ERASMUS UNIVERSITY ROTTERDAM

Bitcoin

A closer look on the technical aspects, volatility and bubble characteristics of the first mover in cryptocurrencies

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This thesis does a broad analysis on the first mover in cryptocurrencies: Bitcoin. Tests are performed to offset Bitcoin's return and volatility to technical aspects, government interventions, release of GPU's and Bitcoin splits. The results yield no strong economic and financial links with Bitcoin's return and volatility to the dataset. Bitcoin is a unique type of asset that shows erratic price and volatility movements that is hard to grasp with conventional economic and financial theory.

1. Introduction

Eight years ago the person under the pseudonym Satoshi Nakamoto introduced the world to a new alternative to fiat currency, Bitcoin[1]. The first cryptocurrency has since the introduction in 2009 experienced a wild ride into today. Nakamoto introduced the bitcoin in a 2009 paper called: 'Bitcoin: A Peer-to-Peer Electronic Payment System' (Nakamoto, 2009). The paper describes a decentralized currency, meaning that no intermediaries such as banks are used for transactions. For proving transactions crypto graphical computations are used in the network of users. While Nakamoto introduced the Bitcoin as a form of payment system that is controlled in a decentralized environment, the Bitcoin is increasingly adopted in the real economy as a currency (Usebitcoins, 2018).

Recently the Bitcoin market has peaked at an all-time high. On 17 December 2017, Bitcoin had a total market capitalization of roughly 327 billion USDs, giving Bitcoin a price of 19536 USD. Also interesting to note is the trade volume at that time. The 24 hours trade volume of Bitcoin was 14 billion USDs. This is an enormous rise compared to the same statistics one year prior to this peak. On December 17 2016, Bitcoin roughly had a market cap of 13 billion USDs and a price of 790 USDs. Also the 24 hour trade volume was only 82 million USDs at that point in time (coinmarketcap, 2018).

Bitcoin has seen some explosive price behavior in the recent years. High volatility and steep price peaks can be observed. After the all-time high in December 2017, Bitcoin's price shortly after halved again to a level of about ten-thousand dollars. These boom and bust cycle like trends have happened more often for Bitcoin, making the cryptocurrency infamous for the volatility and seemingly erratic price behavior.

When looking at google trends in figure 1, the recent hype around Bitcoin is easily recognized. News outlets, journals, academics and (financial) institutions frequently write about the subject.

[1] In this thesis, Bitcoin with the capital B represents the technology and cryptocurrency as a whole, while bitcoins with a lower case b represents individual units of bitcoin.

Figure 1. **The popularity of the search term 'Bitcoin' over a period of 12 months (trends.google.com/trends). The higher the score is, the higher the relative popularity of the search term.**

Starting with news outlets, the term Bitcoin is no longer a term that solely caught the interest of technical people to mainstream investors (Rudegeair & Otani, 2017). With the hype around the subject of Bitcoin and cryptocurrencies in general, speculation arises on the fundamentals and value of the coin. Economist Robert Schiller argues in the New York Times that investing in Bitcoin resembles gambling (Shiller, 2017). He further argues that in the present hype, no proper appraisal of the value of Bitcoin can be made. While the term Bitcoin is more known to the general public and investors, the technological knowledge on cryptocurrencies is lacking. According to Schiller, the efficient market theorem does not apply to Bitcoin given the large price swings and liquidity problems in the sell-side of the market.

The Bitcoin market indeed has experienced large swings. This in turn has given rise to speculation about a present bubble. Schiller is pessimistic about the future of Bitcoin in the before mentioned article due to the high uncertainty about adoption and other movers in the cryptocurrency market. John Cochrane wrote an article on his website on the bubble speculations (Cochrane, 2017). Of course, Bitcoin is not an ordinary asset. It does not generate dividends to make investing in it a rational decision. However, Cochrane speculates on the idea of Bitcoin holding some sort of a convenience yield, implying that having Bitcoin opens the owner up to the possibilities of tax evasion and participating in illegal markets. The anonymity of Bitcoin may also add to the convenience yield, Bitcoin can be used for evading capital controls and therefore making offshore transactions through China possible. Added to this convenience yield, Cochrane adds a speculative demand and a lack of the possibility to short-sell Bitcoin. Once these reasons to hold Bitcoin fade, the bubble will burst.

Of course, the recent boom of Bitcoin and the concept of cryptocurrencies in general have gained attention from large financial institutions. Recently, trading Bitcoin in the financial markets gained more traction through the introduction of future-contracts on the Chicago Mercantile Exchange, the CBOE Futures Exchange and the Cantor Exchange (MoneyandBanking, 2017). The rise of Bitcoin and the concept of cryptocurrencies have led institutions to form an opinion on the matter.

Starting with the European Central Bank (ECB), Vítor Constâncio argued in a speech that crypto-currencies can never prevail as general money substitutes (Constâncio, 2017). Interestingly, Constâncio describes Bitcoin as a speculative asset and not a currency, since it cannot be generally used as an item of exchange. Furthermore he speaks about the consequences of adopting block chain technologies by central banks to create digital currency, disrupting the banking system as we know it.

In the US the focus of the Federal Reserve regarding Bitcoin has been targeted to the dangers to the financial system and the risk of cryptocurrencies (Hamilton, 2017). He urges central banks to be careful implementing digital currencies but does want to adopt new technologies as long as they can be rendered safe. The main problem with Bitcoin is the decentralized nature of it, resulting in financial institutions being unable to control the coin.

For a more complete overview of the stance of central banks on Bitcoin and cryptocurrencies, Bloomberg recently provided an overview (Lam, 2017). While the general consensus is that Bitcoin should be approached with caution, the stances range from straight up calling Bitcoin a tulip (referring to a 17th century bubble in the market for tulips in the Netherlands) or seeing it as a positive technological revolution.

1.1 Research question and hypotheses

Since the first introduction of Bitcoin the market has drastically changed, especially in 2017 we have seen a boom in the market. Some research has been performed on the technical aspects of Bitcoin, the recent hype and boom of Bitcoin demands new research. This thesis will have a broad financial perspective on the first mover in cryptocurrencies. The research construes an analysis to comment on the bubble speculation that is currently present. The research question of this thesis is:

"To what extend is the value of Bitcoin driven by technical aspects and to what extend is the value driven by speculation?"

The research question constructs a more complete view of Bitcoin than a simple yes or no answer on the bubble speculation. A broad dataset with technical aspects of Bitcoin and market variables will be selected to test if Bitcoin's return and volatility have a connection to economic variables.

1.1.1 Hypothesis 1

A well-known aspect of Bitcoin is that it is a very volatile asset. This thesis has a focus on finding the drivers of this volatility and the return of Bitcoin. When it comes to technical drivers, there is even reason to suspect that Bitcoin has no fundamental value and is purely based on speculation. An argument can be made for describing Bitcoin as a digital form of gold, with the price being driven by scarcity and demand.

In order to find potential links with technical factors, Bitcoin will be offset to other bitcoin data and other assets. This makes hypothesis 1:

"The price and volatility of Bitcoin is driven by technical factors."

Schiller argues that no rational value on be put on Bitcoin (Shiller, 2017). Still, underlying Bitcoin is the process of mining Bitcoin. Real costs are made for mining Bitcoin, increasing over time. These costs mainly consist of electricity, which in turn can be a driving factor for the price of Bitcoin. Other technical factors that will be examined are market fundamentals.

1.1.2 Hypothesis 2

The market of Bitcoin was targeted to being a decentralized market where institutions would not play a role. With the boom of Bitcoin institutions are not only forming an opinion on the consequences for the financial system, but also policy makers are threatening to intervene on some exchanges (Cho & Lam, 2017). Apart from potential fundamental value of Bitcoin, this thesis will research the potential shock effects that large news headlines like the threat from South-Korea has on Bitcoin. Potential shock effects of government interventions will be tested in the following hypothesis. Hypothesis 2 of this thesis is:

"Large swings in the price of Bitcoin can be explained by shocks from government interventions."

1.1.3 Hypothesis 3

A large part of the Bitcoin technology involves the process of mining. In this process, the miners subject their hash power to the network. Hash power is the power of calculations done by their used hardware, for example a GPU (general processing unit). The reward for mining is bitcoins. Mining is useful, since the calculations are done to check Bitcoin transactions and place them in the block chain. Although the mining community uses multiple different mining setups, we can see innovations in the market for mining setups that produce more hash power at lower cost. The Bitcoin network chooses the difficulty of mining given the attributed hash power to the network, setting ten minutes to produce a block as a fixed target. This leaves the expectation that there can be temporary competitive advantages between miners leading to shocks in the return and volatility of Bitcoin. This makes hypothesis 3:

"Bitcoin mining hardware innovations lead to shocks in the return and volatility of Bitcoin."

1.1.4 Hypothesis 4

The Bitcoin framework and technology has seen innovations in the form of Bitcoin splits. These splits (forks) develop a new set of rules for the digital currency, and trace back these changes to the entire block chain. An example of these splits is Bitcoin gold. The creators of this separate form of cryptocurrency within the Bitcoin framework developed Bitcoin gold in order to deal with the scalability issues Bitcoin faces. They found the technology would improve if the block size would be increased to 8mb per block (Frankenfield, 2018). This thesis will discuss the recent and most important splits made in the Bitcoin technology. The goal for these splits is to improve Bitcoin and therefore replace Bitcoin with a superior framework. If the splits are successful we should expect a substitution effect. Hypothesis 4 of this thesis is:

"The introduction of Bitcoin splits leads to a substitution effect."

Using dummies for the release dates of the splits, the potential substitution effect is tested.

The rest of this thesis will contain the following parts: part two will give a theoretical framework around Bitcoin and cryptocurrencies. Part three will summarize the data that is used and the means of collection. Part four shows the methodology used to find the results shown in part 5. In part 5 the hypotheses will be answered. Part six gives a conclusion on the research question. Lastly part 7 and part 8 show the appendices and bibliography.

2. Theoretical framework

2.1 Bitcoin: a peer-to-peer electronic payment system

Bitcoin is the first mover in the field of cryptocurrencies. The crypto part of the name cryptocurrencies refers to the digital proving that is used to verify transactions. When looking at normal currencies, we use trust and relying on financial institutions to verify transactions.

