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Marceau Bescher

Flash Crashes: convincing examples of the power of High Frequency Trading

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Abstract

The development of new technologies has created new ways of trading on capital markets. Computing power has permitted High Frequency Trading to become the most active actor on markets and has given competitive advantages associated with the speed of algorithms.

This thesis witnesses the increasing power of High Frequency Trading by focusing on the example of Flash Crashes events. It gives information on the causes and on estimation on the full power of algorithmic traders.

The analysis of different failures because of the new financial uses helps to understand the causes and the scale at which HFT can impact the financial system. As a link to further possible researches, the analyse of the actions taken to counter the risks of algorithmic trading leads to potential improvement in order to solve the unfairness issues of current market places.

Keywords	HFT, Algorithmic Trading, Flash Crash, power, risk

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1 Introduction

Algorithmic Trading is nowadays a common use on financial markets. Representing more than 75% of the trading flow, computers have become the most important traders on stock exchanges (Prakash 2016). The old time when the Wall Street floor was overwhelmed by traders running and yelling is now over. Everybody is now in its office, as close as possible to the marketplace, trading on computers and having tonnes of live charts and analysis. And that represent only a part of it. The other sides of the business are the engineers developing programs and faster computers, the telecom industries increasing the pace of communication…

Following the multiple technologic developments in the last few decades, a particular type of algorithmic trading has raised to the top: High Frequency Trading. This type of trading has profited from the power represented by computers and is now the most powerful tool of the market. However, it still presents risks as we do not have enough tested this technology, brand new. Risk for anomalies known as bug, or glitches for example. Risk for the market as it has shown multiple time it could harm the market.

The most common example to highlights the risks of High Frequency Trading are Flash Crashes. Very short intraday event similar to a crash but mostly recovering in a day. These events are daily occurring on single stocks and sometimes create general Flash Crash. Economists are afraid it could be the origin of the next financial crisis. (Kim 2018)

The main actors of HFT are market makers, hedge funds and investment banks. Those powerful trading companies have in their hands something capable to manipulate a market in a matter of seconds. The precise power of this new technology is still a little blurry as some information are missing. However, it is undeniable that this could cause a major catastrophe on financial markets and having repercussions on the global financial stability.

The aim of this paper is to research the power High Frequency Trading has acquired and the potential it represents today. Particularly focusing on the example of the Flash Crashes to show the impact of this use of algorithmic trading on inefficient markets.

I chose this topic as a result of my curiosity towards the financial markets and trading strategies but also towards the development of new technologies. At first, I wanted to

discuss about the Flash Crashes because it is becoming one of the big concerns of financial markets nowadays with approximatively 12 occurrences a day (Munk 2017). Then by researching on this topic it turned out that I could develop on the issue raised by HFT and take the Flash Crashes only as an example to justify my thoughts. Seeing the development of computing power and the ethical problems linked to it, I choose to focus on HFT' power, extendable not only to the "expectation market" (Martin 2011) but to the whole picture.

I organised this paper by describing some Flash Crashes to introduce the issue of HFT. Then comes an introduction on what's HFT and its impacts on financial markets. Finally, I had a look into some solutions proposed to counter Flash Crashes focused on the disadvantages of HFT on markets.

This paper is mainly a literature review and an analysis of public information as HFT firms are used to keep every information on those strategies for themselves to limit the possibilities of benchmarking. The level of confidentiality in this area makes researches about it harder.

2 Flash Crash historical data

2.1 6 May 2010

Since the beginning of the Recession started in 2009 after the financial crisis, there have been an increasing number of Flash Crashes. This multiplication of uncertain events raises a list of issues and concern for the financial community. The first one to have a look at is the one that happened on May 6th, 2010. Indeed, this is the biggest event ever reported in the Dow Jones Industrial Average [1]as for now. A report from the Securities and Exchange Commission (SEC) has reported a loss of 700 points in minutes and 1000 points in the day (lowest intraday point representing around a 9% loss). Here, the main focus is the time needed for this huge drop: less than 5 minutes. In this report, they give the details of what happened. It started with the economic news about the European Debt Crisis. Traders started to buy securities against the potential default of the Greek government because of huge debt repayments. That created a decline for the euro currency and an increasing in volatility. The NYSE stopped the automatic trading in the high volatile equities by using Liquidity Replenishment Points (LRP). This method is used to stop the automated trades, to fight the volatility and increase the liquidity[2]. Before the market crashed, LRPs were above the average and it probably helped to the changes in prices and liquidity. It helped to pause the volatility but not the liquidity. At 2:30 pm, the market was low and has known a 2.5% in the Dow Jones Industrial Average since the morning. The drop in liquidity scared the traders once again. At 2:32 pm, a large fundamental trader started a huge sell program of E-mini contracts[3] to hedge its equity position. They choose to execute the sell-off by automated transactions. They used algorithmic trading that doesn't consider prices, but only volume of trades. Moreover, they executed the program in 20 minutes, instead of the usual several hours for this huge number of contracts. Executing that much in a short amount of time provoked a chain reaction in the market. Algorithmic traders (ATs), seeing these huge sell-off, stopped. This is a security in most of the algorithms when the market become crazy to

[1] The DJIA is one of the oldest indices in the world and tracks 30 companies traded on the NYSE and NASDAQ

[2] Liquidity is a term used for the numbers of sellers and buyers. A perfect liquidity represents a market with the same number of sell order and buy order at the same price so that transactions happen immediately.

[3] Electronically traded futures contracts representing a fraction of the value of a corresponding futures contract (Investopedia)

avoid risks. As AT represents the main part of the trades, the liquidity went down in minutes and some shares has been traded for a penny! (SEC 2010)

After this Flash Crash, the SEC approved the Limit Up-Limit Down rules in 2012 to avoid too important price movements. This has been created to address extraordinary market volatility. When a price of an equity goes down or up over a certain limit, this serve as a circuit-breaker and will stop the trades on this particular equity and wait for the liquidity of the stock come back to a normal rate. (LULD plan)

From the beginning of the crash, the market took 36 minutes to recover from almost all the losses. (Twin, 2010) The rapid recovery has been created by opportunists HFT taking advantages of the low prices to buy and wait for the recovery before selling and make profits. The important volume made a fast bounce back possible.

