	0.0055	0.1031	0.0024	124.5000	202.5000	149.5000	232.5000	0.0080	0.0000	0.0010	0.0000
11:00	1.9743	3.2626	2.7227	3.3110	0.0579	0.0028	0.0108	0.0025	153.5000	229.5000	208.5000	231.5000	0.0007	0.0000	0.0000	0.0000
11:15	1.1901	3.0275	0.5360	3.2237	0.2437	0.0051	0.5960	0.0031	128.5000	229.5000	101.5000	215.5000	0.0060	0.0000	0.0344	0.0000
11:30	-1.5646	3.2619	-0.0705	3.8491	0.1285	0.0028	0.9443	0.0006	-87.5000	231.5000	27.5000	232.5000	0.0711	0.0000	0.5804	0.0000
11:45	3.7465	3.5919	0.6684	3.6464	0.0008	0.0012	0.5092	0.0010	191.5000	218.5000	35.5000	232.5000	0.0000	0.0000	0.4746	0.0000
12:00	2.0958	3.2530	2.1756	3.4945	0.0449	0.0029	0.0379	0.0015	170.5000	232.5000	152.5000	232.5000	0.0001	0.0000	0.0008	0.0000
12:15	0.4583	-1.1736	-2.1925	3.5055	0.6501	0.2501	0.0365	0.0015	75.5000	-87.5000	-134.5000	230.5000	0.1222	0.0711	0.0038	0.0000
12:30	-0.2575	-0.4502	-0.5225	3.9960	0.7986	0.6559	0.6053	0.0004	19.5000	27.5000	19.5000	222.5000	0.6954	0.5804	0.6954	0.0000
12:45	0.6221	1.6513	1.3123	2.9971	0.5387	0.1095	0.1997	0.0055	-29.5000	113.5000	71.5000	217.5000	0.5530	0.0168	0.1442	0.0000
1:00	2.3814	2.1435	-2.6082	2.9874	0.0240	0.0406	0.0142	0.0057	173.5000	153.5000	-150.5000	217.5000	0.0001	0.0007	0.0009	0.0000
1:15	2.6270	2.9087	2.0045	3.1596	0.0136	0.0069	0.0544	0.0037	219.5000	229.5000	151.5000	232.5000	0.0000	0.0000	0.0008	0.0000
1:30	2.4526	2.7516	2.3700	3.3618	0.0204	0.0101	0.0247	0.0022	172.5000	183.5000	150.5000	232.5000	0.0001	0.0000	0.0009	0.0000
1:45	1.4978	2.8973	1.9426	3.6659	0.145	0.0071	0.0618	0.0010	98.5000	231.5000	132.5000	232.5000	0.0405	0.0000	0.0044	0.0000
2:00	2.8404	2.8952	2.6677	2.9613	0.0082	0.0071	0.0124	0.0061	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
2:15	4.2905	4.3305	4.1664	4.1698	0.0002	0.0002	0.0003	0.0003	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
2:30	3.9638	4.0929	4.0802	4.0926	0.0004	0.0003	0.0003	0.0003	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
2:45	4.2820	4.3460	4.1954	4.3311	0.0002	0.0002	0.0002	0.0002	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
3:00	4.5907	4.4776	4.4243	4.5425	0.0001	0.0001	0.0001	0.0001	232.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
3:15	3.8178	4.0092	3.7037	3.9685	0.0007	0.0004	0.0009	0.0004	220.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000
3:30	2.7376	4.0204	2.9054	3.7476	0.0105	0.0004	0.0070	0.0008	169.5000	232.5000	218.5000	232.5000	0.0001	0.0000	0.0000	0.0000
3:45	2.7536	4.0728	4.1022	4.3433	0.0101	0.0003	0.0003	0.0002	186.5000	232.5000	232.5000	232.5000	0.0000	0.0000	0.0000	0.0000