Nakamoto proposes a decentralized coin that is basically a chain of digital signatures in chronological order (Nakamoto, 2009). An owner of a certain amount of bitcoins can transfer it by signing it with a hash of the previous transaction and therefore proofing that this person in facts owns that amount of bitcoins. Furthermore the anonymized identity (public key) of the recipient of the transactions is added as well. This can then be used as a proof of ownership in following transactions. In order to mitigate the risk of people trying to spend money that they do not own, a public record of all transactions is kept. Transactions are only accepted if the majority of the network agrees that the person performing the transaction is the rightful owner of the coin. All transactions are put in so called ‘blocks’ and stored under a hash when the network has verified the transactions.

2.1.1 Mining Bitcoin

The incentive for the network to verify transactions in a decentralized manner as described is the concept of ‘mining’ coins. Similar to mining gold, the person invests energy and therefore bears costs by building a new block. As a reward the miner receives bitcoins. This fee for verifying the transactions of the network can be funded through transaction costs. The size of the transaction cost is dependent on the willingness of miners to invest energy to verify your transaction and therefore has a trade-off between the size of the transaction fee and the speed of the transaction. Figure 2 shows a schematic overview of the way transactions are stored in blocks.

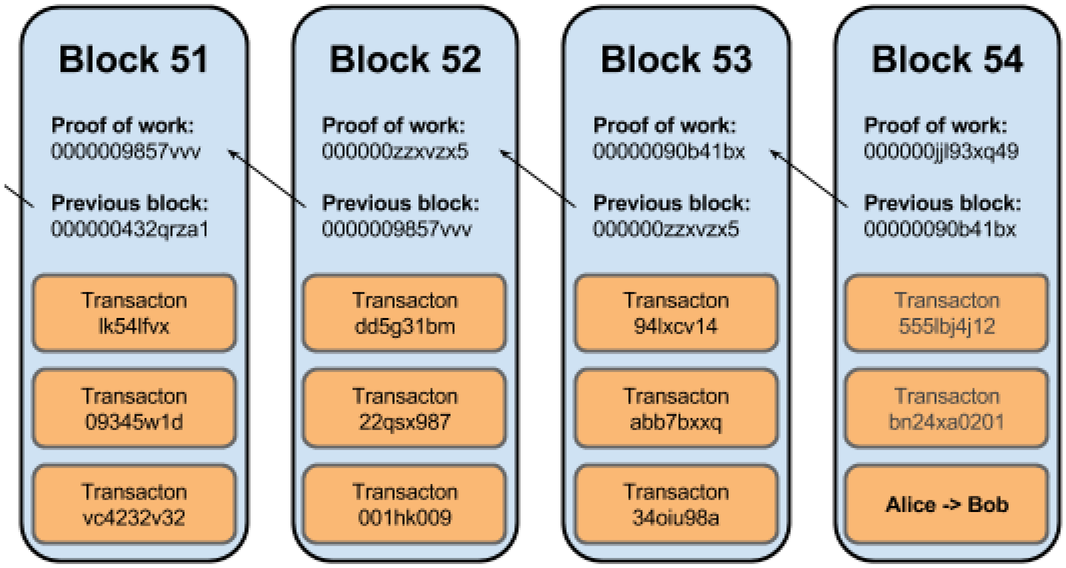

Figure 2. Yevgeniy Brikman, 2014.

There have been different 'ages' for mining techniques. While miners started using their central processing unit (CPU) for mining, they quickly found that the graphical processing unit (GPU) is more suitable for mining since it is faster at 'hashing' data. Currently, the most competitive hardware for mining bitcoins is the using an application-specific integrated circuit (ASIC). This hardware produces the highest speed at while consuming less power (bitcoinmining.com).

The Block Reward is the amount of bitcoins received for completing a block in the block chain. This reward is halved roughly every four years. Currently the reward is at 12.5 bitcoins per block (Draupnir, 2016). The moments where the reward is halved will be added in the analysis since there are potential effects to both the price of Bitcoin and the volatility.

Bitcoin mining has a constant difficulty target of ten minutes per block. If the contributed hash power from the network is increased, leaving everything else constant, blocks would be discovered at a faster rate than ten minutes. The difficulty will be increased so that the time to find a new block will be around ten minutes again.

2.1.2 Anonimity

An important aspect of bitcoin is the privacy it entails. Since owners of bitcoins are anonymous for the network, policy makers are weary of the way bitcoin can be used for money laundering. A report from the Immigration and Customs Enforcement agent from the United States shows that the currency is used by criminals (De, 2017). In figure 3 an overview of this privacy aspect is shown. While the transactions of bitcoin are known to the network, the identities of the owners of currency are not. Although privacy is a commonly sought for human right, especially in this age, this aspect does implicate some problems for governments. Apart from the illegal activity, having an effective tax system is very challenging when the wealth of citizens is not visible for tax authorities.

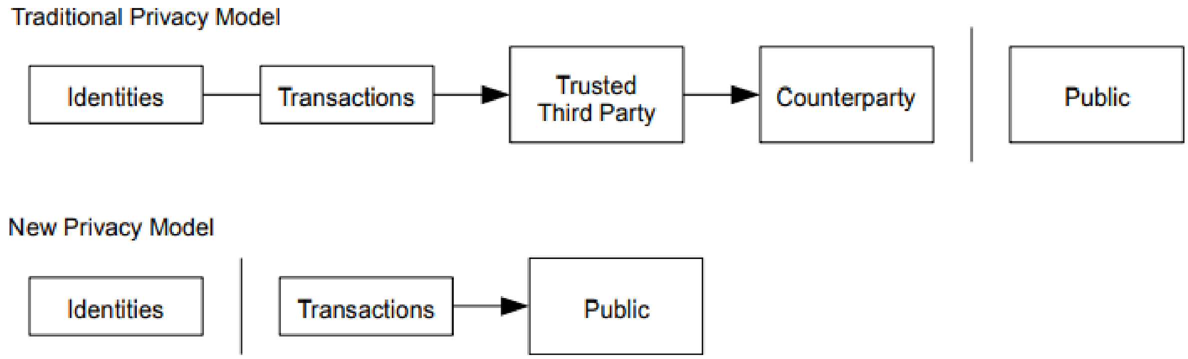

Figure 3. **Nakamoto, 2009.**

2.2 Bitcoin defined as a financial asset

The category that Bitcoin falls under is cryptocurrencies. A debate in the literature and broader is ongoing about classifying it. Extensive research has been done to fit the exchange rate data of Bitcoin in common distributions. Chu, Nadarajah and Chan find that Bitcoin's log-returns best fit the generalized hyperbolic distribution (Chu, Nadarajah, & Chan, 2015). They find that Bitcoin's exchange rate has complicated dynamics. It also had very high volatility and very high return for the observed period.

A more theoretical economic approach to defining Bitcoin has been done by David Yermack (Yermack, 2013). The properties of money are defined as a medium of exchange, a unit of account and a store of value. Bitcoin can be used in some instances as means of exchange. However, transactions predominantly go through middleman and exchanges, accepting bitcoins and swapping them with conventional currencies. An example of a marketplace that accepted bitcoins directly is the silkroad, a marketplace that anonymously sold drugs and guns through the darkweb. In the beginning of Bitcoin, transactions on this illegal site accounted for nearly halve of the trading volume. This meant bitcoins were mainly used for their privacy properties and were used for an illegal niche market. The largest part of Bitcoin transactions are done for speculative investment and transferring from one to another investor. Getting access to bitcoins as a consumer can be quite an obstacle due to making an account, purchasing bitcoins and then safely storing it in a wallet. Lastly, bitcoins cannot be spent on credit, to make a transactions, a person already has to own them.

When it comes to the currency definition, it is also challenging to define Bitcoin as a unit of account. Due to the high volatility and large value of one bitcoin, it is hard for consumers to translate a price presented in Bitcoin to the underlying value. For example, it is hard for a consumer to value a deal on a cup of coffee for 0.00025839 bitcoins.

Bitcoin can also not fulfill the property of storing value. Bitcoins cannot physically be touched and must be stored in a digital wallet. Even though you can argue that using the right digital protection, Bitcoin can be properly stored, the value of the cryptocurrency is still very volatile. It is far from sure that the value paid for the Bitcoin on acquisition is (close to) the same value when selling it.

The market for Bitcoin is still a very young one that faces a lot of obstacles to get general adoption from consumers, merchants and large firms. The currency definition cannot be fit and other obstacles exist. Computer knowledge is needed to use bitcoins, there is no consumer protection in transactions and exchange rate risk cannot be properly hedged. Governments and central banks are reluctant to embrace Bitcoin as a real alternative to fiat currency. Lastly, Bitcoin exchanges can have varying prices and the more popular ones are prone to security breaches (Moore & Christin, 2013).

Aside from the theoretical approach to defining Bitcoin, extensive research has been done offsetting Bitcoin to other major currencies. Figure 4 shows descriptive statistics from Bitcoin and other major currencies (Chu, Nadarajah, & Chan, 2015). Bitcoin shows vastly different behavior compared to other major currencies. It has a higher mean and median, a lower minimum and a higher maximum. This large spread also comes to light when we look at the interquartile spread, the skewness and variance.

Concluding we can see similarities between Bitcoin and fiat currencies, although it does not fully follow the definition. Also while looking at the data; Bitcoin should not be viewed as currency, but rather as a speculative asset with questionable fundamentals.