The official cause of this crash has been originally put under the huge sell-off of an investment fund in Kansas named Waddell and Read. $4.1 bn of futures contracts trying to be sold by one actor destroyed the liquidity of the market. However, in 2015, the FBI found out that another trader was also responsible for the illiquidity responsible for the price drop. Navinder Singh Sarao, a trader in London has been accused of manipulating the market just before the crash with the same technique used by the investment fund. The federal institution stated that his sell orders represented as much order as the whole market buy orders, just minutes before the fall. So, they are saying that, 5 years after the event, they found out that just one guy was responsible for a trillion dollars whipped off. So, the official cause of the crash is the sell-off of two actors in the market impacting on the liquidity of the market and inducing the price drop. (Verity 2015)

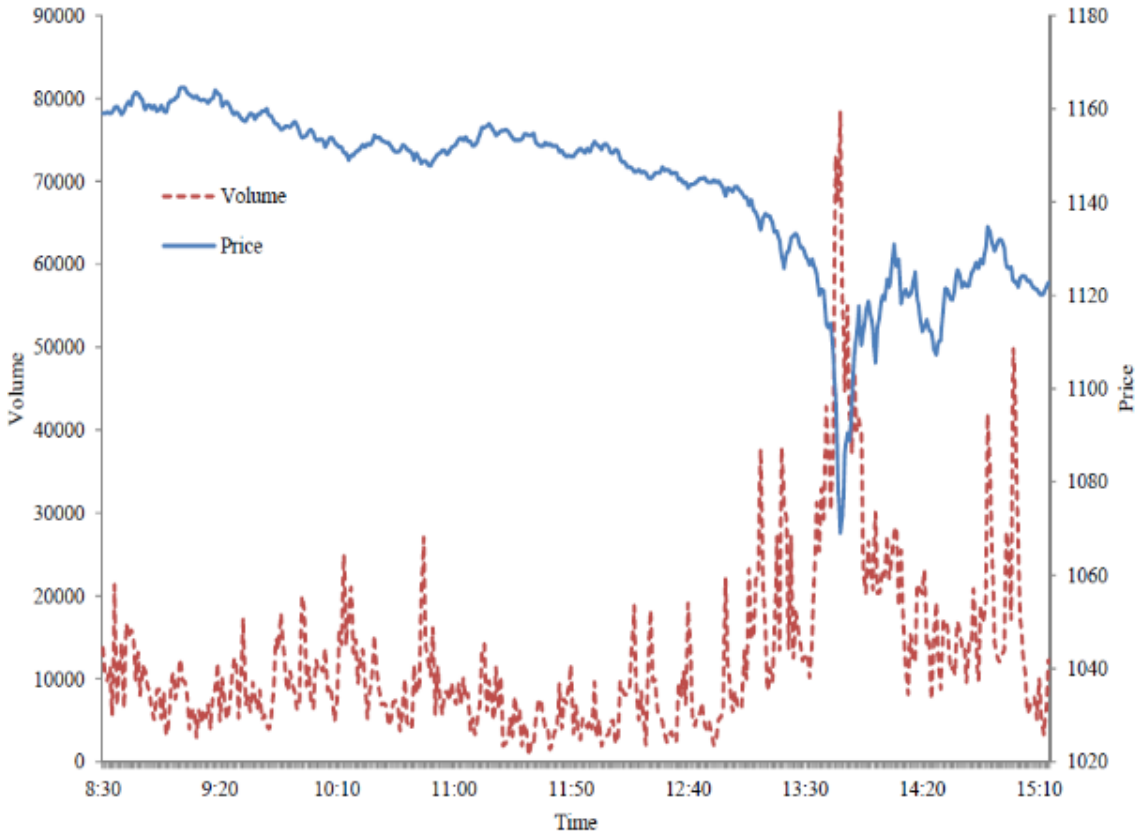

Figure 1 Prices and Trading Volume of the E-Mini S&P 500 Stock Index Futures Contract 6 May 2010

Source: CFTC

The volume associated with the fall in price show that the increase of volume went on only one side (sell) and harmed the liquidity of the market before coming back to a normal liquidity and volume in the end of the day.

2.2 24 August 2015

The Flash Crash occurred on the 24 of August 2015 has been generated by a lot of different factors. The Federal Reserve had previously announced a wish of raising the interest rates from September 2015. Raising the interest rates is usually used to fight against inflation but it also creates more expensive loans leading to a raise of the risk of debt. On the previous Friday, the price of the oil went down to 40$ a barrel, compared to over 100$ two months before. This is a good point for customer, however, for investors, it means that some companies make less money. In addition, China's expectations of their economic growth were fixed to 7% but the results showed a real difference with the reality. On the Monday, China registered a loss of around 40% of their stock market. This has been caused by the drop in the price of global commodities.

Knowing that China is the biggest producer of commodities, the huge effect is understandable. On the 24th of August 2015, after all those events, there was a drop of 1100 points in the DJIA in the first five minutes of trading. Traders to counter this encouraged a massive trend of buying hedges to secure positions. (Wearden 2015)

This had the same impact as the flash crash of May 2010: higher volatility, lower liquidity, fall in prices. The dealers did their job and sold a lot of protection (mainly put options) to the panicked traders. Accumulating the sales for a dealer is acquiring more and more long positions. So, to protect themselves, they finally had to do the same as the traders and sell as well and feed the vicious circle that was going on. Something else about this crash is that some stocks didn't open on time because of the uncertainty of the market. That helped rising the volatility. This also blocked the calculation of ETF's "fair prices", so a lot of trade with inexplicable prices occurred. The result was a 10% loss in the S&P 500 stock exchange.

The LULD rule created in 2012 hasn't proved its efficiency during this crash. It originally has been created to prevent single security issues. However, more than 1200 LULD has been triggered on the 24th of August. This has indeed reduced the sharp prices moves but it has also made the recovery slower. Market makers had to manually modify their automated pricing systems because of the loss of information created by the number of trading halts. Many firms were not ready for this volume of pauses, and encouraged the slow recovery compared to the pace at which the market plunged. (Egan 2015)

The following charts shows the volatility difference between a normal trading day and the 24th August during the period when the flash crash occurred. We can see a net difference between the two, result of uncertainty and low liquidity in the market.