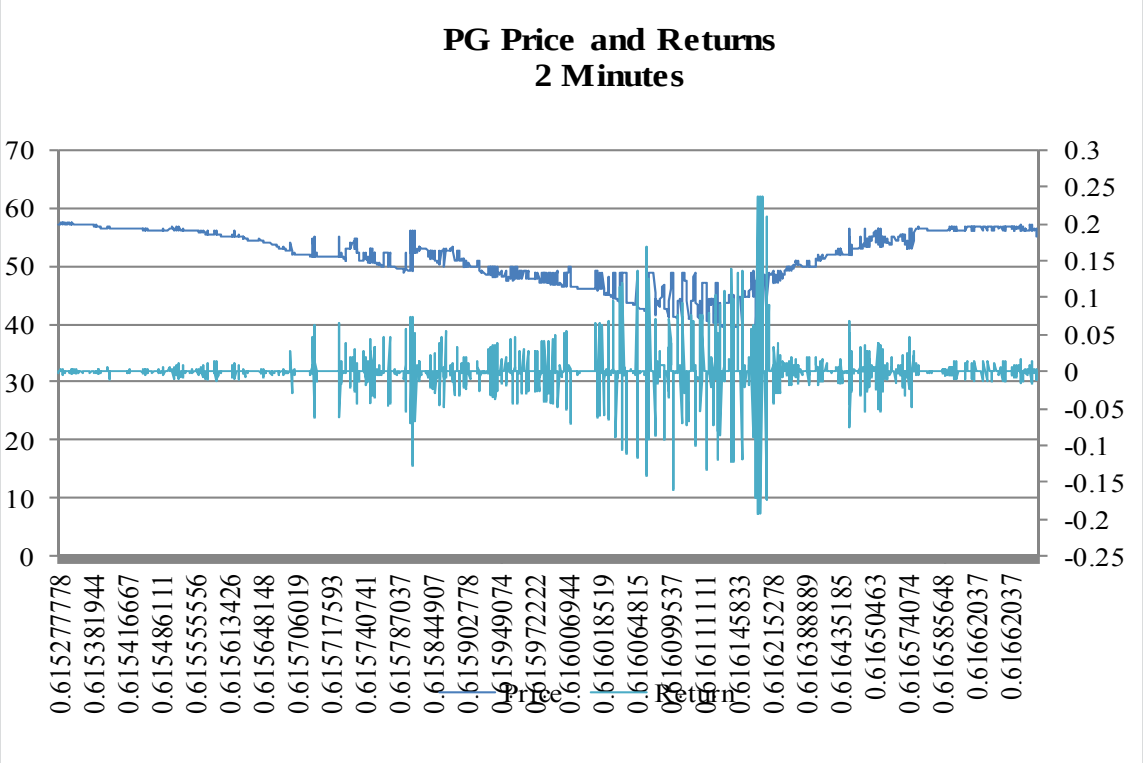

Average Volume
6000000
5000000
4000000
3000000
2000000
1000000
0
5159442.533
848954.9333
9:30
9:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
3:00
3:15
3:30
3:45
4-Feb
3-May
6-May
19-May
11-Oct