Statistics	Bitcoin	OZ	BR	CA	CH	EU	UK	JP
Minimum	–0.664	-0.067	-0.118	-0.050	-0.055	-0.046	-0.045	-0.046
First quartile	–0.012	-0.004	-0.005	-0.003	-0.004	-0.004	-0.003	-0.003
Median	0.004	-0.0002	-0.00005	0	0	0	-0.00006	0.00009
Mean	0.005	-0.00005	0.0001	-0.00005	-0.0001	-0.00004	0.00001	0.00004
Third quartile	0.025	0.004	0.004	0.003	0.004	0.003	0.003	0.004
Maximum	0.446	0.088	0.097	0.043	0.085	0.038	0.039	0.037
Interquartile range	0.037	0.008	0.009	0.006	0.008	0.007	0.006	0.007
Range	1.109	0.155	0.215	0.094	0.139	0.085	0.084	0.083
Skewness	–1.503	0.866	0.110	-0.076	0.358	-0.145	0.055	-0.253
Kurtosis	22.425	12.707	13.826	5.765	9.170	2.662	4.413	3.889
Standard deviation	0.069	0.008	0.010	0.006	0.007	0.006	0.006	0.006
Variance	0.005	0.00007	0.0001	0.00003	0.00005	0.00004	0.00003	0.00004
Coefficient of variation	15.156	-157.291	96.649	-108.894	-57.625	-143.498	419.938	147.998

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Figure 4. **Chu, Nadarajah & Chan, 2015.**

2.3 Exchanges

In the beginning after the introduction in 2009, bitcoins were traded privately. Since Bitcoin is a decentralized currency, the market could not be formed by standard institutions. In 2010 Mt.Gox claimed their position as market leader (Brandvold, Molnár, Vagstad, & Valstad, 2015) and held a market share of about 80%. Structurally the market for bitcoins has had some problems. These have been liquidity issues but have also been regulatory issues. Mt.Gox is a leading example of these problems. While they started off as the market leader for trading bitcoins, the exchange had problems with withdrawals during 2013, resulting in a premium to the price compared to other common exchanges like Bitstamp. The high volatility led to enormous spreads between exchanges, with 10 April 2013 as moment where the price of bitcoins was 143% higher at Mt.Gox compared to Bitstamp. After a large hacking operation took place and Mt.Gox announced that large amounts of consumer bitcoins were stolen, more withdrawal issues arise and they filed for bankruptcy, leaving a curator to sell the remaining bitcoins. This is still affecting the market, since a large portion of total bitcoins are yet to be sold, leading to a soaring increase in bitcoin supply (Franzoni, 2018).

What happened with Mt.Gox is not a fluke in the market for Bitcoin. BTC China is another large exchange that has had discrepancies with other exchanges. Following the news that large Chinese companies would start accepting Bitcoin as a form of payment, demand for the bitcoins paid for in Yuan surged. The bitcoins in the BTC China exchange started trading at a premium. This led to a government intervention, through a meeting with the Peoples Bank of China and third party payment companies, shutting down their business with Bitcoin exchanges in China. BTC China stopped accepting Yuan for deposits and the price dropped relative to the rest of the market. What is interesting to note here is that at this time BTC China was not small in the total market. BTC China accounted for about 50% of the market share and still adoption from large companies and subsequently government intervention had such large effects on this particular exchange (Brandvold, Molnár, Vagstad, & Valstad, 2015).

These events raise the question of what factors affect the differences in prices between exchanges. Brandfold et. al. discuss the events that shock the market such as the government intervention in China and the hacking of Mt.Gox. The factors that can also explain these differences are market size, exchange volume, price of entry and currency of trade. They performed research on the major exchanges around the year 2014. At this time Bitcoin has had the first periods of price increases. The researchers find that there are leading exchanges when it comes to price discovery and other exchanges follow after that.

The differences in prices in a normal liquid market should lead to arbitrage opportunities. But the sole fact that Bitcoin exchanges have structural discrepancies in price should already signal that there must be some issue to capitalize on the opportunities. Smith assumes that there should be some form of high transaction cost for Bitcoin (2016). Bitcoin is a uniform globally traded asset, but wanting to buy Bitcoin in other parts of the world is still challenging. Trying to capitalize on the arbitrage opportunities is risky and costly due to high transaction time, transaction fees, trading fees, currency exchange fees and withdrawal time (Brandvold, Molnár, Vagstad, & Valstad, 2015). The development and nature of the discrepancies in price are beyond the scope of this thesis but it is important to note.

In Figure 5 an overview is shown of the recent volume of Bitcoin for the major actors in the market. Bitfinex is currently the market leader when it comes to trading volume. For analyses purposes, the thesis will be using weighted prices of Bitcoin which are widely available. Differences in prices between exchanges will be ignored. Particular events affecting or targeting individual exchanges or countries will be analyzed as being potential shocks to the Bitcoin market as a whole.

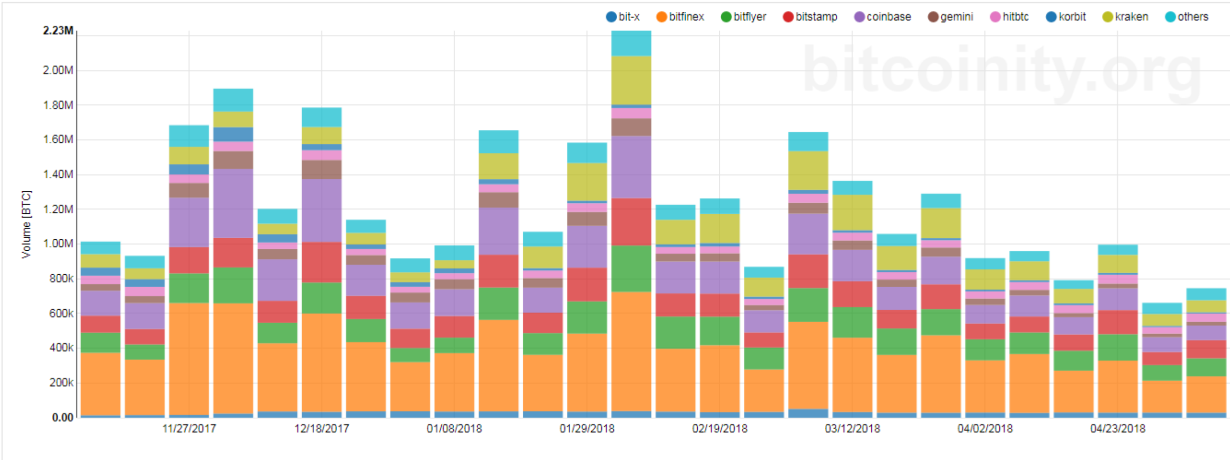

Figure 5. **Bitcoin trading volume (bitcoinity.com).**

2.4 Technical drivers

This thesis has a focus on two categories explaining the price and volatility of Bitcoin: technical drivers and other drivers. As already discussed in the introduction, there is an ongoing debate if Bitcoin has any fundamental value at all. Still, mining bitcoins cost energy and resources must be invested in to receive bitcoins. In this section the techical drivers that will be researched are discussed.

2.4.1 Energy prices

Key to Bitcoin is the energy it consumes. Very simply put, a miner or a mining company would invest in the hardware that is suitable for mining bitcoins. After that, the only variable cost involved is the consumption of electricity. Bitcoin mining does not involve any other variable like investing time or human effort. Criticism is continuously rising targeted at the energy consumption of the network. In real terms, the power used in the network is similar to the energy consumption of the Czech Republic and could power over 6 million US households (Digiconomist, Bitcoin Energy Consumption Index). Bitcoin accounts to 0.3% of the world total energy consumption.

Energy prices are generally denominated as an amount of dollars per Kilowatt-hour ($/kwh). It is virtually impossible to exactly deduct the average electricity price that is paid by miners. As a proxy for energy prices, crude WTI oil futures contracts are used.

2.4.2 Gold

From a theoretical viewpoint, Bitcoin can be compared to gold. Similar to gold, Bitcoin requires effort to retrieve. For gold this is a physical activity and for Bitcoin it is investing hardware and electricity in order to retrieve it. From an investing portfolio standpoint it can be interesting to diversify with cryptocurrencies, since research has already shown that Bitcoin performs similarly to gold when exposed to shocks (Dyhrberg, 2016).

Another factor that is interesting in the context of commodities is the link between Bitcoin and the real economy. In the discussion in the introduction it became clear that Bitcoin has not been largely adopted in the real economy and furthermore Bitcoin cannot be classified as a currency. Commodities like oil can be used as a proxy for the macro-economic environment.

2.4.3 Hardware efficiency

Although this thesis will have a focus on the marginal costs associated with mining bitcoins, the mining hardware plays an important role for Bitcoin. The difficulty of Bitcoin mining is increased as the hash power of the network is increased. Subsequently you can argue that the technology innovations should have no effect on the price of Bitcoin. If new technology is introduced that is more cost efficient, the network will adopt it and mine Bitcoin at the new energy cost. The difficulty of Bitcoin mining will then be increased to the new level of technology, rendering the increased efficiency of the mining pool ineffective.

There could however be a competition alongside miners that leads to temporary competitive advantages. If a miner is the first mover on new technology, the miner will mine at the same difficulty while the process for the individual is more efficient than the rest of the pool. The expectation is that new mining technology has no lasting effect on the Bitcoin price.

2.4.4 Bitcoin Splits (Forks)

The Bitcoin technology is completely open-source. This means that everyone in the network has full access to the implemented technology. The technology is fully decentralized and therefore between users, a debate is ongoing about the technology. This can lead to a fork, where one group of miners wants to keep the existing rules of the network and the other group wants to implement technical changes. A potential change in protocol that can be implemented with a hard fork is an increase in block size. A hard fork is incompatible with the previous standard, whereas a soft fork involves minor changes that are still compatible with the previous protocol.

Figure 6 shows graphically how a hard fork works. A group of miners decides to split off from the old protocol and implement a set of new rules. This still means that the rules will be working retrospectively. This results in all previous transactions still being valid under the new rules. So if a miner had already mined a certain number of coins under the old rules, these coins would still exist after the split, even though the new protocol is implemented.

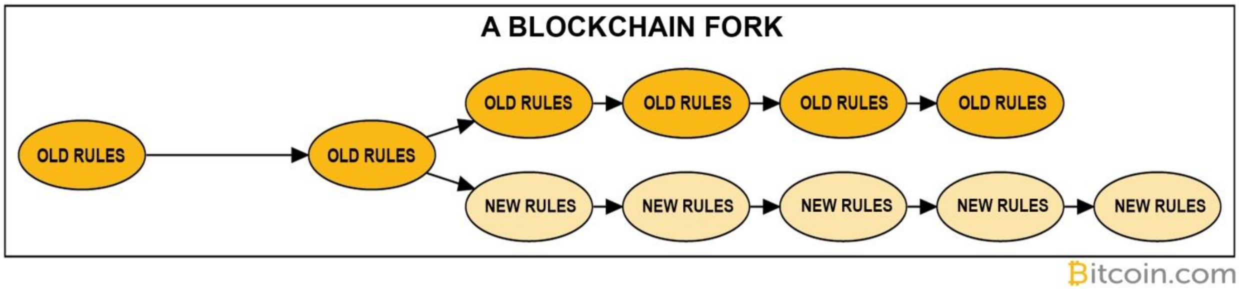

Figure 6. **Bitcoin splits (news.bitcoin.com).**

Using forks, the software used for Bitcoin can constantly be developed, being both an opportunity as well as a threat. Bitcoin has increasing competition from other cryptocurrencies like Ethereum, which is a more energy efficient coin. If Bitcoin would stick to the standard protocol, perhaps the market of other cryptocurrencies beats Bitcoin as the number one choice. Hard forks give the Bitcoin network the opportunity to develop the software within the Bitcoin framework. There is however the risk of fragmentation. There have been a few successfully adopted hard forks since late 2017 and a constant debate over the best form of Bitcoin can lead to uncertainty among users and investors. Here the major Bitcoin splits will be discussed.