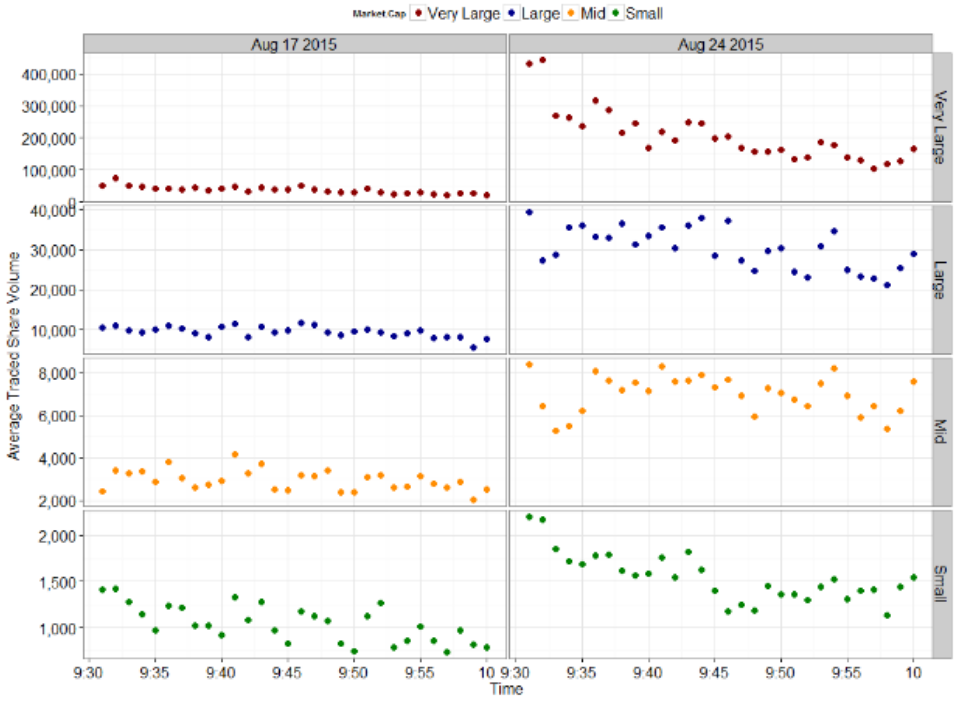

Figure 2 Average traded share volume for Corporates by market capitalization for each minute from 9:30 to 10:00 on August 24 compared to August 17

Source: SEC

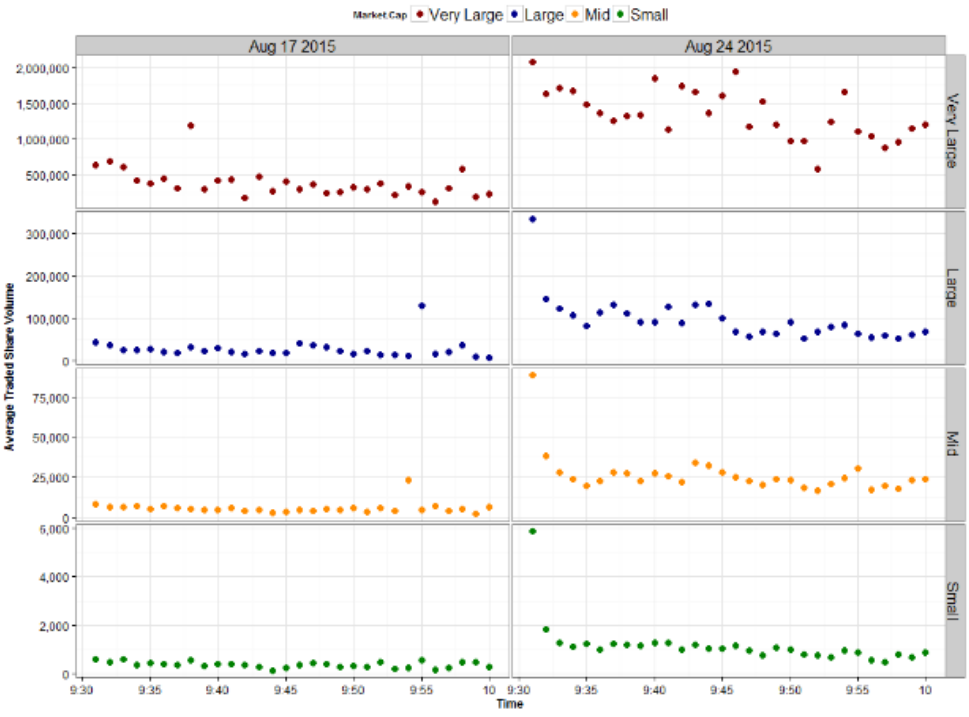

Figure 3 Average traded share volume for ETPs by market capitalization for each minute between 9:30 and 10:00 on August 24 compared to August 17

Source: SEC

The week after, Larry Summers has written in the Financial Times that the Federal Reserve shouldn't raise the interest rates in September. He thinks that regulators must not interfere with the current situation of the market. He calls for "secular stagnation" and state that it's not the role of the Fed to resolve the problem. The government apparently thought the same. They thought it could harm even more the market so they postponed the rates hiking. Considering that the market is currently still fragile and in the same situation, it was maybe not the right thing to do. (Udland 2015)

2.3 5 February 2018

On Monday the 5th of February 2018, one of the biggest declines in a day for the DJIA and S&P occurred. At the lowest intraday point, the Dow was down 1597 points, or 4,6%. After a catastrophic Friday with a 666 points loss, the Monday followed the move and closed down by more than 1100 points. The causes were multiple: the last trading day was quite bad, a new chairman for the Federal Reserve nominated, concerns about the potential rise of inflation and interest rates. Jerome Hayden Powell has been assigned to the position of Fed Chair on this Monday. The decline in the stock market has been seen as a test, occurring each time a new chairman is nominated (Imbert 2018). Additionally, since 2009 the economic conditions are such that the economic growth is constant and not too important and the inflation in the US stays low. 9 years with economic growth but no outstanding inflation makes the investors worried about a potential change. It would also mean a raise in the interest rates. We can also add that as the employment rates in the USA were quite high, the power of the employees was rising, so it could have impacted the wages asked (less competitivity between workers). A wage increase would lower the profitability of companies and lower the returns for investors. The indebted countries are also a matter of uncertainty and risks. All those facts scared the investors once again. So, they focused on buying hedges and the liquidity of the market went down, creating volatility, and interacting with HFTs that are regardless to price and don't understand that the market is going down. Within just minutes, the 800 points down at 3pm in the Dow became the lowest point of 1597 points down. Overall, DJIA moved more than 5100 points in the day, which represents 25% of its value.

The S&P took 13 days to recover from this loss (compared to other flash crashes that usually take few hours or a few days to recover).