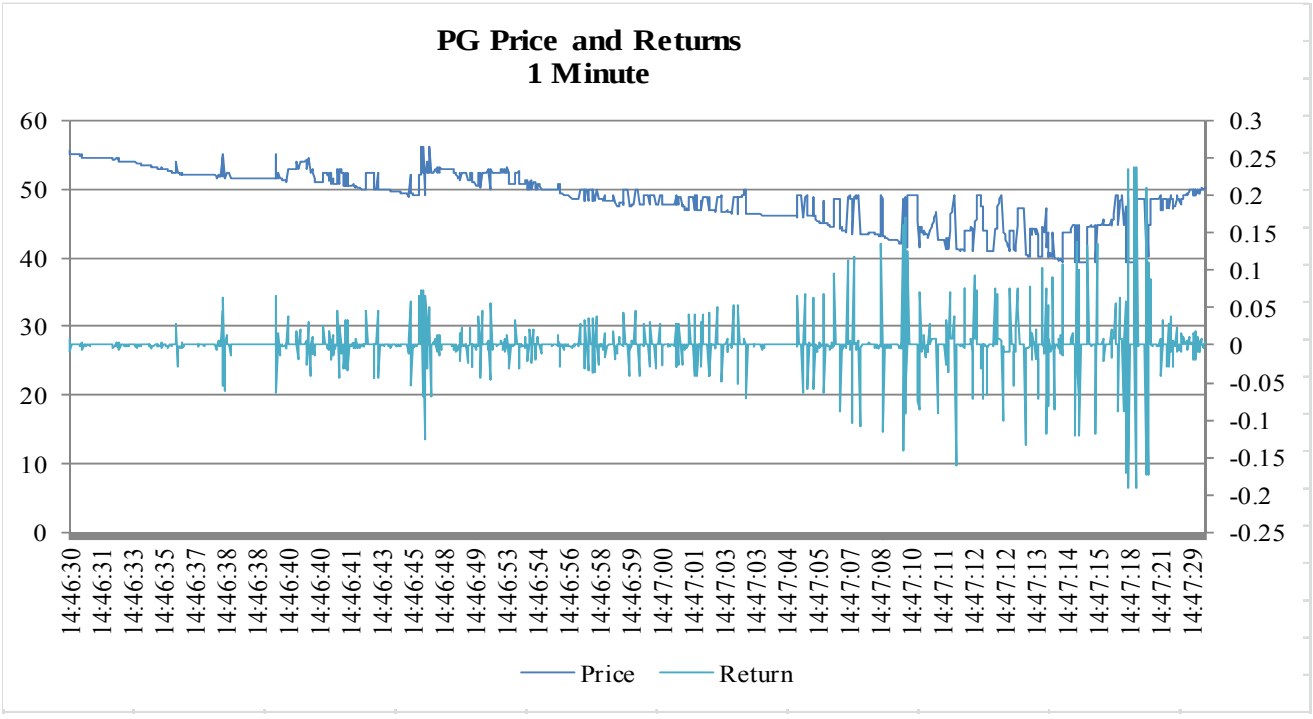
Appendix F: Procter and Gamble

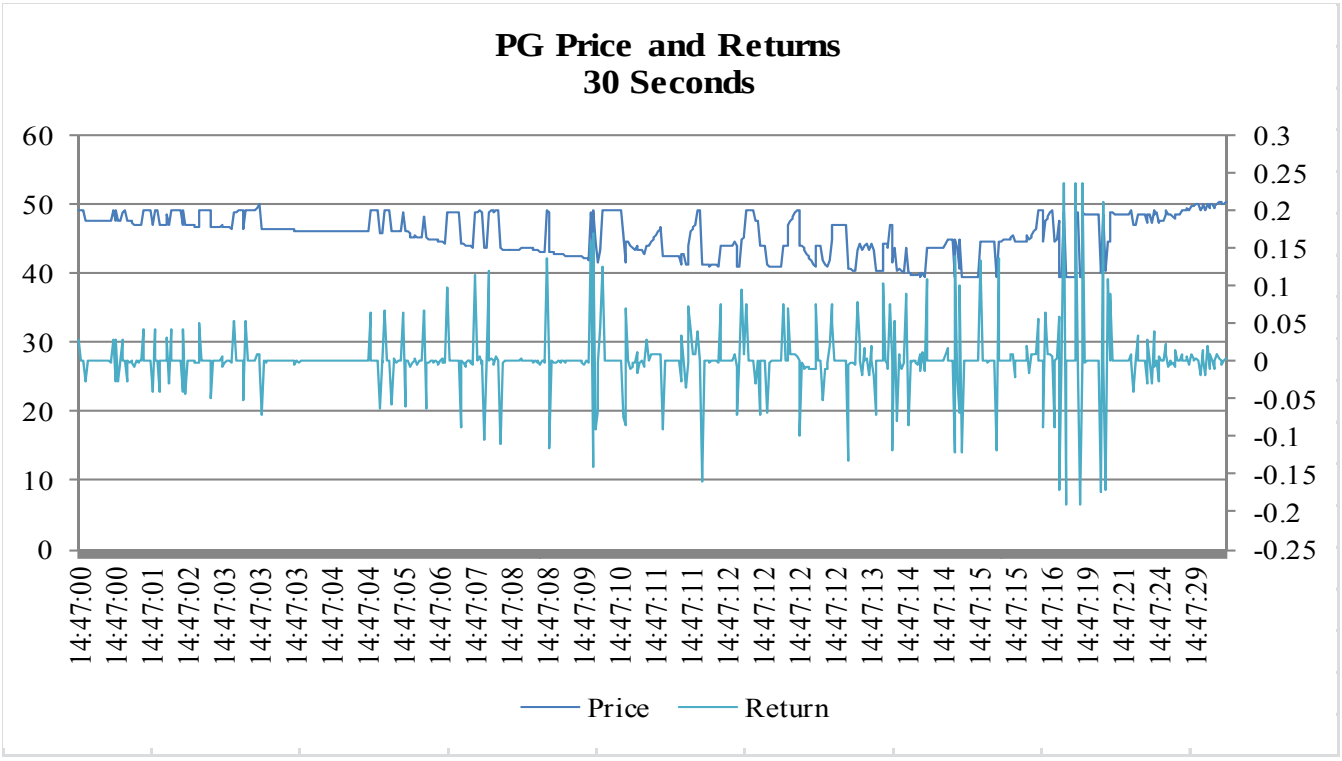


(Source data Yahoo, 2012)




PG Price and Returns
2 Minutes
70
60
50
40
30
20
10
0
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0.61527778
0.61538194
0.61541667
0.61548611
0.61555556
0.61561343
0.61564815
0.61570602
0.61571759
0.61574074
0.61578704
0.61584491
0.61590278
0.61594907
0.61597222
0.61600694
0.61601852
0.61606481
0.61609954
0.61611111
0.61614583
0.61621528
0.61638889
0.61643519
0.61650463
0.61657407
0.61658564
0.61662037
0.61662037
Price
Return


PG Price and Returns
1 Minute
60
50
40
30
20
10
0
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
14:46:30
14:46:31
14:46:33
14:46:35
14:46:37
14:46:38
14:46:38
14:46:40
14:46:40
14:46:41
14:46:43
14:46:45
14:46:48
14:46:49
14:46:53
14:46:54
14:46:56
14:46:58
14:46:59
14:47:00
14:47:01
14:47:03
14:47:03
14:47:04
14:47:05
14:47:07
14:47:08
14:47:10
14:47:11
14:47:12
14:47:12
14:47:13
14:47:14
14:47:15
14:47:18
14:47:21
14:47:29
Price
Return


PG Price and Returns
30 Seconds
60
50
40
30
20
10
0
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
14:47:00
14:47:00
14:47:01
14:47:02
14:47:03
14:47:03
14:47:03
14:47:04
14:47:04
14:47:05
14:47:06
14:47:07
14:47:08
14:47:08
14:47:09
14:47:10
14:47:11
14:47:11
14:47:12
14:47:12
14:47:12
14:47:12
14:47:13
14:47:14
14:47:14
14:47:15
14:47:15
14:47:16
14:47:19
14:47:21
14:47:24
14:47:29
Price
Return

1 Minute 30 Seconds of PG Trading

Time	Number Of Trades	Average Return	Time	Number Of Trades	Average Return	Time	Number Of Trades	Average Return
14:46:30	18	-0.000378495	14:46:59	59	-6.65755E-05	14:47:28	5	-0.004808973
14:46:31	40	-0.000105328	14:47:00	30	4.64634E-05	14:47:29	28	0.001729051
14:46:32	16	-0.000435619	14:47:01	25	0.000830214	14:47:30	3	-6.02417E-05
14:46:33	15	-0.000470083	14:47:02	25	0.000652801	14:47:31	1	0
14:46:34	21	-0.000499258	14:47:03	54	-0.000936687	14:47:32	5	5.4493E-05
14:46:35	16	-0.000246804	14:47:04	64	7.52915E-05	14:47:33	3	0.005092416
14:46:36	16	-0.000674996	14:47:05	16	-0.000774406	14:47:35	15	-0.001284842
14:46:37	57	0.000980666	14:47:06	9	-0.001136135	14:47:36	24	2.81353E-05
14:46:38	66	-0.000943121	14:47:07	26	-9.30454E-05	14:47:38	7	5.71429E-09
14:46:39	14	-0.000336694	14:47:08	42	0.000341023	14:47:39	47	0.000853994
14:46:40	63	-4.60845E-05	14:47:09	24	-0.000155957	14:47:40	23	2.79996E-05
14:46:41	21	-7.04308E-05	14:47:10	32	0.00188222	14:47:41	12	3.01633E-07
14:46:42	28	0.001382751	14:47:11	44	-0.00036335	14:47:42	29	0.000984304
14:46:43	21	-0.00201418	14:47:12	85	0.000281477	14:47:45	18	0.000427708
14:46:44	15	-0.000655722	14:47:13	30	0.000842961	14:47:46	47	0.000875204
14:46:45	19	-0.000234612	14:47:14	33	0.001514371	14:47:47	19	-0.001195835
14:46:46	3	-0.000407083	14:47:15	52	0.002582087	14:47:48	6	0.004077057
14:46:47	12	0.007068272	14:47:16	7	0.000886765	14:47:49	7	-0.002100798
14:46:48	32	0.000473706	14:47:17	4	-0.027036553	14:47:50	11	0.001070065
14:46:49	35	-0.000117837	14:47:18	10	0.028181757	14:47:51	6	0.001849526
14:46:50	12	0.000175763	14:47:19	6	0.007236002	14:47:52	28	-0.001503716
14:46:51	1	-0.047238095	14:47:20	13	-0.00193092	14:47:53	77	0.000725175
14:46:52	4	0.01248277	14:47:21	14	0.006964939	14:47:54	11	0.000360927
14:46:53	43	-0.000536132	14:47:22	3	-0.002446598	14:47:55	58	0.000182811
14:46:54	18	-0.00125848	14:47:23	9	-0.003060361	14:47:56	123	-8.72158E-06
14:46:55	29	-0.000643436	14:47:24	4	0.000553794	14:47:57	22	-0.000480728
14:46:56	19	-0.00045211	14:47:25	3	0.001762217	14:47:58	36	-0.000495047
14:46:57	21	-0.000198568	14:47:26	1	0.022918419	14:47:59	1	0
14:46:58	23	0.000051473	14:47:27	1	0.008633094	**Grand Total**	**2566**	**0.000233638**