2.4.4.1 Bitcoin Cash

Bitcoin Cash was adopted by a set of miners on 1 august 2017. Already introduced in the original paper of Nakamoto (Nakamoto, 2009), the size of blocks should be continuously challenged. The developers of Bitcoin Cash were worried about the scalability of Bitcoin (Frankenfield, 2018). With the increased adoption of users, the waiting time for transactions was pretty high. To accelerate the transaction process, the hard fork of Bitcoin Cash introduced blocks with a size of 8mb. There are however some security concerns for Bitcoin Cash due to the way the difficulty can be adjusted, even with a small network.

2.4.4.2 Bitcoin Gold

Bitcoin Gold was introduced for different reasons than Bitcoin Cash (Song, 2017). Jack Liao wanted Bitcoin Gold to be better virtual gold than Bitcoin through changing the proof-of-work technology (the hashing). At the introduction point, the mining was dominated by ASIC's and Liao wanted to implement a proof-of-work method that was more feasible for the original used hardware for mining, CPU's and GPU's. Introducing Equihash instead of the normal SHA-256 protocol for mining, the enormous competitive advantage for ASIC's over CPU's can be mitigated. Under the standard SHA-256 protocol, ASIC's could mine at a speed that is a million times faster than the hash power of a CPU. The fork was implemented on 24 October 2017.

2.4.4.3 Bitcoin Private

The last hard fork that will be discussed in this thesis is the one of Bitcoin Private. Another reason for a hard fork was introduced here. The developers of Bitcoin Private were concerned for the privacy of users in the network. They changed the protocol in such a way that it incorporates zk-SANRK, allowing for shielded transactions (Brutman, Layton, Sulmone, Stuto, Hopkins, & Creighton, 2018). This allows users of the network further anonymity. This can be attractive since previously data from users had been hacked. With the increased privacy, Bitcoin Private also uses the more GPU friendly Equihash methodology, has larger blocks and smaller block time.

The hard splits of Bitcoin can put pressure on the original protocol, since they introduce solutions for common criticism on the original Bitcoin. In this thesis, the introduction of the splits and there price development will be researched in the light of the return and volatility of Bitcoin. We know that no coin has full support from the network and that there is a competition about finding the best coin. It is worth investigating if this idea is represented in the effect between Bitcoin and the introduced alternatives that use the same history in the block chain ledger.

2.4.5 Transaction costs

Every time a bitcoin transaction is made, a transaction fee is paid. This fee will be send to the miner that verifies the transaction. The height of the fee is dependent on the amount of kilobytes that is required to be stored in the block chain for the transaction. Transaction fees are necessary to insure that miners will be interested in verifying transaction over time, and thus keeping the network secured (Houy, 2014). When Houy wrote his paper, only 0.4% of the miner's rewards were the result of transaction fees, while the rest were giving through new bitcoin creation. Over time, with block rewards halving every four years, the reward for miners will skew more towards transaction fees, this trend is already becoming visible as of now.

Transaction fees are an interesting topic since they have created a market of supply and demand on their own. Every ten minutes a new block is made and added to the block chain. The block has limited space and therefore a limited amount of transactions that can be stored. Of course, miners will choose to add transactions to the block chain that reward them the highest transaction fees. An increasing user base of in the network has driven up transaction fees. There is a high demand for bitcoin transactions, and due to the constraints of the block chain, transaction fees are soaring. These issues are sought to be resolved using a larger block size or smaller block time, which were implemented in the Bitcoin Cash and Bitcoin Private variants.

2.5 Other drivers

2.5.1 News events and trends

As discussed in the introduction, a lot of hype has been surrounding Bitcoin and cryptocurrencies in general. Kristoufek has done some research on drivers of the price of Bitcoin. Using a methodology of wavelets, he researched among other things the effect of Wikipedia searches and google searches on Bitcoins' price (Kristoufek L. , 2015). In a previous study, positive feedback loops were found through social media searches (Garcia, Tessone, Mavrodiev, & Perony, 2014). It is hard to distinguish the reasons for people to search for the word 'Bitcoin' in search engines, but in general we can assume that an increasing interest in the cryptocurrency leads to an increasing interest to actually invest in it. This then increases demand and lastly of course, the price (Kristoufek L. , 2015). Data from 2011 to 2014 was used. Interestingly, Kristoufek found shifting directions of the relationship between the price of Bitcoin and the interest. He found that in periods the growing interest in Bitcoin led to surging prices, such as in a short peak price in the first quarter of 2013. In the early parts of his data, he found that prices were leading the searches.

Using recent data from Google and Wikipedia, this thesis will also describe the continuous relationship between the interest and Bitcoin and the price. If the exceedingly growing interest in the coin over the past years was an important factor in the soaring price, it shows that the price of Bitcoin is largely attributed to speculative interest. Kristoufek poses to already have found a temporary bubble in the Bitcoin price and finds that interest both pushes the bubble further upwards and also supports the bust of the temporary bubble (Kristoufek L. , 2015).

2.5.2 Government intervention

With Bitcoin rising as a more dominant factor in asset value and potentially disrupting the traditional financial system, government agencies and other regulators are keeping a keen eye on the developments. Even though Bitcoin is a fully decentralized currency, it is far from immune to the regulatory environment. For this thesis, the potentially most impactful decision from a regulatory perspective will be added to the dataset.

The most significant government interventions have been done by China and South Korea.
China, as a large player in the Bitcoin market has had multiple moments where it tries to crackdown the Bitcoin market (Bloomberg, 2017). Their first serious attempt was announced on 4 September 2017, where the people's bank of China announced a ban on Initial Coin Offerings (ICO). These offerings had

become a large resource for raising funds for all sorts of endeavors in the real economy. In the beginning of 2018, China proposed further measures. In a statement on 4 February 2018 the Peoples Bank of China announced that it would block access to all domestic and foreign cryptocurrency exchanges and ICO websites.

South Korea announced on 29 September 2017 that it will be banning all kinds of Initial Coin Offerings. Apart from these large events, government and regulatory officials have made statements about Bitcoin throughout the years. There have been negative and positive comments. For example, recently the BIS manager Carstens said there is a strong case for government intervention, ECB president Draghi is ready to act when euro holders get to exposed and Britain's prime minister May is considering clamping down on Bitcoin (Bosley & Speciale, 2018).

2.5.3 Convenience yield

The adoption of Bitcoin has resulted in some ethical and moral questions. Apart from the power usage of Bitcoin, with is similar to the entire power usage of Chile (Digiconomist, Bitcoin Energy Consumption Index, 2018), Bitcoin has more than once been linked with criminal activity. This aspect of Bitcoin is interesting to link to a common part of commodity futures markets, the convenience yield. Like there is value for holding barn in a warehouse, compared to buying it when needed, the same could apply to Bitcoin (Cochrane, 2017). Convenience yield is the benefit of holding an asset. This benefit for holding Bitcoin can be various things and activities. Bitcoin users have anonymity, allowing tax evasion, dealing in criminal goods, other criminal activities and anonymously transferring capital across border.

In a recent study researchers found that almost halve of the Bitcoin transactions are related to illegal activity (Foley, Karlsen, & Putnins, 2018). For this thesis of course it is virtually impossible to quantify the convenience yield, because of a lack of data. If there is a convenience yield for Bitcoin, it can be substantially attributed to illegal activity and can therefor explain a part of the value of Bitcoin.

2.6 Bubbles

2.6.1 Bubble theory

As mentioned previously, researching Bitcoin's financial data goes hand in hand with the concept of bubbles. We can define financial bubbles as the drift of prices from fundamental value (Phillips & Yu, 2011). In Bitcoin's respect, one can argue that it has no fundamental value and all value can be attributed to a bubble. Still this thesis makes a distinction to potential fundamental drivers and speculation on Bitcoin resulting in a bubble forming. Since there is no economic rationale to the sudden high returns and subsequent price increases, a collapse is in theory inevitable. Another bubble characteristic is high volume trading in both the forming period and the collapse.

In respect to Bitcoin and general interest affecting price and return, positive feedback loops from searches have been found (Garcia, Tessone, Mavrodiev, & Perony, 2014). Kristoufek also found that the boom and bust cycles of Bitcoin can at least be partially be explained by the interest in the currency, in other words: the hype (Kristoufek L. , 2013).

2.6.2 Rational bubbles

In basic finance theory, assets are valued at the discounted stream of future dividends. For Bitcoin, similar to gold, no dividends are generated. Any other observed value we do not attribute to fundamentals and are seen as bubbles (Meltzer, 2002).

The concept of a rational bubble is that of a lasting drift from fundamental value for a particular asset in a particular time span. Independent of fundamental factors, the discounted future value of an asset must be equal to the value of the asset today. In this concept, the bubble is not expected to collapse for a certain time period, which makes selling the asset today not the only rational thing to do. To test the rational bubble hypothesis is however nearly impossible (Meltzer, 2002).

Another theoretical difficulty in attributing rational bubbles to assets is the property of an infinite increase in value. We discount future bubble value of the asset to today into infinity, making the assets exceed the worlds GDP in time. For Bitcoin a temporary rational bubble could in theory exist. If we assume the soaring Bitcoin price is partially caused by a bubble, this bubble could be a rational bubble. With a rational bubble, the use of the Bitcoin network increases in the near future and the value of being able to make transaction with bitcoins increases, the value can be expected to increase. The concept of convenience yield can be used in this regard as well.