Markets still have a good recovery, due to the confidence investors have in the market because of the high profitability of the big companies and the 50% growth on stock exchange in the last two years (CNBC).

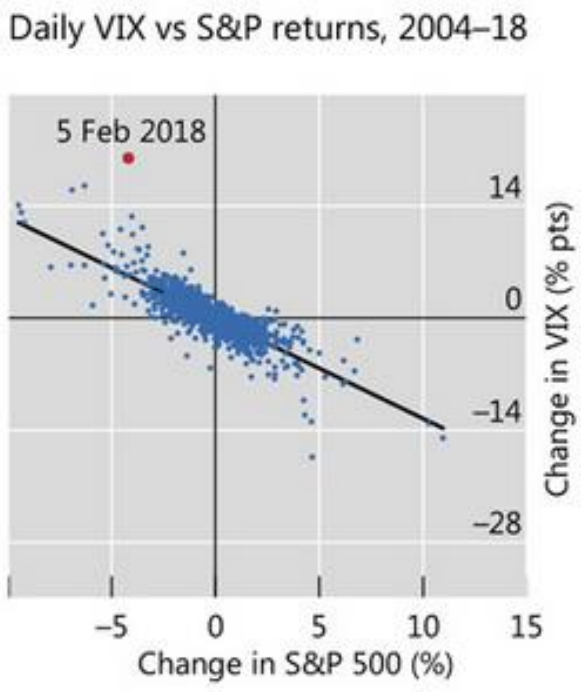

Figure 4 Daily VIX vs S&P returns, 2004-18

Source: BIS

The red point represents the modification in the VIX (volatility index of the S&P 500) on the 5th of February. It shows the incredible increase in the volatility during this day. Increasing volatility is the prove of important price movements.

2.4 Similarities/Differences – Results of the previous analysis

A lot of Flash crashes have been recorded. This is a sample of similar events to establish similarities and pattern applicable to this kind of events.

What we can observe when comparing the facts before those bad days is the global market environment. Each time, news, economic instability and sometimes more are responsible of a rise in the market stress, uncertainty. When markets are considered as dangerous and the investors lose confidence, they have a tendency of selling. Usually after one or a few days of decreasing results in the stock exchanges, flash crashes are a result of fear and stop-loss sell-offs.

An increasing volatility due to an uncertain market is a cause of an increasing risk on the market. We also observe a change in the volume traded at the moment of the fall, always increasing. It shows that a crash is the consequence of a mass movement in the same way, harming the liquidity and the prices on the markets.

"The issue is the lack of clear catalysts to embolden investors to buy into weakness as many have stopped to gaze at charts and wallow in worry rather than to take advantage of dislocations" Citigroup's Tobias Levkovich (Financial Time 2015)

What Mr Levkovich is explaining is the reaction created by uncertainty. The snowball reaction is the multiplication of the sell orders instead of the tries to replenish the liquidity. The pace at which the prices fall makes it hard for the opportunists that take profit from the fall of the prices to act before it goes too low. Glitches in the market efficiency are created by two things: human nature and computing power. The human nature is highlighted when the market is under stress and the traders go crazy, as well as the algorithms (that were created by human to react that way if the market is uncertain). We must not forget that code is created by a programmer. A programmer is human and incorporate its thoughts of the market in the program.

Another similarity between flash crashes is that the huge sell-off accelerating the events are sometimes operated by the same company/trader. A tendency of using the pace of technology to manipulate the market and profit from opportunities it creates is growing up on stock exchanges. Even though fines are applied to such activities, it doesn't impeach some to try.

The day when it appears is also probably a concern to deal with. The majority of big flash crashes happened on a Monday, as well as the crash in 1987 that is called "Black Monday". It seems that weekends can increase the impact of some bad news and induce a very low liquidity just before the opening of the market on the Monday. But the 6th May 2010 was a Thursday and show that it can happen any day, if the symptoms are present and strong enough. Symptoms that do not deal well with algorithmic trading strategies.

3 Algorithmic Trading Impact

3.1 Development of algorithmic trading

Algorithmic trading is the use of computer programs in order to automate one or more steps of a trading process. It can be used in many forms: data analysis, buy and sell recommendations, trade executions. Born in the 70s in the USA after the informatisation of orders in markets, it has known a slow development during the 20st century before exploding in the 2000s because of the fractioning of the minimum amount per order (0.01 dollar instead of 0.0625). Algorithmic trading has basically started to grow after the crash of 1987 when the DJIA lost more than 20% of its value in a day. The universal access to information at the same time induced a mass movement from the traders because of uncertainty and worries in the market. This induced a lot of changes by the SEC. Before 1997, we were mostly talking about automated trading. In 1997, the Electronic Communication Network (ECN) have been created. (Leshik 2011: 7-18) Those informatic centres are links between professionals and brokers allowing informatic transactions. Those are programs working 24 hours a day and made the market automatized. This was the beginning of what we call now algorithmic trading. From that point, the main focus has been the improvement of assisted trading, or even algorithmic trading by optimise data mining, sorting, decision making and transaction costs. The job of a traders has been in a transition period to become now more a monitoring work. Then in 2001, the change of the fragmentation of prices in the market has permitted tighter differences between prices in favour of some algorithmic strategies. Originally created to lower the cost for small investors and individuals, it didn't have the expected consequences. It reduced trading margins for market makers and forced some companies to adopt electronic order management systems and any technology that would make trades faster and cheaper to face the reduction of margin. All the advantages proposed by algorithms was the best way to avoid reducing their profits. (Kim 2007: 1-7)

Algorithmic trading has developed itself thanks to the technological improvement occurred mostly in the sectors of computing, telecommunication. The improvement of computers made algorithms more efficient: accurate and fast, when the telecommunications discoveries made the transmissions of information quicker than a blink of an eye. However, Algorithm added incredible barriers to the environment, either

for new entrants or small actors of the market. To become competitively performant in stock exchanges now, it costs an incredible amount of money to put together traders, technologists, quantitative market analysts, software programmers and the IT hardware needed for the business. The principle of fair markets, if it has existed, is no longer associated to stock exchange.