** Outlined cell indicates 10 highest entries

Appendix G– Excerpt from Findings Regarding The Market Events of May 6, 2010

EXECUTIVE SUMMARY

On May 6, 2010, the, the prices of many U.S.-based equity products experienced an extraordinarily rapid decline and recovery. That afternoon, major equity indices in both the futures and securities markets, each already down over 4% from their prior-day close, suddenly plummeted a further 5-6% in a matter of minutes before rebounding almost as quickly.

Many of the almost 8,000 individual equity securities and exchange traded funds ("ETFs") traded that day suffered similar price declines and reversals within a short period of time, falling 5%, 10% or even 15% before recovering most, if not all, of their losses. However, some equities experienced even more severe price moves, both up and down. Over 20,000 trades across more than 300 securities were executed at prices more than 60% away from their values just moments before. Moreover, many of these trades were executed at prices of a penny or less, or as high as $100,000, before prices of those securities returned to their "pre-crash" levels.

By the end of the day, major futures and equities indices "recovered" to close at losses of about 3% from the prior day.

WHAT HAPPENED?

May 6 started as an unusually turbulent day for the markets. As discussed in more detail in the Preliminary Report, trading in the U.S opened to unsettling political and economic news from overseas concerning the European debt crisis. As a result, premiums rose for buying protection against default by the Greek government on their sovereign debt. At about 1 p.m., the Euro began a sharp decline against both the U.S Dollar and Japanese Yen.

Around 1:00 p.m., broadly negative market sentiment was already affecting an increase in the price volatility of some individual securities. At that time, the number of volatility pauses,

also known as Liquidity Replenishment Points ("LRPs"), triggered on the New York Stock Exchange ("NYSE") in individual equities listed and traded on that exchange began to substantially increase above average levels.

By 2:30 p.m., the S&P 500 volatility index ("VIX") was up 22.5 percent from the opening level, yields of ten-year Treasuries fell as investors engaged in a "flight to quality," and selling pressure had pushed the Dow Jones Industrial Average ("DJIA") down about 2.5%.

Furthermore, buy-side liquidity[6] in the E-Mini S&P 500 futures contracts (the "E-Mini"), as well as the S&P 500 SPDR exchange traded fund ("SPY"), the two most active stock index instruments traded in electronic futures and equity markets, had fallen from the early-morning level of nearly $6 billion dollars to $2.65 billion (representing a 55% decline) for the E-Mini and from the early-morning level of about $275 million to $220 million (a 20% decline) for SPY[7] Some individual stocks also suffered from a decline their liquidity.

At 2:32 p.m., against this backdrop of unusually high volatility and thinning liquidity, a large fundamental trader[8] (a mutual fund complex) initiated a sell program to sell a total of 75,000 E-Mini contracts (valued at approximately $4.1 billion) as a hedge to an existing equity position.

Generally, a customer has a number of alternatives as to how to execute a large trade. First, a customer may choose to engage an intermediary, who would, in turn, execute a block trade or manage the position. Second, a customer may choose to manually enter orders into the market. Third, a customer can execute a trade via an automated execution algorithm, which can meet the customer's needs by taking price, time or volume into consideration. Effectively,

[6]We use the term "liquidity" throughout this report generally to refer to buy-side and sell-side market depth, which is comprised of resting orders that market participants place to express their willingness to buy or sell at prices equal to, or outside of (either below or above), current market levels. Note that for SPY and other equity securities discussed in this report, unless otherwise stated, market depth calculations include only resting quotes within 500 basis points of the mid-quote. Additional liquidity would have been available beyond 500 basis points. See Section 1 for further details on how market depth and near-inside market depth are defined and calculated for the E-Mini, SPY, and other equity securities.

[7]However, these erosions did not affect "near-inside" liquidity – resting orders within about 0.1% of the last transaction price or mid-market quote.

[8]We define fundamental sellers and fundamental buyers as market participants who are trading to accumulate or reduce a net long or short position. Reasons for fundamental buying and selling include gaining long-term exposure to a market as well as hedging already-existing exposures in related markets.

a customer must make a choice as to how much human judgment is involved while executing a trade.

This large fundamental trader chose to execute this sell program via an automated execution algorithm ("Sell Algorithm") that was programmed to feed orders into the June 2010 E-Mini market to target an execution rate set to 9% of the trading volume calculated over the previous minute, but without regard to price or time.

The execution of this sell program resulted in the largest net change in daily position of any trader in the E-Mini since the beginning of the year (from January 1, 2010 through May 6, 2010). Only two single-day sell programs of equal or larger size – one of which was by the same large fundamental trader – were executed in the E-Mini in the 12 months prior to May 6. When executing the previous sell program, this large fundamental trader utilized a combination of manual trading entered over the course of a day and several automated execution algorithms which took into account price, time, and volume. On that occasion it took more than 5 hours for this large trader to execute the first 75,000 contracts of a large sell program.[9]

However, on May 6, when markets were already under stress, the Sell Algorithm chosen by the large trader to only target trading volume, and neither price nor time, executed the sell program extremely rapidly in just 20 minutes. [10]

This sell pressure was initially absorbed by:

• high frequency traders ("HFTs") and other intermediaries[11] in the futures market;

• fundamental buyers in the futures market; and

[9]Subsequently, the large fundamental trader closed, in a single day, this short position.
[10]At a later date, the large fundamental trader executed trades over the course of more than 6 hours to offset the net short position accumulated on May 6.
[11]See Section 1 for the context in which high-frequency trading and market intermediaries are defined for the E-Mini.