3 Data

The largest part of the data will be Bitcoin data. Furthermore other variables must be retrieved. Large news events and government interventions must be hand collected through search engines in order to research their effect on the exchange rate on Bitcoin.

3.1 Bitcoin data

With Bitcoin being a decentralized currency and heavily dependent on the network and community surrounding it, Data is largely publicly available. For the data on Bitcoin, Chu, Nadarajah & Chan (Chu, Nadarajah, & Chan, 2015) suggest to use the Quandl database. This database contains daily updated data on exchange rates for a large number of cryptocurrencies, of course Bitcoin included. An alternative used in this thesis is coindesk (coindesk.com). They provide a Bitcoin price that is consisting of an average between the major exchanges of Bitcoin. For this thesis the daily price data from coindesk is used. As an unbiased measure for volatility, the absolute return of Bitcoin is used (Andersen, Bollerslev, Diebold, & Ebens, 2001). The proxy for Bitcoin volatility is calculated as follows:

$$Equation\ 1{:}\ Bitcoin\ volatility = \left| LN\left(\frac{Price_t}{Price_{t-1}}\right) \right|$$

Data on transaction costs, transaction volume, number of transactions, mining difficulty and hash rate can be retrieved from blockchain.info. Data is available from the start of 2009 and onwards, the period that will be used for this thesis is 1 april 2016 until 10 may 2018. The other bitcoin data from blockchain.info is updated on a two daily basis. A recent dataset is used since the large usage growth and important innovations in Bitcoin happened recently.

Data from the Bitcoin splits is collected from coinmarket.com. The site supports data on daily price data for Bitcoin Cash, Bitcoin Gold and Bitcoin Private since their introduction. Similar to the normal Bitcoin price data, equation 1 is used to calculate a proxy of the volatility of the Bitcoin splits.

3.2 Market variables

From the Quandl database commodity data can be retrieved (www.quandl.com). Daily data on oil prices is gathered using the WTI crude oil future contract. Furthermore the daily spot price on gold is taken from the Quandl database. Lastly the VIX index, as a measure for option implied volatility and financial stress on global markets is added. Daily adjusting closing price data of the VIX index is retrieved from finance.yahoo.com.

3.3 Trends

Trends and interest can be measured following the interest in the topic of Bitcoin for the websites Google and Wikipedia (Kristoufek L. , 2015). Google has some tools to be able to capture momentary large interest in Bitcoin through a certain event (trends.google.com). Therefore added to the dataset are the relative measures for interest in the search term 'Bitcoin' in Google Search. The scale for interest is a measure between 1 (low interest) and 100 (high interest).

The usage of the Wikipedia page on Bitcoin is added to the dataset. Wikipedia provides daily data of the absolute number of page views of the page attributed for Bitcoin (stats.wikimedia.org/#views-stat-grok-se). This number can therefore be a proxy for the interest in Bitcoin for a given day.

3.4 Government intervention and other events

In order to study the effect of events, data on potential significant moment in time for Bitcoin are handpicked. Using the most common search engine Google and large news providers, three government intervention events are added.

3.5 Other data

Other data includes releases of innovations in mining hardware. Although it is expected that the difficulty of mining will compensate for the larger attributed hash power, there could be a lag in this. If the market does not incorporate new technology at a rapid pace, the innovations can affect Bitcoin's price. Release data of NVIDIA GPU's and AMD GPU's are added to the dataset. The number of hardware innovations used for this thesis is 10 unique products suitable for Bitcoin mining.

Another aspect of Bitcoin that can affect the Bitcoin market is the block reward. As discussed earlier, the block reward is the amount of Bitcoin miners receive for finding new blocks. The block reward is set to halve every 4 years and one moment where the reward halved is in added to the dataset.

3.6 Descriptive statistics

This section will describe the data used for the analysis. The data is split in multiple tables and figures for an orderly view.

3.6.1 Bitcoin and Bitcoin Splits

In appendix 7.1 detailed statistics on the sample of the index weighted Bitcoin price from coindesk is shown. Immediately the large swings in the asset are visible. With a minimum of $417.01 and a maximum of $19343.04 the price of Bitcoin has experienced some large swings over the sample period. Furthermore it is striking that the standard deviation of the price is larger than the mean.

In appendix 7.1 the log returns and absolute log returns of Bitcoin and the included splits are shown. The sample size for the Bitcoin splits is limited due to their introduction late in the sample.

3.6.2 Difficulty and Hash Rate

In figure 7 the linear relation between the mining difficulty and the attributed power, the hash rate is shown. As the network produces a higher power for solving the algorithms, the network adjusts the difficulty of solving the algorithms. This way the time for finding a new block is kept relatively constant on 10 minutes per block. In the graph we find that this relation indeed is visible for the hash rate and difficulty.

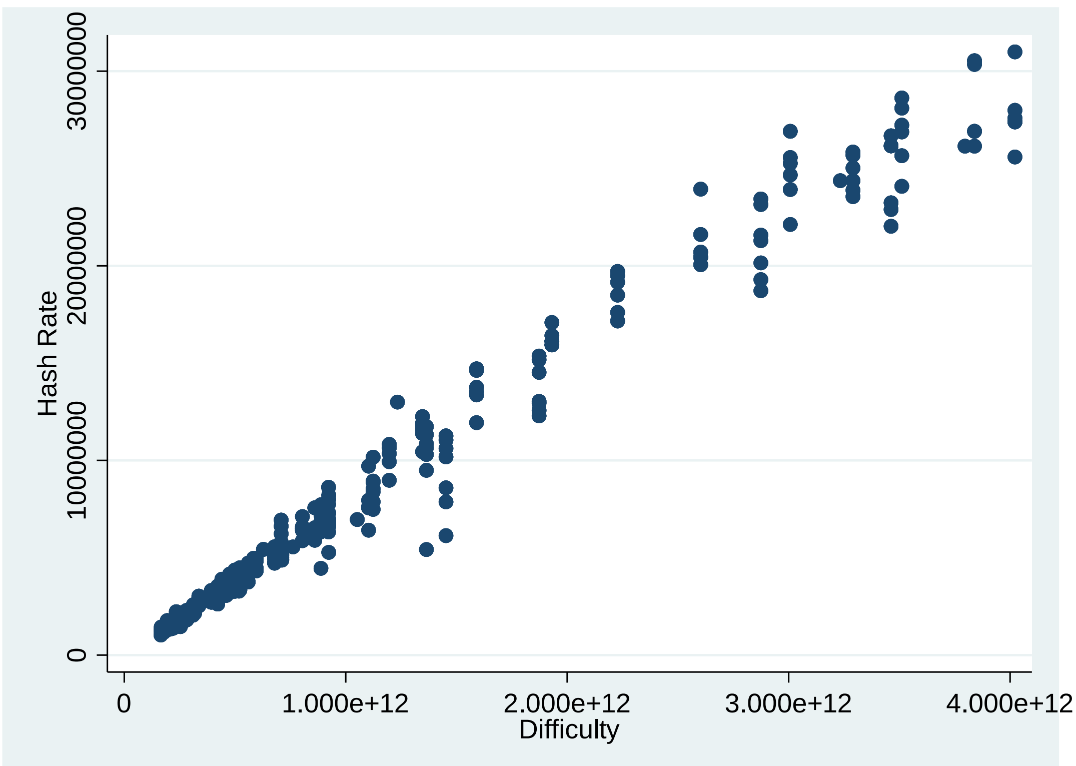

***Figure 7*. The linear relation between hash rate and difficulty.**

3.6.3 Transaction volume and number of transactions

For the observed period the Bitcoin price has soared. In figure 8 and figure 9 we find the number of transactions and the transaction volume of the Bitcoin network. The number of transactions has not seen a dramatic increase in late 2017 like the Bitcoin price and transaction volume has seen. This can be attributed to the technical boundaries of the amount of Bitcoin transactions that can be performed daily given the hash rate and difficulty. Due to Bitcoins' price increase, the traded value did drastically increase at the same rate of transactions.

***Figure 8*. The development of transaction volume over time.**

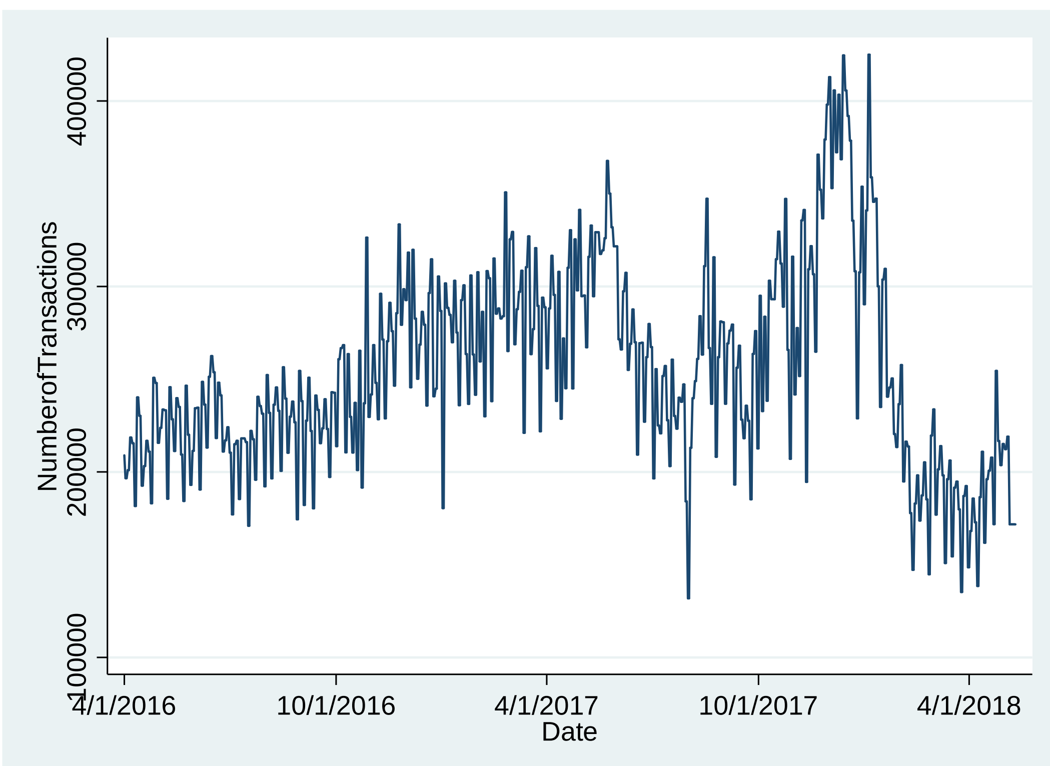

***Figure 9*. The development of number of transactions over time.**

3.6.4 Trends

Included in the dataset is trend data from Google and the amount of page views for the Wikipedia page on Bitcoin. For the Google trend data, an index is used based on a weekly relative measure. The index number 0 represents the lowest amount of interest in the given period and the index number represents the peak interest. For the search data we observe a peak interest in late 2017, where the Bitcoin price soared. Wikipedia page view data is retrieved on a daily basis and also shows a peak in late 2017.