Different strategies exist within algorithmic trading. The most known are:

- Arbitrage

This a strategy based on profiting from inefficiency in different stock exchange. For companies listed in different stock exchanges, their price must be the same for each market. An arbitrage algorithm will profit from the delay of price updating between stock exchanges. It works for companies, but also for currencies and commodities. To be efficient, the algorithm needs to be fast enough to profit from the difference before it disappears, or before someone do the same. (Moffatt 2017)

- Pairs Trading

It is similar from the previous strategy as it has the same purpose: benefiting from market weaknesses. The difference is that instead of profiting from stocks listed on different stock exchanges, this strategy is based on securities that are highly correlated. Their beta must be very close, or even equals, meaning that their prices move the same way. The weakness exploited here is the variation in the beta associated with those two securities. That means when the correlation variates, you expect that it will become normal again soon, so you short or long the two stocks to profit from the movement of prices, consequences of the knowledge of a weakness on a market. That means you have to be the first to see this inefficiency before the others do the same and the securities become efficient again. To perform this strategy, you need to short the stock that is considered overvalued and long the one that is undervalued considering the usual correlation of the stocks.

For the readers without any trading competences, let's say you have 2 stocks which their prices move the same way. When one moves, the other should move the same way (considered as market efficiency). But if the market is inefficient, when the price of stock A goes down, stock B does not move or go up. That means, in this case, stock A is

undervalued or stock B is overvalued. As you expect the two shares to keep the same changes, you expect that B will move down or A move up to come back to a normal price and correlation between both stocks. So, you short (sell) B and long (buy) A and then you do the opposite when the prices move in the way you expected.

This is a wide-spread technique as you can earn money twice by shorting one and long the other. But the risk is also higher. Instead of earning the double you could lose the double.

- Mean Reversion, Scalping and Index fund Trading

The principle of Mean Reversion is based on historical information. By determining the range of price of a security for a determined period, you can calculate the average trading price of one share. Then if you rely on the historical data, you will buy when the price is below the average trading price and sell when it's above. (Butler 2016)

An Index fund replicates the price of an indices or a commodity. To be accurate, it needs to readjust its portfolio at some points. Following the regulations of the market, they release their changes plans a long time before they trade so that they keep their investors well informed. This information creates opportunities for traders to trade before an index fund is adjusted. That means if you know that this index fund will soon buy this specific commodity for example, then you want to buy it as soon as possible because it will soon go up. An explanation to this theory is that the trades announced by index funds are usually huge and will create movement in the market. If you know that a lot of buy order will be placed on the market, then you know that the price will rise at this moment. So, you can buy now that its not too expensive and sell when the price rise. It is the same for the opposite: a huge sell off will lower the prices so you can profit from shorting the security concerned. (Maverick 2015)

Scalping is a strategy that requires a high execution speed (minutes, seconds, or even less in the case of algorithms). It is mostly used by professional traders. The principle is to go long for very short time and then you sell when a small difference in a price occurs. The profitability here is possible because of the huge amount of money invested and the high amount of trades completed within a day. Relying on historical data, the trader will decide the trades by the possibility of upward movements. This consists of not waiting when a share price goes up, profit from a lot of small gains. (Milton 2016)

- High Frequency Trading

High frequency trading is a considered as a type of trading and is also the strategy associated to it. Nowadays it is the most common and influential form of algorithmic trading. It relies on the speed and number of the trades to generate profits. The faster the better

The first three strategies can be used as well by human as by machines, whereas the speed required by the last strategy is not available for humans.

3.2 High Frequency Trading

Time is the main target. We are not talking here about seconds, not even milliseconds. A trade operated by this kind of algorithm represents microseconds, less than a blink of an eye to be concrete. Time has always been a competitive advantage when talking about trading, even before the invention of the computer. From the beginning of the financial system, the pace at which you collected the information was determining your capacity to be the best. It all started with the telegraph, one of the first major technology in matter of telecommunication. However, what we are experiencing now is another level of development. It all started after the crash of 1987 when the Small Order Execution Systems were put in motion. Indeed, the Small Order Execution Bandits exploited this new system by doing a lot of trades that were individually slightly profitable. Originally built to help individual investors, it opened opportunities for fast-paced trading.

HFT is a form of algorithmic trading that requires a lot of facilities. To perform algorithmic trading, you need algorithms that will trade automatically. To trade at a high frequency and be competitive, you need those algorithms working on a sub-milli-second basis. So, you don't only need good coders but also performing infrastructures.

Michael Lewis wrote "Flash Boys" on the history of the creation and optimization of fibre cable between Chicago and New Jersey. He illustrates how important the infrastructures are in order for HFT to compete. It is not just a matter of little geniuses behind their computer developing codes that are more and more similar to an artificial intelligence, it also requires a lot of outside collaboration. He described the story of Barksdale and Spivey, principal actors in the construction of a fibre cable line between the Chicago Mercantile Exchange and Carteret, New Jersey where is located the Nasdaq Data Centre.

The existing line in 2008 between the two exchanges was not a straight line. Spivey found out that by having a straight line, the exchange of information could be faster by

a couple of microseconds. Estimating that those microseconds were important enough to build an entire new line, he started to think about it. With the help of a construction and a telecom company, he started this crazy project. It was crazy enough that no one had thought about it. Crazy because it required to dig into mountains, hard rocks, get the approval to pass through highways and so on… just to benefit from microseconds. The whole project cost was estimated by Spivey at 300 million dollars. The construction took more than a year and they did their best to avoid the slightest modification of route to have the straightest line possible. They have put a lot of effort to keep it secret as long as possible to not being front-ran[4] by competitors. With the help of a consultant, the estimation of the potential profit made by a bank with this line in a year was $20 billion. They estimated that they could sell to 200 players[5] at $300,000 a month. That means a slightly faster information transfer was worth 10 times the other lines.

Brennan Carley even said that some "would sell their grandmother for a microsecond". (Lewis 2014)

In front of the reality of how powerful this new line was, some buyers had even asked Spivey to double the price to prevent competitors of buying it. They all wanted it but for their own. (Lewis 2014: 15-150)

Nowadays, with the improvement of the computing power, an HFT trader is basically faster than a regulator. Indeed, the pace required to follow all the transactions and activity of those algorithm raises issues for regulators to enforce the laws. It is also the reason why Flash Crash exists. Algorithmic trading made possible the term of "flash crash" and HFT usually makes it worse.

3.3 Role of HFT in the creation of Flash Crashes

High Frequency Trading is very criticized. The reasons are multiple: aggressive trading, black box algorithms, role in Flash Crashes…

"An aggressive investment strategy is a means of portfolio management that attempts to maximize returns by taking a relatively higher degree of risks" (Chen 2017). The way

[4] Front-running is when a trader trades an asset because he has foreknowledge of a transaction that will influence the price of this asset, resulting in a likely profit (Investopedia)
[5] Only 200 because they wanted to keep this line as an advantage on others. If everyone can use it, then it isn't an advantage anymore.