• cross-market arbitrageurs[12] who transferred this sell pressure to the equities markets by opportunistically buying E-Mini contracts and simultaneously selling products like SPY, or selling individual equities in the S&P 500 Index.

HFTs and intermediaries were the likely buyers of the initial batch of orders submitted by the Sell Algorithm, and, as a result, these buyers built up temporary long positions. Specifically, HFTs accumulated a net long position of about 3,300 contracts. However, between 2:41 p.m. and 2:44 p.m., HFTs aggressively sold about 2,000 E-Mini contracts in order to reduce their temporary long positions. At the same time, HFTs traded nearly 140,000 E-Mini contracts or over 33% of the total trading volume. This is consistent with the HFTs' typical practice of trading a very large number of contracts, but not accumulating an aggregate inventory beyond three to four thousand contracts in either direction.

The Sell Algorithm used by the large trader responded to the increased volume by increasing the rate at which it was feeding the orders into the market, even though orders that it already sent to the market were arguably not yet fully absorbed by fundamental buyers or cross-market arbitrageurs. In fact, especially in times of significant volatility, high trading volume is not necessarily a reliable indicator of market liquidity.

What happened next is best described in terms of two liquidity crises – one at the broad index level in the E-Mini, the other with respect to individual stocks.

LIQUIDITY CRISIS IN THE E-MINI

The combined selling pressure from the Sell Algorithm, HFTs and other traders drove the price of the E-Mini down approximately 3% in just four minutes from the beginning of 2:41 p.m. through the end of 2:44 p.m. During this same time cross-market arbitrageurs who did buy the E-Mini, simultaneously sold equivalent amounts in the equities markets, driving the price of SPY also down approximately 3%.

Still lacking sufficient demand from fundamental buyers or cross-market arbitrageurs, HFTs began to quickly buy and then resell contracts to each other – generating a "hot-potato"

[12]9 Cross-market arbitrageurs are opportunistic traders who capitalize on temporary, though often small, price differences between related products by purchasing the cheaper product and selling the more expensive product.

volume effect as the same positions were rapidly passed back and forth. Between 2:45:13 and 2:45:27, HFTs traded over 27,000 contracts, which accounted for about 49 percent of the total trading volume, while buying only about 200 additional contracts net.

At this time, buy-side market depth in the E-Mini fell to about $58 million, less than 1% of its depth from that morning's level. As liquidity vanished, the price of the E-Mini dropped by an additional 1.7% in just these 15 seconds, to reach its intraday low of 1056. This sudden decline in both price and liquidity may be symptomatic of the notion that prices were moving so fast, fundamental buyers and cross-market arbitrageurs were either unable or unwilling to supply enough buy-side liquidity.

In the four-and-one-half minutes from 2:41 p.m. through 2:45:27 p.m., prices of the E-Mini had fallen by more than 5% and prices of SPY suffered a decline of over 6%. According to interviews with cross-market trading firms, at this time they were purchasing the E-Mini and selling either SPY, baskets of individual securities, or other index products.

By 2:45:28 there were less than 1,050 contracts of buy-side resting orders in the E-Mini, representing less than 1% of buy-side market depth observed at the beginning of the day. At the same time, buy-side resting orders in SPY fell to about 600,000 shares (equivalent to 1,200 E-Mini contracts) representing approximately 25% of its depth at the beginning of the day.

Between 2:32 p.m. and 2:45 p.m., as prices of the E-Mini rapidly declined, the Sell Algorithm sold about 35,000 E-Mini contracts (valued at approximately $1.9 billion) of the 75,000 intended. During the same time, all fundamental sellers combined sold more than 80,000 contracts net, while all fundamental buyers bought only about 50,000 contracts net, for a net fundamental imbalance of 30,000 contracts. This level of net selling by fundamental sellers is about 15 times larger compared to the same 13-minute interval during the previous three days, while this level of net buying by the fundamental buyers is about 10 times larger compared to the same time period during the previous three days.

At 2:45:28 p.m., trading on the E-Mini was paused for five seconds when the Chicago Mercantile Exchange ("CME") Stop Logic Functionality was triggered in order to prevent a

cascade of further price declines. In that short period of time, sell-side pressure in the E-Mini was partly alleviated and buy-side interest increased. When trading resumed at 2:45:33 p.m., prices stabilized and shortly thereafter, the E-Mini began to recover, followed by the SPY.

The Sell Algorithm continued to execute the sell program until about 2:51 p.m. as the prices were rapidly rising in both the E-Mini and SPY.

LIQUIDITY CRISIS WITH RESPECT TO INDIVIDUAL STOCKS

The second liquidity crisis occurred in the equities markets at about 2:45 p.m. Based on interviews with a variety of large market participants, automated trading systems used by many liquidity providers temporarily paused in reaction to the sudden price declines observed during the first liquidity crisis. These built-in pauses are designed to prevent automated systems from trading when prices move beyond pre-defined thresholds in order to allow traders and risk managers to fully assess market conditions before trading is resumed.