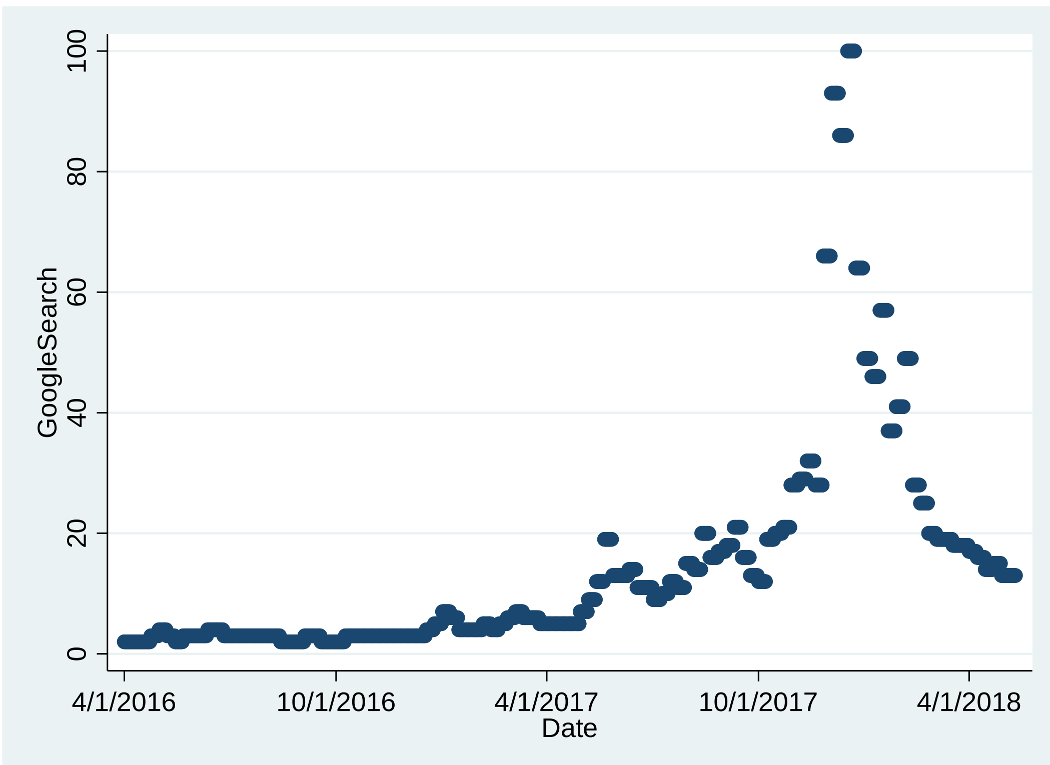

***Figure 10*. The relative interest for the search term 'Bitcoin' in the search engine Google.**

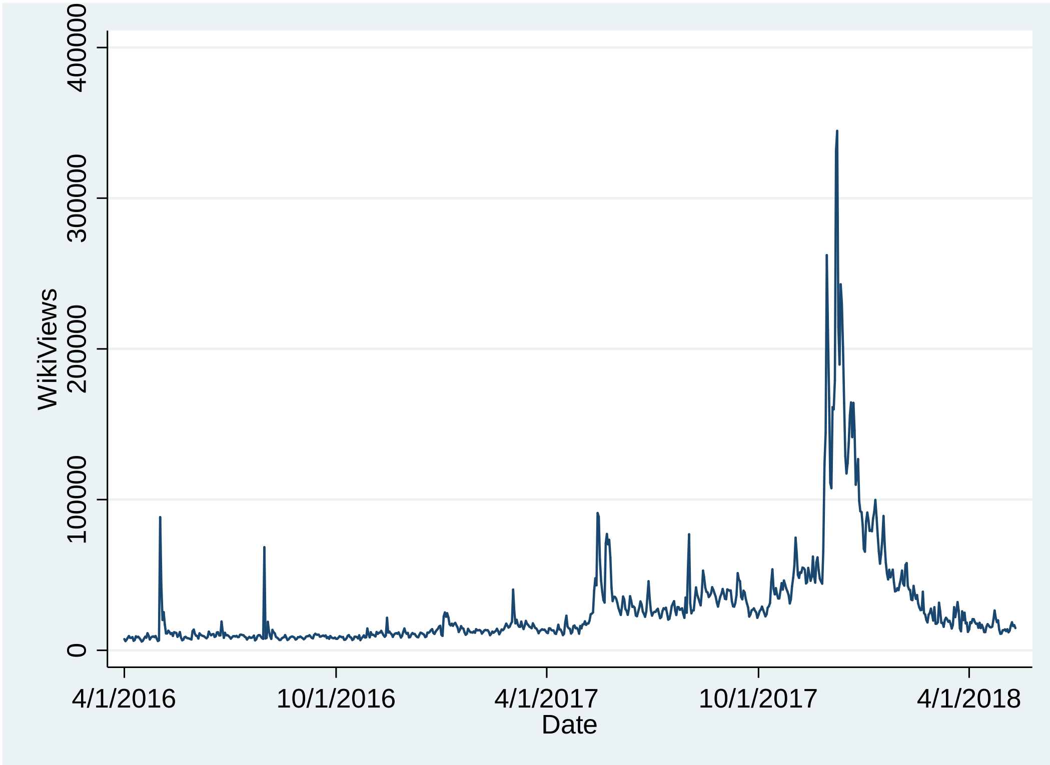

***Figure 11*. The absolute number of Bitcoin page views on Wikipedia.**

3.6.5 Event data

The last data that is shown in this section is the potentially significant event data over the sample period. Included are the release of commonly used hardware for Bitcoin mining from Nvidia and Radeon. Furthermore three government interventions are included. The introduction dates for the used Bitcoin splits are added. Lastly the shift of the block reward from 25 bitcoins per block to 12.5 bitcoins per block is included as a potentially significant event.

Date	Event
27/5/2016	Release GeForce GTX 1080
10/6/2016	Release GeForce GTX 1070
9/7/2016	Block reward is changed from 25 bitcoins to 12.5 bitcoins
19/7/2016	Release GeForce GTX 1060
2/8/2016	Release Nvidia TITAN X
5/3/2017	Release GeForce GTX 1080 Ti
6/4/2017	Release Nvidia TITAN Xp
17/5/2017	Release GeForce GT 1030
23/07/2017	Introduction of Bitcoin Cash
14/8/2017	Release Radeon RX Vega 64
28/8/2017	Release Radeon RX Vega 56
4/9/2017	ICO's Banned in China
29/09/2017	ICO's banned in South-Korea
23/10/2017	Introduction of Bitcoin Gold
2/11/2017	Release GeForce GTX 1070 Ti
4/2/2018	China Banning announcing ban of trading by banning foreign exchanges
10/3/2018	Introduction of Bitcoin Private

***Table 1*. A summary of all events used in this thesis, sorted chronologically.**

4 Methodology

This thesis uses both financial data and event data to study the price and volatility of Bitcoin. Dealing with Bitcoin data with bubble-like characteristics and explosive price movements, it is especially relevant to thoroughly perform some robustness checks on the relevant data and models.

Serial/auto correlation is tested using the Breusch-Godfrey LM test. Furthermore stationarity is tested using the Dickey-Fuller test. Testing for heteroscedasticity is done using the Breusch-Pagan-Godfrey test and lastly variables are checked for normal distribution using the Jarcque-Bera test. For these tests a P-value <0.05 is a violation leading to rejection of the H0 hypothesis.

4.1 Hypothesis 1

Hypothesis 1 of this thesis is:

"The price and volatility of Bitcoin is driven by technical factors."

The log return of Bitcoin and the absolute log return as a proxy of volatility will be regressed to the technical factors in the dataset. For technical aspects firstly we examine Bitcoin data. Real costs are made for mining bitcoins, which are represented in the transaction fees and in the hash rate. Furthermore included are the trade volume and the total number of transactions. In order to prevent facing non-stationarity problems with the Bitcoin data, the first difference is taken for multiple variables. Lastly a dummy variable is added for the change in block reward that took place in 2016.

Real market factors are also added in the analysis for hypothesis 1. The returns of the commodity gold and WTI Oil Futures are incorporated in the model. The VIX index is added as a proxy for option implied volatility.

The models used for hypothesis 1 are:

$$\begin{aligned} RetBitc = cons + \beta_1 \Delta TransactionCost + \beta_2 \Delta Difficulty + \beta_3 \Delta MiningRevenue \\ + \beta_4 \Delta NumberofTransactions + \beta_5 \Delta Transactionvolume + \beta_6 \Delta HashRate \\ + \beta_7 WTIReturn + \beta_8 GoldReturn + \beta_9 \Delta VIX + \delta_1 BlockReward \end{aligned}$$

$$\begin{aligned} AbsRetBitc = cons + \beta_1 \Delta TransactionCost + \beta_2 \Delta Difficulty + \beta_3 \Delta MiningRevenue \\ + \beta_4 \Delta NumberofTransactions + \beta_5 \Delta Transactionvolume + \beta_6 \Delta HashRate \\ + \beta_7 WTIReturn + \beta_8 GoldReturn + \beta_9 \Delta VIX + \delta_1 BlockReward \end{aligned}$$

Rejecting hypothesis 1 implies that there are no fundamentals found that drive Bitcoin's price and volatility.

4.2 Hypothesis 2

Hypothesis 2 of this thesis is:

"Large swings in the price of Bitcoin can be explained by shocks from government interventions."