HFT is considered as an aggressive strategy is their association to capital management. The algorithm concerned will invest incredible amount of money without keeping capital to maximize the potential return. To reduce those risks, it will not keep any long positions in the end of the day, in contrary to a classic investor. It usually trades only when the liquidity of the market permits it.

However, it is quite hard to find tangible proofs of how an algorithm works in details. As I said before, the codes used are considered as black box. Companies using it only look at the input and the output but not how the process works. The criticizing of black box comes from the knowledge of the risk associated. As a black box doesn't show the processing of the information, you can not really define an accurate risk evaluation. In addition, the technology used is quite new and the retrospection on the potential risks is till limited. Machine learnings, a lot used now, are algorithm functioning a bit like an artificial intelligence. They learn from the market and from the data they collect. So, knowing what is in the black box is impossible as the algorithm will change and add line of codes itself. (Lewis & Monett 2017) This is the result of artificial intelligence researches, especially machine learning. Machine learning is described as a subset of AI, it is an algorithm that learns itself but is not considered as an AI because it not enough developed. The fact that it changes the code itself would require a constant check from the engineer but sometimes they can not even understand why the algorithms write those lines. In addition, as those algorithms are not AI, they have trouble reacting to unknown situation. This lack of adaptation is what creates glitches.

Lack of information concerning process and risk make HFT dangerous. The examples given in the previous part are proves of its impact. Indeed, algorithmic trading is the factor creating those Flash Crashes. We demonstrated that the origins of a crash are usually uncertainty in the market. Bad news, bad week of trading… have all an impact on the creation of a crash. However, the speed at which a Flash Crash occurs can not be created by let's say human traders. Looking at the volume of trades responsible of the price's movements, you can deduce that computers has a part of responsibility.

HFT is nowadays responsible of more than 75% of the market trading volume (variations depending on the studies and medias). It makes it the majority actor of the market. Interactions between the human trader and the machine is not always a good mix. When the fear and uncertainty enter the market, human nature has a tendency of selling its assets to buy hedges and counter a fall in the market. An algorithm response to volume,

liquidity, trends and more. So, when a huge movement appears in one of these factors, it can create glitches resulting in crashes. A machine learning is not considered as a true artificial intelligence as it has some trouble taking the right decisions in front of unknown situations. A huge sell-off movement can represent this kind of situations. If the algorithm doesn't understand what is going on, it can either follow the movement, stop trading or whatever. Imagine the 75% of the market volume reacting by stop trading or follow the movement. This create a snowball that send the market into a fall. Then imagine that those 75% of the market has the capacity to react in microseconds. That's how in minutes you can have losses of trillion of dollars.

However, Flash Crashes are also characterized by the pace at which the fall recovers. HFT makes it fall, but also gives it back liquidity when the market is low. Cheap stocks, traded below average prices, makes algorithms buy again and replenish the liquidity on the market. It can actually be very profitable for those algorithms. HFT can be essential in order for the market to recover fast enough to not fall. Market Makers use HFT to bring liquidity to the market and compensate sell-off.

Several times HFT has proven that they were able to beat the entire market. On the 6th of May 2010, one guy tried to spoof the market and created a flash crash because the volume of trades generated was too fast for the exchanges to maintain the order flow and proper pricing adjustments. It happened the same on August 22, 2013 and May 18, 2012 when trading has been paused for certain shares because of too high volume or glitches in the pricing system.

3.4 Potential Power of HFT

To illustrate the issue generated by HFT and highlight the scale at which those algorithms can have impact on, Knight Capital is a company interesting to look at. Knight Capital Group LLC was an American global financial services firm. It was mostly known for its high-frequency trading algorithm as it allowed them to become the largest trader in US equities in 2012. He was responsible of 15% of the shares traded in the US. This year was also, unfortunately, their worst year reported due to a trading error.

On the 1st of August 2012, the company has registered a loss of 440 million dollars due to an algorithm mistake. This day, they implemented an update of existing algorithm in their trading system. This was part of their HFT strategy. In a matter of minutes, Knight

Capital was possessor of 4.5 billion dollars in action. The origin of this error is a response from the company to a new dark pool implemented by the NYSE. Dark pools are similar to stock exchanges as they provide trading services but have the advantage of being private markets and avoiding information to be public. It was originally created to allow big trades without interfering with a stock price. With the development of algorithmic trading and the importance of information, dark pools have developed a lot because it avoids the risk of being front-ran and it usually lowers trading costs. It now represents more trading volume than every public stock exchange in the US. The NYSE, who wanted to exploit this potential source of revenue, started to create its own. In June 2012, it received the last approval needed from the SEC to launch Retail Liquidity Program, the dark pool of the NYSE, and announced it would open on the 1st of August 2012. They literally gave less than 2 months to prepare.

Knight Capital Group LLC's director Thomas Joyce decided to take the opportunity to enter the market and started the development of its current algorithm Smart Market Access Routing System (SMARS)[6] to fit the new environment. This HFT algorithm was reconfigured to add a "RLP" component to the code and transform an old unused part of the code called Power Peg so that I wasn't used. The week before the launch of RLP, an engineer uploaded the eight servers of SMARS with the new version. Unfortunately, with the limited time associated to this project, no verification and test have been done and that the engineer made a mistake during the installation by deploying the right code to only 7 of the 8 servers.

When the dark pool went live, the mess started. The confusion created by the engineer's mistake and the changes of the code started to processing millions of orders that were not intended. What happened is that the changes in the code for the 7 first servers activated the Power Peg part of the code in the last server. As the main strategy of this code was to buy high and sell low (strategy to manipulate a market and induce changes), the millions of trades were set up in the way of this strategy. By buying and selling huge amount of trades making losses, the company attained a loss of 4.5 billion at the lowest point of the day. Indeed, the result of this strategy was the stop in the trades, as the SEC regulated it after the 2010 Flash Crash with circuit breakers. This stop had the consequence of lowering the share prices, so lowering the value of the investments. 30 minutes after the opening of the stock exchange, engineers had found the problem and

[6] SMARS: HFT algorithm built by Knight Capital that was able to execute thousands of orders per second

shut down SMARS, but the company was in huge troubles. In a week, the stock price of the company went down by over 70%. The positive thing here is that they limited their losses to 440 million dollars at the end of the day. The next week, several investors raised 400 million to save the company and Getco LLC, one its competitors, merged to become KCG Holdings. (Tabbaa 2018)

A catastrophe here has been avoided but looking at the example show the impact HFT can have. One mistake, from one engineer, and a company could have registered a loss of 4.5 billion dollars in 30 minutes. Considering that there were 8 servers, what would have happened if the error would have concerned 4 or 5 or 6 of the actual servers? A new technology needs to be tested and verified before being used. It was like putting a plane on the market and make it transport people without have been tested before. It enhances another example related to the power of HFT.