After their trading systems were automatically paused, individual market participants had to assess the risks associated with continuing their trading. Participants reported that these assessments included the following factors: whether observed severe price moves could be an artifact of erroneous data; the impact of such moves on risk and position limits; impacts on intraday profit and loss ("P&L"); the potential for trades to be broken, leaving their firms inadvertently long or short on one side of the market; and the ability of their systems to handle the very high volume of trades and orders they were processing that day. In addition, a number of participants reported that because prices simultaneously fell across many types of securities, they feared the occurrence of a cataclysmic event of which they were not yet aware, and that their strategies were not designed to handle.[13]

[13]10 Some additional factors that may have played a role in the events of May 6 and that are discussed more fully in Sections 2 and 3 include: the use of LRPs by the NYSE, in which trading is effectively banded on the NYSE in NYSE-listed stocks exhibiting rapid price moves; declarations of self-help by The Nasdaq Stock Market, LLC ("Nasdaq") against NYSE Arca, Inc. ("NYSE Arca") under which Nasdaq temporarily stopped routing orders to NYSE Arca; and delays in NYSE quote and trade data disseminated over the Consolidated Quotation System ("CQS") and Consolidated Tape System ("CTS") data feeds. Our findings indicate that none of these factors played a dominant role on May 6, but nonetheless they are important considerations in forming a complete picture of, and response to, that afternoon.

Based on their respective individual risk assessments, some market makers and other liquidity providers widened their quote spreads, others reduced offered liquidity, and a significant number withdrew completely from the markets. Some fell back to manual trading but had to limit their focus to only a subset of securities as they were not able to keep up with the nearly ten-fold increase in volume that occurred as prices in many securities rapidly declined.

HFTs in the equity markets, who normally both provide and take liquidity as part of their strategies, traded proportionally more as volume increased, and overall were net sellers in the rapidly declining broad market along with most other participants. Some of these firms continued to trade as the broad indices began to recover and individual securities started to experience severe price dislocations, whereas others reduced or halted trading completely.

Many over-the-counter ("OTC") market makers who would otherwise internally execute as principal a significant fraction of the buy and sell orders they receive from retail customers (i.e., "internalizers") began routing most, if not all, of these orders directly to the public exchanges where they competed with other orders for immediately available, but dwindling, liquidity.

Even though after 2:45 p.m. prices in the E-Mini and SPY were recovering from their severe declines, sell orders placed for some individual securities and ETFs (including many retail stop-loss orders, triggered by declines in prices of those securities) found reduced buying interest, which led to further price declines in those securities.

Between 2:40 p.m. and 3:00 p.m., approximately 2 billion shares traded with a total volume exceeding $56 billion. Over 98% of all shares were executed at prices within 10% of their 2:40 p.m. value. However, as liquidity completely evaporated in a number of individual securities and ETFs,[14] participants instructed to sell (or buy) at the market found no immediately available buy interest (or sell interest) resulting in trades being executed at

[14]11 Detailed reconstructions of order books for individual securities are presented at the end of this report, exploring the relationship between changes in immediately available liquidity and changes in stock prices. This rich data set highlights both the broad theme of liquidity withdrawal on May 6, as well as some of the nuanced differences between securities that may have dictated why some stocks fell only 10% while others collapsed to a penny or less.

irrational prices as low as one penny or as high as $100,000. These trades occurred as a result of so-called stub quotes, which are quotes generated by market makers (or the exchanges on their behalf) at levels far away from the current market in order to fulfill continuous two-sided quoting obligations even when a market maker has withdrawn from active trading.

The severe dislocations observed in many securities were fleeting. As market participants had time to react and verify the integrity of their data and systems, buy-side and sell-side interest returned and an orderly price discovery process began to function. By approximately 3:00 p.m., most securities had reverted back to trading at prices reflecting true consensus values. Nevertheless, during the 20 minute period between 2:40 p.m. and 3:00 p.m., over 20,000 trades (many based on retail-customer orders) across more than 300 separate securities, including many ETFs,[15] were executed at prices 60% or more away from their 2:40 p.m. prices. After the market closed, the exchanges and FINRA met and jointly agreed to cancel (or break) all such trades under their respective "clearly erroneous" trade rules. (U.S. Commodity Futures Trading Commisision and U.S. Securities and Exchange Commission, 2010)

[15]Section 2 discusses the disproportionate impact the market disruption of May 6 had on ETFs.

Appendix H- Components of the Dow Jones Industrial Average

Ticker	Company
MMM	3M Co.
T	AT&T
AA	Alcoa Inc.
AXP	American Express Co.
BAC	Bank of America
BA	Boeing Co.
CAT	Caterpillar Inc.
CVX	Chevron
CSCO	Cisco Systems Inc.
KO	Coca-Cola Co.
DD	E.I. DuPont de Nemours & Co.
XOM	Exxon Mobil
GE	General Electric Co.
HPQ	Hewlett-Packard
HD	Home Depot Inc.
INTC	Intel Corp.
IBM	International Business Machines Corp.
JPM	JPMorgan Chase
JNJ	Johnson & Johnson
KFT	Kraft Foods Inc. Cl A
MCD	McDonald's Corp.
MRK	Merck & Co. Inc.
MSFT	Microsoft Corp.
PFE	Pfizer Inc.
PG	Procter & Gamble Co.
TRV	Travelers Cos.
UTX	United Technologies Corp.
VZ	Verizon Communications
WMT	Wal-Mart Stores Inc.
DIS	Walt Disney Co.

(Dow Jones, 2012)

REFERENCES

(2010). Brett mock, a senior sales trader at btig talks about.. Traders Magazine, Retrieved from http://www.tradersmagazine.com/issues/23_317/high-frequency-trading-flash-crash-market-making-106827-1.html

Anderson , D. (2011). Statistics for business and econmonics. (11 ed.). Cengage Learning.

Armstrong, J. (2011). Up for grabs. Traders Magazine, Retrieved from http://www.tradersmagazine.com/issues/24_327/hfts-brokers-naked-access-108063-1.html

Becker,L. (2011). How France can regulate HFT. International Financial Law Review, 30(5), 49.