For this hypothesis potential significant government interventions are examined. An event study methodology is implemented. The event study will offset the cumulative actual returns to the cumulative expected return in an event horizon. The difference between the 'normal' expected return and the actual return is defined as the abnormal return:

$$Equation\ 2: AR_{b,t} = R_{b,t} - E(R_{b,t})$$

Where $AR_{b,t}$ represents the Abnormal Return at a given day t, $R_{b,t}$ represents the return of Bitcoin at a given day t and $E(R_{b,t})$ represents the Expected Return of Bitcoin at a given day t. The market-adjusted model will be used in order to calculate the expected return. The standard 3-factor CAPM model is used to offset Bitcoin to the CCI30 Bitcoin index. The CCI30 index is an index that has weighted measures of 30 different cryptocurrencies since 2015. The data is downloaded from the website of the index (CCI30). Furthermore for the CAPM model the daily worldwide risk free rate as given by Kenneth French is 0 for the estimation period (French, 2018), risk free rate can therefore be ignored in calculating CAPM. The resulting model to calculate alfa and beta for the expected return is:

$$Equation\ 3: E\left(R_{b,t}\right) = rf + \beta(R_{m,t} - rf)$$

Where rf represents the risk-free rate and $R_{m,t}$ represents the return of the cci30 index at a given day t.

Calculating the cumulative abnormal return for a given event window is done as follows:

$$Equation\ 4: CAR(t_1, t_2) = \sum_{t=t_1}^{t_2} AR_{b,t}$$

Where CAR is the cumulative abnormal return, t_1 is -2 days before the event and t_2 is 5 days after the event. This means that for every event examined, an 8 day event horizon is examined.

For testing the hypothesis, a t-test on the CARs is performed. The equation for testing the hypothesis that an event has no significant effect is defined as:

$$Equation\ 5: t_{CAR_e} = \frac{CAR_e}{\sigma_{CAR_e}}$$

Where t_{CARe} is the t-value for a given event e, CAR_e is the cumulative abnormal return for a given event e and σ_{CARe} is an estimation of the standard error of the CAR.

The standard deviation for the cumulative abnormal return is calculated as a multiplication of the standard deviation of the abnormal returns for the event horizon with the span of the horizon. σ_{CARe} is calculated as follows:

$$Equation\ 6: \sigma\hat{}2_{CAR_e} = H_t * \ \sigma\hat{}2_{AR_e}$$

Where $\sigma\hat{}2_{CARe}$ is the CAR variance, H_t is the horizon span, calculated as the last day minus the first day. $\sigma\hat{}2_{Are}$ is the variance of the abnormal returns in the event horizon.

As a robustness check, two more event horizons are taken next to the main 8-day event horizon. The first other event horizon calculates the CAR for the 10 days prior to the event. The second other event horizon calculates CAR over the 15 days after the event.

Next to the short time shocks, potential lasting effects of events are analyzed in a dummy analysis. In the dummy analysis the variables used in the models of hypothesis 1 are added as control variables. In two regressions the news events are added as dummy's to see if a permanent change in return or volatility is found after the events:

$$\begin{aligned} RetBitc = cons \\ &+ \beta_1 \Delta TransactionCost + \beta_2 \Delta Difficulty + \beta_3 \Delta MiningRevenue \\ &+ \beta_4 \Delta NumberofTransactions + \beta_5 \Delta Transactionvolume + \beta_6 \Delta HashRate \\ &+ \beta_7 WTIReturn + \beta_8 GoldReturn + \beta_9 \Delta VIX + \delta_1 BlockReward + \delta_2 ICO\_China \\ &+ \delta_3 ICO\_SK + \delta_4 Tradeban\_China + \delta_5 BitcoinGold + \delta_6 BitcoinCash \\ &+ \delta_7 BitcoinPrivate \end{aligned}$$

$$\begin{aligned} AbsRetBitc = cons \\ &+ \beta_1 \Delta TransactionCost + \beta_2 \Delta Difficulty + \beta_3 \Delta MiningRevenue \\ &+ \beta_4 \Delta NumberofTransactions + \beta_5 \Delta Transactionvolume + \beta_6 \Delta HashRate \\ &+ \beta_7 WTIReturn + \beta_8 GoldReturn + \beta_9 \Delta VIX + \delta_1 BlockReward + \delta_2 ICO\_China \\ &+ \delta_3 ICO\_SK + \delta_4 Tradeban\_China + \delta_5 BitcoinGold + \delta_6 BitcoinCash \\ &+ \delta_7 BitcoinPrivate \end{aligned}$$

4.3 Hypothesis 3

Hypothesis 3 of this thesis is:

"Bitcoin mining hardware innovations have no lasting effect on the price of Bitcoin."

In the dataset release dates of various hardware suppliers are found. For these hardware releases similar to hypothesis 2, event studies will be performed to test for significant shocks to Bitcoin's return.

4.4 Hypothesis 4

The last hypothesis of this thesis is:

"The introduction of Bitcoin splits leads to a substitution effect."

Testing this hypothesis is once again done through a regression model. If the introductions of Bitcoin splits (partially) replace the original Bitcoin script, we expect to see a lasting effect on Bitcoin after the introduction of a split. Therefore a regression is run with the splits added as dummy variables on both the return and volatility of Bitcoin. The dummies for the split-introduction are added in the dummy-analysis for hypothesis 2.

Next to the dummy analysis testing long term effects of the introduction of splits, the introduction dates are also added in the before mentioned event study. It is possible that the introduction of Bitcoin splits lead to a temporary shock to the market.

Through the dummy analysis and event study the hypothesis will be tested and a conclusion can be formed on the potential substitution effect of introducing the Bitcoin splits to the crypto market.

5 Results

In this section the outcomes of the hypotheses are discussed. The outcomes of the robustness checks are discussed with the hypotheses. The robustness tests on individual variables are found in appendix 7.2 and show no problems.

5.1 Hypothesis 1

Hypothesis 1 is focused on Bitcoin data and real market factors potentially explaining return and volatility patterns of Bitcoin. Robustness checks have been done on the return data used. For the return of Bitcoin, the return of gold and the WTI oil return no unit root is found. Furthermore the returns follow a normal distribution. Using the first difference of the Bitcoin data, no stationarity issues are found. All variables can be used in the time-series regression.

The results of model one presented in appendix 7.3 show a regression with Bitcoin's log return as dependent variable. The model has low explanatory power given the R-squared value of 0.0146. The gold return is the only significant variable in the regression. The significant positive relation that Bitcoin's return has to the return of gold implies potential similarities in asset-types. (Dyhrberg, 2016) Already found that gold reacts similar to shocks when compared with Bitcoin. Bitcoin has similarities to gold and has been described as a form of digital gold. For similar reasons that investors resort to gold, investors could resort to Bitcoin.

The model finds no other significant variables, the other real market factors like WTI oil returns and VIX index are not significant. All of the underlying Bitcoin data also show no significant relation to Bitcoin's return. Bitcoin's return therefore hardly seems to be driven by technical aspects and market variables. Robustness checks on the model have been performed. For model one no serial correlation issues are found or heteroscedasticity issues.

Model two in appendix 7.3 shows a regression of the absolute return of Bitcoin, as a proxy of Bitcoin's volatility, to the Bitcoin data and market variables. Again, the model shows relatively low explanatory power with an r-squared 0.0297.

The robustness checks on model two also shows that there is serial correlation and that the model shows signs of heteroscedasticity. Including lag-variables for the absolute return of Bitcoin are not sufficient to overcome the autocorrelation and heteroscedasticity issues. Newey-West standard errors are therefore used. The results of the model using Newey-West standard errors are shown in appendix 7.4.

The resulting robust model finds a significant positive relation with the difficulty, the computation power needed to solve for new blocks. An increase in difficulty means that the attributed power to the network has increased. Subsequently, this can mean more activity in the market in general, leading to higher volatility.

Secondly, the dummy for the block reward has a significant positive relation to Bitcoin's volatility. After the block reward halved, Bitcoin's volatility significantly increased. A larger focus on the transaction costs after the reward change can be an explanation for the higher volatility.

Both models show no strong explanatory power of Bitcoin being driven by fundamental Bitcoin data or fundamental market data. However, the significant relation between the gold return and Bitcoin return and the significant relation with the difficulty and block reward with Bitcoin's volatility are present. Even though significant relations are found, type-I errors seems likely given the scale of the models. Therefore hypothesis 1 is rejected.

5.2 Hypothesis 2

For Hypothesis 2, a selection of three potentially significant news events is tested in an event study. Since hypothesis three and hypothesis four also use the event study methodology, the results of all events can be found in appendix 7.6 and are sorted chronologically**.** The event study tests if a certain event significantly impacts Bitcoin's return in the 8-day event horizon.

One out of three events has significantly impacted Bitcoin's return on the standard 5%-significance level. The decision to ban initial coin leads to a positive shock to absolute return. From an economic viewpoint, this is an odd result, since government interventions are expected to affect the market in a negative way.

Looking at the total results of all event studies, hardly significant events are found. The fact that the intervention in South-Korea is significant, a smaller market than the Chinese market that also intervened in ICO's, is likely a Type-I error.

It is therefore concluded that the tested intervention events do not lead to significant shocks to Bitcoin's return. Changing the event horizon to 10 days before the event or 15 days after the event does not render different results as well. Hardly significant events are found.

In the dummy analysis in appendix 7.5 no permanent changes to the return or volatility of Bitcoin are found after the news events. Hypothesis 2 is therefore rejected.

5.3 Hypothesis 3

The third hypothesis of this thesis tests potential shocks in hardware innovations. The event study methodology has been used to test for significant cumulative abnormal returns when new hardware that is suitable for Bitcoin mining is introduced. In appendix 7.6 an overview is given of the event study results.

Of all the hardware innovation added to the dataset, only the release of the GeForce GT 1030 impact Bitcoin's return in a negative way on a 5%-level. Again, this result cannot lead to economic conclusions. The GT 1030 is a relatively weak GPU and with no other significant shocks for stronger cards, the result is likely to also be a type-I error. Hypothesis 3 is therefore rejected.

5.4 Hypothesis 4

The fourth hypothesis introduces the concept of Bitcoin-splits. Bitcoin Cash, Bitcoin Gold and Bitcoin Private use the Bitcoin framework with a change in the technology, potentially substituting the original Bitcoin.