Michael Lewis in his book Flash Boys, describe the story of a Russian engineer and informatician Serge Aleynikov. He started to learn computer engineering in his home country with limited screen time. Russians were known to be good for coding because of this limit of time, that forced them to build optimised lines. When Goldman Sachs hired him, it was because he was one of the best in his category. HFT is about speed as said before. The shorter the code is, the faster it is. So, if you could build optimised algorithm, you were valued millions. Russians, with a limited screen time, were forced to think about the shortest possibility, which was High Frequency Traders are looking for. Serge Aleynikov worked at Goldman Sachs for a while and worked on the development of their system. However, he didn't like the spirit of the company and left. When he came back to his home city, the FBI was waiting for him in front of his plane. The reason was the fact that Aleynikov was saving his work on personal devices and Sachs considered it as an act of thieve because they didn't want him to use what he did for the company. This accusation was based on intellectual property rights of the company. When you sign a work agreement, there is usually some mentions of property rights and confidentiality. As he was not a part of the company anymore, he wasn't allowed to keep any of his work at Goldman Sachs. 'He had in his possession computer code that could be used to manipulate markets in unfair ways' One of the biggest banks in Wall Street had the power to manipulate the entire market with HFT, that means everyone using this strategy was technically capable of the same. That is maybe the first time you could see how powerful this technology could be. The prove of power here is

not the will to protecting their Intelligence property, as it is a common use for corporation but the pace and the scale at which they acted is a prove of the power of the information held by Aleynikov. Having the FBI waiting for him less than a week after he retires is impressive. Goldman said they didn't want it to be in "bad hands", but that means they could use it to manipulate markets in their favour, right?

3.5 Market changes due to HFT

This new technology has had big impacts on the market. Stock exchanges as we knew before are no longer the same and the rules have changed. In finance, you always learn to higher your earnings and lower your risks. HFT has found a way to do as big banks years ago: lower the risks. Big banks during the last financial crisis weren't impact as much as the owner of bonds. Indeed, when people were losing their houses, executives were earning bonuses. Some traders may have loosed their jobs, but they could find another one without too much difficulties. The government even paid for the debts that those financial institutions couldn't pay back. So, in the end, bankers earned money whereas tax payers were paying for the risk taken by them. That first revealed the unfairness of the financial system.

Now, with HFT, you add another layer of risk delegation. You have first, the tax payer, then the banks, and then on the top you have now HFT firms. Michael Lewis explain this change with the example of flash crashes. During the flash crashes occurring for the last decade, we have seen the consequences on all actors. You can see that HFT firms are the one that lose the less, even win from those crashes whereas banks are more likely to lose money. The reason here is that high frequency trading is only based on intraday trading. At the end of the day, the company doesn't hold any shares. A banker could keep its stocks for 2 days for example because he expects a growth in the following days. HFT uses a different approach that is: you trade when you are sure to make money, let the others take the risks. There is still a question here: Why did I say that the HFT were delegating risks to the banks? Well, the incredible number of trades that an aggressive algorithm does in a day is the answer. We saw before that when a crash occurs, algorithmic traders are the first to react and they usually stop trading if the movement is too important. That means when something goes wrong, your liquidity in the market goes down by the number of trades operated by HFT, which can represent a majority in the market. Less liquidity, price fall, holders of stocks lose money. They

basically avoid the risks and let the others handle it. The transfer of risk between HFT and bank is that classical traders in banks can hold a stock for let's say 2 days, so if the banker has a lot of long position when the market crashes, he loses a lot of value. In addition, big losses usually occur during the night or just before the market opens because of a lower liquidity. The HFT algorithm is not impact by that as it keeps stocks for usually less than 2 minutes and do not keep any long positions throughout the day, everything is sold before the market closes. There is also another reason of the power of HFT. Their speed, above the others, allow them to sell to other investors when a fall is happening, because the transaction will be before the buyer noticed the change. By delegating the risks to banks, I meant here selling them stocks before they fall. It is like selling a CDO [7]that is full of bad unsecure loans, the client doesn't really know what he buys. The game is still the same, the one who has the information can secure himself by using the ignorant people. With the CDO, the ignorance was explained by the length and complexity of the contract. Now, it is the speed at which you acquire the information. We end now with a more complex market, with more unfairness and more differences. (Pflimlin 2011)

[7] Collateralized Debt Obligation: Financial product composed by different cash-flow generating assets building a pool to benefit from better credit rating in the end. It was supposed to lower the risk but ended up causing the financial crisis of 2007-2008 (Investopedia)

4 Reactions to this strengthening technology

4.1 SEC/CFTC changes after flash crashes

Facing the risk of this kind of algorithmic trading, regulators tried to improve the security of the market by passing some laws to limit their impact.

The risks and issues faced because of HFT are:

- Dangerous Volatility
- 90% of the total HFT orders cancelled
- Transparency because of the amount of trades
- Manipulating power

Some laws have been voted to face those situations. Those regulations are composed by trade volume limitation, price bidding limitation, time limits, circuit-breakers… (Spicer 2011)

Examples referring to the volatility issue:

- LULD

Limit Up-Limit Down has been created in 2012 targeting the wild volatility occurring on markets. Already explained before in this study, LULD's purpose it to prevent from trading errors and manipulative trading by cancelling unreasonable orders. This helps in time of high volatility by reducing it. The downside of this regulation is that it doesn't cover intraday crashes caused by reasonable enough orders. As the prices limit are updated all over the day, an order that would have been unreasonable in the beginning of the day can be acceptable in the end of the day.

- Ban on "stub" quotes

"A stub quote is an offer to buy or sell a stock at a price so far away from the prevailing market that it is not intended to be completed" (SEC, 2010-216)

It has been decided after the Flash Crash that stub quotes will be banned. Stub quotes are used for 2 different reasons: market makers than don't want to bring liquidity to a stock so use this technique to fake their contribution to liquidity, or for example when huge price movement occurs to buy very cheap stocks are sell it at a very high price.