Barnes, S. (2010). Regulating High-Frequency Trading: An Examination of U.S. Equity Market Structure In Light of the May 6.2010 Flash Crash [Kindle Fire Version]. Retrieved from Amazon.com

Benoit, D. (2012, March 23). *Bats initial public tease: Nine seconds of free fall*. Retrieved from http://blogs.wsj.com/deals/2012/03/23/bats-initial-public-tease-nine-seconds-of-free-fall/?KEYWORDS=bats ipo

Benoit, D. (2012, March 25). *Bats goes full court press to try and explain friday*. Retrieved from http://blogs.wsj.com/deals/2012/03/25/bats-goes-full-court-press-to-try-and-explain-friday/?KEYWORDS=bats ipo

Berkeley,A., Katz,G., O'Brien,W. & Sarkar,A., R.Schwartz (Chair), "What Makes an Exchange a Unique Institution". Baruch College, The Economic Function of a Stock Exchange. New York, NY. 4 October, 2011.

Berman, D. (2012, January 4). So, what's your algorithm? . Wall Street Journal. Retrieved from http://online.wsj.com/article/SB10001424052970203462304577138961342097348.html

Betancourt, L., VanDenburgh, W. M., & Harmelink, P. J. (2011). Understanding the 'Flash Crash.'. CPA Journal, 81(1), 40-45.

Caplan, K., Cohen, R., Lenz, J., & Pullano, C. (2009.). Dark Pools of Liquidity. *Alternatives Newsletter*. Retrieved April 22, 2012, from www.pwc.com/us/en/alternative-investment/assets/NY-10-0105-PwC-alt-Caplan.pdf

Carlson, M. (2007). Retrieved from Finance and Economics Discussion Series Divisions website: http://www.federalreserve.gov/Pubs/feds/2007/200713/200713pap.pdf

Chapman, P. (2011). Defending the turf. Traders Magazine, Retrieved from http://www.tradersmagazine.com/news/sellside-defends-buyside-hft-107526-1.html

Chapman, P. (2010). Hfts shun options marts. Traders Magazine, Retrieved from http://www.tradersmagazine.com/issues/23_316/hft-options-markets-exchanges-spdr-106689-1.html

CME Group Index Services LLC. (2010, 12 31). The History of the Dow. Retrieved 12 4, 2011, from Dow Jones Industrial Average: http://www.djindexes.com/mdsidx/downloads/brochure_info/Dow_Jones_Industrial_Average_Brochure.pdf

CME Group Index Services LLC. (2011). DJIA Historical Timeline. Retrieved December 4, 2011, from Dow Jones Industrial Average Interactive Learning Center: http://www.djaverages.com/

CME Group Index Services LLC. (2011, November 30). Fact Sheet. Retrieved December 4, 2011, from Dow Jones Industrial Averages: http://www.djindexes.com/mdsidx/downloads/fact_info/Dow_Jones_Industrial_Average_Fact_Sheet.pdf

D'Antonia, J. (2012, March). Cat's long and winding road. Traders Magazine, Retrieved from http://www.tradersmagazine.com/issues/25_334/consolidated-audit-trail-data-109845-1.html

Dark pools definition (n.d). *Financial Times Lexicon*, Financial Times, Retrieved April 22, 2012, from http://lexicon.ft.com/Term?term=dark-pools

Dow Jones. (2012). Retrieved from http://www.djaverages.com/?go=industrial-components

Flash trading definition (n.d). *Financial Times Lexicon*. Financial Times. Retrieved April 22, 2012, from http://lexicon.ft.com/Term?term=flash-trading

Gross, D. (2007, June). The Truth About Investment Bubbles. Inc. pp. 71-73.

Haldane, A. (2011). The race to zero - Speech by Andrew Haldane, 8 July 2011. Bank of England . Retrieved January 14, 2012, from http://www.bankofengland.co.uk/publications/news/2011/068.htm

Intercontinentalexchange announces first ear results of high frequency trading policy; innovative method proves highly effective. (2012, February 29). Retrieved from http://ir.theice.com/releasedetail.cfm?ReleaseID=652686

Keim, B. (2012, February 16). Nanosecond trading could make markets go haywire. Wired , Retrieved from http://www.wired.com/wiredscience/2012/02/high-speed-trading/

Mehta, N., Thomasson, L., Barrett, P. M., Kearns, J., Kisling, W., & Coy, P. (2010). The Machines That Ate The Market. Bloomberg Businessweek, (4180), 48-55.

One big, bad trade. (2010, October 1). The Economist, Retrieved from http://www.economist.com/blogs/newsbook/2010/10/what_caused_flash_crash

Patterson, S. (2010, May 18). How the 'Flash Crash' Echoed Black Monday---May 6 Selloff Had Parallels to 1987; Electronic Trading Magnified Selling Pressure This Time. Wall Street Journal (Eastern Edition), p C.1. Retrieved December 4, 2011, from ABI/INFORM Global. (Document ID: 2035448591).

Patterson, S. (2010, June 30). Fast Traders Face off With Big Investors over 'Gaming'. Wall Street Journal (Eastern Edition), p. C.1. Retrieved December 4, 2011, from ABI/INFORM Global. (Document ID: 2069277411).

Perez, E. (2012, March 08). Edgar perez, author, the speed traders: An insider's look at the new high-frequency trading phenomenon that is transforming the investing world, at high frequency trading panel, seventh annual mit sloan investment management conference. Retrieved from http://prurgent.com/2012-03-08/pressrelease229455.htm

Peterson, K. (2010, September 10). These Traders Play Only the Open and Close - WSJ.com. Wall Street Journal. Retrieved April 22, 2012, from http://online.wsj.com/article/SB100014240

Philips, M. (2012, March 19). Regulators are slow to act on speed traders. Bloomberg Businessweek, Retrieved from http://www.businessweek.com/articles/2012-03-19/regulators-are-slow-to-act-on-speed-traders

Quote stuffing definition . (n.d.). *Financial Times Lexicon* . Retrieved April 22, 2012, from http://lexicon.ft.com/Term?term=quote-stuffing

Ramage, J. (2010). Making sense of the complex. Traders Magazine, Retrieved from http://www.tradersmagazine.com/issues/23_315/making-sense-of-the-complex-106428-1.html

Rehfeld, B. (2010). Flash crash: A day to remember. Traders Magazine, Retrieved from http://www.tradersmagazine.com/issues/23_310/flash-crash-may-6-105905-1.html

Rose, C. (2011). The Flash Crash Of May 2010: Accident Or Market Manipulation?. Journal Of Business & Economics Research, 9(1), 85-90.