This decision counter those two uses and obligate the market makers to put reasonable orders to the market to bring liquidity.

- "Clearly erroneous" trades clarification

"An erroneous trade is a stock transaction that deviates so much from the current market price that it is considered wrong." (Kenton 2018)

Those erroneous trades can be cancelled by the stock exchange if the request is done quickly enough and that it is justified. Usually happening during crashes because of software glitches, it is not normal and regulators try to increase the security of the market and that way not having afraid investors leaving the market.

This feature existed before 2010 but has been a little bit clarified after the Flash Crash to avoid any misjudgement.

Orders cancellation:

- Fees or restrictions on orders

> "Cancellation fees have been introduced by the Canadian regulatory authority IIROC with the explicit aim of curbing high-frequency spam. The Milan Stock Exchange and the NASDAQ Stock Market introduced an excess order fee for high quote-to-trade ratios in April and July 2012 (see SEC, 2012). Cancellation fees are also imposed by Eurex for order-to-trade ratios exceeding 5, on NASDAQ OMX for ratios exceeding 100, as well as on the German stock exchange. The new MiFID2 European Directive also foresees the introduction of cancellation fees to curb excessive quote-to-trade ratios." (Rojcek 2016)

Cancellation fees has been created to fight against the large number of cancelled orders especially by HFT. An estimate of 90% of the orders of HFT algorithms are cancelled. This creates fake liquidity and by applying these fees, regulators expect to obtain a more transparent and accurate market. (SEC 2019)

Transparency and manipulating power:

- Large trader reporting

> "Requires large traders: Transactions in securities exceeding 2 million shares or $20 million in a day, or 20 million shares or $200 million in a month; to identify themselves to the Commission. That way, they will have to give some information and be more traceable. Effective date: October 3, 2011" (SEC)

The commission requires important actors of the market to give precise information about their activities. As we seen before, the technologic development makes it hard for regulators to control everything happening on the market. This is a way of facilitating the controls.

- Consolidated audit trail

The consolidated audit trail has been proposed right after the Flash Crash of 2010. It is a continuity in the large trader reporting. Since 2014, the plan called CAT NMS plan has been modified a lot and has been approved by the SEC at first in 2016, even if some changes have been made before. 5 years it has really started and it is still not operational. The objective is to build an audit software to analyse every trade done by the most important traders in the market to be able to control and follow new technologies. Originally supposed to start collecting data from industry members in November 2018, delays have postponed it to April 2020 for now for large industry members, and April 2021 instead of November 2019 for small ones. Regulators had expected this project to be simpler to execute. (CATNMS Plan 2019)

When you look at the details of the events occurring during a Flash Crash, you can see the contribution of the SEC and CFTC in the control (or at least tentative of control) of the drop and recovering processes. But even if they have an impact, Flash Crashes still exist and according to MarketWatch, 12 mini flash crashes[8] are reported every day in average. Those anomalies reported by algorithmic trading systems have a big impact on the uncertainty of the market and all the actions taken by regulators have not suppressed those events. For now, the law enforcement is failing to its mission, even if the market is going up since 2009.

Circuit-breakers have shown their weaknesses. For example, for securities traded in several markets, it is not efficient. A circuit-breaker act only on its stock exchange, so when it stops the trades on one security like a currency, it doesn't stop it to be traded on other markets. Another point is the mentality of the market, if traders are feeling selling anyway, they will carry on as soon as the trades become available again.

[8] Mini Flash Crashes is related here to important price movement appearing on only 1 security. It's the same event as a flash crash but at a smaller scale

4.2 Technological Balance

The technologic advantage given by HFT increase the differences on the market. Even the SEC have trouble controlling it and following the activity of all the actors of the market. Worries have been raised concerning certain uses of algorithmic trading and the fact that a lot of actors possess this technology now is even more worrying as the computing power represented is in the hands of the big actors on the markets. Too much HFT could be meaning the raise of fraud and manipulation as the regulators can not follow all the trades happening.

Another solution has been tested in the US by the official opening of the Investor Exchange (IEX) in 2016. IEX is a stock exchange that went public in 2016, competing against others like Nasdaq and the NYSE. This market targets equality of chances for all investors by imposing 350 microseconds delay on every trade. The NYSE has beginning to do the same but only for small and mid-cap company shares. Other countries such as Japan, France, Finland… has imposed a taxation on cancellation of some trades under certain circumstances to avoid market manipulation. All of those changes help reducing the risk of Flash Crashes but it has to be worldwide actions and there has to be more like these. The US impact the entire economy and the example of the two flash crash in a month, in December and January, are a prove that the market is becoming even more unstable.

The IEX tries to put aside the disadvantages and unfairness of HFT. However, it shows that HFT is not all bad a negative as it only restricts aggressive and predatory strategies. Indeed, the policies of the exchange mainly target predatory strategies as they bring the more unfairness on the market by overusing their competitive advantage which is the speed of the data sourcing and trading execution. (Mc Crank 2017)

5 Conclusion

High Frequency Trading has become an important matter on financial systems. Raising issues and risks such as illiquidity momentum, volatility peeks, multiplying the scale of some events. HFT are subject of controversy.

Flash Crashes are proofs of these defaults in the financial system. Establishing a quantitative evaluation of the power of HFT is complicated but the analysis of crashes can bring estimates on the potential consequences of a failure. Things have been tried to counter glitches and frauds, but it is still occurring. HFT have such an incredible power that it's quite hard to control. Is it reasonable to let those companies have such a power that they could make the global financial system?

However, HFT is not the original cause of crashes. Even if they can modify their codes themselves, they are still created by someone, by a human. So, by definition, the machine cannot really have any responsibilities. It still creates glitches, increase volatility during bad times, accelerate the falls, higher the scale.

By accelerating the growth of finance, it creates more and more unwanted consequences. Perhaps it's not a surprise. When you consider that Charles Mackay, in 1852, came with the theory of bubbles and crashes saying that when the growth is too important then it will crash at some point. The technology makes this phenomenon faster and faster, that's why there is more and more of those flash crashes. It's quite similar to the industrialization. Machines have been developed to produce faster and improve profits. Now, we just took into consideration that the idea was maybe not the best as we are destroying the resources available that will one day disappear (non-renewable energies for example). The growth of the market does not look sustainable when we consider economists saying that a 10% loss in the market is just considered as a "correction" and that they are worried about a potential new financial crisis incoming. The development of the market induced by algorithmic trading could harm it faster and with more impact. (Salmon 2012)

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