Russolillo, S. (2011, September 12). Big Investors Cite Concern Over High-Frequency Trading. Wall Street Journal (Online). Retrieved December 4, 2011, from ABI/INFORM Global. (Document ID: 2451651181).

Russolillo, S. (2012, March 23). *Apple shares go batty, but stock trading back to normal*. Retrieved from http://blogs.wsj.com/digits/2012/03/23/apple-shares-go-batty-but-stock-trading-back-to-normal/?KEYWORDS=apple trade halt

Sassoon, A. B. (2011). Algo Trading in the Liquidity Mirage. Futures, 38-40.

Scotti, M. (2010). In a flash. Traders Magazine, Retrieved from http://www.tradersmagazine.com/issues/23_317/flash-crash-may-sec-brokerage-volumes-hft-106817-1.html

Securities and Exchange Commission. (2012). Self-Regulatory Organizations; EDGA Exchange, Inc.; Notice of Filing and Immediate Effectiveness of Proposed Rule Change to Amend EDGA Rule 11.14 to extend the operation of the single stock circuit breaker pilot program until July 31, 2012. Retrieved from Securities and Exchange Commission website: http://www.sec.gov/rules/sro/edga/2012/34-66227.pdf

Securities and exchange commission. (2011, April 05). SEC announces filing of limit up-limit down proposal to address extraordinary market volatility. Retrieved from http://www.sec.gov/news/press/2011/2011-84.htm

Sec adopts large trader reporting regime. (2011, July 26). Retrieved from http://www.sec.gov/news/press/2011/2011-154.htm

Sec proposes consolidated audit trail system to better track market trades. (26, May 2010). Retrieved from http://www.sec.gov/news/press/2010/2010-86.htm

Seitz,J.,&Kloos, E. (2010). Don't overreact. International Financial Law Review, 29(10),39.

SIFMA, (2011). Impact of high frequency trading and considerations for regulatory change. Retrieved from SIFMA website: http://www.sifma.org/issues/item.aspx?id=8589936694

Simon, Matthew. "Equity Volumes? Expect the Worst, Hope for the Best." TABB Forum. TABB Group, 26 Jan. 2011. Web. 1 Apr. 2012. <http://tabbforum.com/opinions/equity-volumes-expect-the-worst-hope-for-the-best>.

Sparrow, C. (2011, November 22). Why its hard to know the impact of high frequency trading [Online forum comment]. Retrieved from http://www.tabbforum.com/channels/regulatory/opinions/why-it's-hard-to-know-the-impact-of-high-frequency-trading

Strasburg, J. (2011, August 16). A Wild Ride to Profits. Wall Street Journal - Eastern Edition. pp. C1-C2.

Steinert-Threlkeld, T. (2011, May 6). *Flash crash flash: High frequency trading will get thoroughly examined, schapiro says*. Retrieved from http://www.securitiestechnologymonitor.com/news/-27831-1.html?pg=1

Sussman, Adam. "What Isn't In the Flash Crash Report." TABB Forum. TABB Group, 01 Oct. 2010. Web. 01 Apr. 2012. <http://tabbforum.com/opinions/what-isn%27t-in-the-flash-crash-report>.

"The Equity Market Is Now Controlled By The Machines." Interview by Chris Martenson. Chris Martenson. 4 Feb. 2011. Web. 1 Apr. 2012. <http://www.chrismartenson.com/page/transcript-joe-saluzzi-high-frequency-trading-equity-market-now-controlled-machines>.

The Flash Crash Aftermath: Responses to the Trading Events of May 6, 2010. (2010). Insights: The Corporate & Securities Law Advisor, 24(7), 2-10.

U.S. Commodity Futures Trading Commisision and U.S. Securities and Exchange Commission. (2010). Findings Regarding The Market Events of May 6, 2010.

US Securities and Exchange Commission (2010, November 3). Sec adopts new rule preventing unfiltered market access. Retrieved from http://www.sec.gov/news/press/2010/2010-210.htm

U.S. Senate, Committee on Banking, Housing and Urban Affairs. (2010). Examining the causes and lessons of the may 6th market plunge. Retrieved from US Government Printing Office website: http://www.gpo.gov/fdsys/pkg/CHRG-111shrg62513/pdf/CHRG-111shrg62513.pdf

Urstadt, B. (2010). Trading Shares in Milliseconds. Technology Review, 113(1), 44-49.

Watson, T. (2011). Rise of the MACHINES. Canadian Business, 84(9), 56-59.

Watson, T. (2011, September 27). Journalists vs. high-frequency traders. Canadian Business. CanadianBusiness.com. Retrieved January 14, 2012, from http://www.canadianbusiness.com/blog/business_briefings/47825--journalists-vs-high-frequency-traders

What is e-mini. (2011). Retrieved from http://www.forexbite.com/trading-courses/forexdictionary-E-mini-681

Yahoo. (2011). Historical Prices. Retrieved December 4, 2011, from Yahoo Finance: http://finance.yahoo.com/q/hp?s=^DJI+Historical+Prices

Yahoo. (2012). Historical Prices. Retrieved April 9, 2012, from Yahoo Finance: http://finance.yahoo.com/q?s=PG&ql=1

Yu, J. (2011, August). *A glass half full: contrarian trading in the flash crash*. Retrieved from http://www.rhsmith.umd.edu/finance/pdfs_docs/SeminarFall2011/YuJialin.pdf

Zwick, S. (2011). High-Frequency Trading: Good, bad or just different? Futures, 54-58.