An event study has been performed on the introduction dates of the three different splits, the results can be found in appendix 7.6. The Bitcoin splits can lead to a negative shock on Bitcoin's return upon introduction. The results show no significant shocks at the introduction dates of the splits.

No significant permanent changes to Bitcoin's return are found in the dummy analysis. This implies that no substitution effect has taken place through the introduction of the Bitcoin splits.

In the dummy analysis a significant effect of the introduction of the splits is found on Bitcoin's volatility. After the introduction of Bitcoin Gold and Bitcoin Cash, a permanent positive shock to Bitcoin's volatility is found. A possible explanation can be a broadening of the market, with investors more likely to switch between different cryptocurrencies. The introduction of the latest split, Bitcoin Private leads to a permanent negative change on Bitcoin's volatility. It must be noted that the sample size for the period after the introduction of Bitcoin Private is small, so the observed change in volatility must be perceived with caution. In general, Bitcoin's volatility has increased over time in the dataset.

Although it is found that Bitcoin is strongly related to the Bitcoin splits, the splits do not impact the return of Bitcoin through their introduction. The Bitcoin splits therefore do not lead to a substitution effect. Hypothesis 4 is therefore rejected.

6 Conclusion

This thesis is aimed at trying to get a sense of understanding for the drivers of the explosively volatile asset Bitcoin by looking at fundamentals and events. The research question of this thesis is:

"To what extend is the value of Bitcoin driven by technical aspects and to what extend is the value driven by speculation?"

No convincing evidence is found that Bitcoin's value is driven by technical aspects or market variables. Notably, Bitcoin does show a significant positive relation to the return of gold. With Bitcoin being described as a form of digital gold and a safe haven for storing money in stressful times, this view of Bitcoin is strengthened by the results of this thesis. Next to gold, a broad range of technical aspects and market factors have been researched. Difficulty and the change in block reward are found to impact the volatility of Bitcoin. With the scale of the used models, it is concluded that no convincing significant relation exists. The found significant variables are concluded to likely be type-I errors.

The Bitcoin network is run on miners that mine for blocks. GPU's that are likely to be used by Bitcoin miners have been added to the dataset. The release of GPU's could fundamentally affect the Bitcoin market. In the performed event study for the releases of the broad range of GPU's it has been concluded that no results are found that lead to the economic conclusion of GPU-introductions leading to shocks in Bitcoin's value.

Another focus point of this thesis has been government interventions in the Bitcoin market. Three news events have been tested on potential short term and long term effects on Bitcoin. The event study showed no significant shocks around the event horizons. Furthermore, the dummy analysis showed no significant long term effects on Bitcoin's return or volatility.

In the market for cryptocurrencies, alternatives in the Bitcoin framework have been introduced. These Bitcoin splits could substitute Bitcoin due to investors switching to the newly introduced form of cryptocurrency. No evidence is found on the introduction of splits affecting the return of Bitcoin. The introduction of Bitcoin splits are also found to not lead to shocks to return or volatility. There is however a relation found between the introduction of the Bitcoin splits and the volatility of Bitcoin. The introduction of the larger splits Bitcoin Cash and Bitcoin Gold have led to a sustained increase in volatility of Bitcoin, while the introduction of Bitcoin Private has led to a decrease of Bitcoin's volatility.

Before drawing a conclusion about the performed research, prevalent data challenges that were found during the analysis must be discussed. Bitcoin is an asset that has a track record of explosive price movements with hard to comprehend reasons from an economic point of view. This is also what the results have shown; it is challenging to find fundamental factors driving Bitcoin. Finding a proper benchmark for an event study on Bitcoin is difficult, since Bitcoin is a worldwide asset that hardly has links with the real economy. The best available benchmark has been taken, the CCI30 index.

With the prevalent data challenges taken into account, this research has taken a broad dataset of Bitcoin data, other variables and events. Little significant relations with Bitcoin's return and volatility have been found, and the significant relations have a very weak explanatory power. Bitcoin is not found to be convincingly driven by technical aspects or market data. Bitcoin seems to be a unique type of asset showing erratic price and volatility movements that cannot be explained by rational economic and financial theory. The presence of a financial bubble is therefore a likely conclusion.

7 Appendix

7.1 Descriptive statistics

Price Bitcoin

	Percentiles	Smallest		
1%	421.2	417.01		
5%	452.58	418.09		
10%	574.11	418.42	Obs	771
25%	673.59	419.38	Sum of Wgt.	771
50%	1263.54		Mean	3777.109
		Largest	Std. Dev.	4264.356
75%	6140.53	17608.35		
90%	10035	18960.52	Variance	1.82e+07
95%	13412.44	19086.64	Skewness	1.407236
99%	16937.17	19343.04	Kurtosis	4.14338

***Table 2*. Descriptive statistics of the absolute price of Bitcoin.**

Variable	Obs	Mean	Std. Dev.	Min	Max
RetBitc	770	.0039008	.0431879	-.1829846	.2264123
AbsRetBitc	770	.0290337	.0321928	.0000127	.2264123
RetBCG	201	-.0107972	.1549261	-1.252583	.6939435
AbsRetBCG	201	.0886362	.1273719	.0006266	1.252583
RetBCP	63	-.0150802	.142148	-.3820672	.6704037
AbsRetBCP	63	.0983519	.1029953	.0017568	.6704037
RetBCC	293	.0043381	.1080109	-.4460382	.4315819
AbsRetBCC	293	.0737697	.0788963	.0000825	.4460382

***Table 3*. Descriptive statistics of Bitcoin and Bitcoin splits.**

7.2 Robustness tests

Variable name	Number of lags	Test Statistic	Unit root
Return Bitcoin	3	-14.266	no
Δdifficulty	3	-14.746	no
Δmining revenue	3	-17.812	no
Δnumber of transactions	3	-28.929	no
Δtransaction volume	3	-13.149	no
Δhash rate	3	-21.842	no
Gold return	3	-13.584	no
ΔVIX index	3	-14.107	no

***Table 4*. Dickey-Fuller test for unit root.**

Shapiro-Wilk test for normal data

Variable name	N	Z-value	Normally distributed
Return Bitcoin	770	8.545	yes
Δdifficulty	770	12.834	yes
Δmining revenue	770	10.668	yes
Δnumber of transactions	770	9.846	yes
Δtransaction volume	770	10.148	yes
Δhash rate	770	10.886	yes
Gold return	770	8.362	yes
ΔVIX index	770	12.522	yes

***Table 5*. Shapiro-Wilk test for normal data.**

7.3 Models hypothesis 1 and model robustness tests

VARIABLES	(1) Model1 RetBitc	(2) Model2 AbsRetBitc
ΔTransCost	-0.0264	-0.0220
	(0.0520)	(0.0384)
ΔDiff	-0.0709	0.107*
	(0.0773)	(0.0571)
ΔMinRev	-0.00981	-0.00341
	(0.0588)	(0.0435)
ΔNumTrans	-0.0179	-0.0120
	(0.0512)	(0.0379)
ΔTransVol	0.0295	0.00430
	(0.0233)	(0.0172)
ΔHrate	0.0428	0.0150
	(0.0323)	(0.0239)
GoldReturn	0.490**	0.345*
	(0.249)	(0.184)
ΔVIX	0.0252	0.0165
	(0.0201)	(0.0148)
WTIReturn	0.0184	-0.112
	(0.0993)	(0.0734)
DumBR	1.31e-06	-0.000822***
	(0.000373)	(0.000276)
Constant	0.00408	0.0405***
	(0.00554)	(0.00410)
Observations	769	769
Adjusted R-squared	0.002	0.017
r2	0.0146	0.0297

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In model 1 the dependent variable in the OLS regression is the log daily return of Bitcoin. In model 2 the dependent variable in the OLS regression is absolute log daily return of Bitcoin. ΔTransCost represent the change in transaction costs, ΔDiff is the change in difficulty of solving blocks, ΔMinRev is the change in mining revenue, ΔNumTrans is the change in number of Bitcoin transactions, ΔHrate is the change in hash rate, GoldReturn is the log return of the commodity gold, ΔVIX is the change in the VIX volatility index, WTIReturn is the log return for a crude WTI oil futures contract and DumBR is the dummy variable for the change in block reward.

Model Robustness tests	Breusch-Pagan test for heteroscedasticity	Heteroscedasticity	Breusch-Godfrey LM test for serial correlation	Serial correlation
Model 1	0.4188	No	0.1021	No
Model 2	0.0248	Yes	0	Yes

***Table 6*. The robustness test for models 1 and 2. Model 2 shows heteroscedasticity and serial correlation.**

7.4 Model 2 with Newey-West standard errors

VARIABLES	(1) Model2NW AbsRetBitc
ΔTransCost	-0.0220
	(0.0334)
ΔDiff	0.107**
	(0.0530)
ΔMinRev	-0.00341
	(0.0399)
ΔNumTrans	-0.0120
	(0.0348)
ΔTransVol	0.00430
	(0.0190)
ΔHrate	0.0150
	(0.0247)
GoldReturn	0.345*
	(0.181)
ΔVIX	0.0165
	(0.0160)
WTIReturn	-0.112*
	(0.0671)
DumBR	-0.000822***
	(0.000282)
Constant	0.0405***
	(0.00456)
Observations	769

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Model 2NW has regressed model 2 using Newey-West standard errors. The Newey-West standard errors are used to contest the found heteroscedasticity and serial correlation problems.

7.5 Dummy analysis

VARIABLES	(1) Model3 RetBitc
ΔTransCost	-0.0243
	(0.0523)
ΔDiff	-0.0680
	(0.0777)
ΔMinRev	-0.0151
	(0.0593)
ΔNumTrans	-0.0158
	(0.0516)
ΔTransVol	0.0262
	(0.0235)
ΔHrate	0.0460
	(0.0324)
GoldReturn	0.477*
	(0.250)
ΔVIX	0.0249
	(0.0201)
WTIReturn	0.0225
	(0.0997)
DumBR	-6.64e-06
	(0.000392)
DumBTG	-0.0118
	(0.00982)
DumBTC	0.00547
	(0.00700)
DumBCP	-0.00323
	(0.00925)
DumICOChina	-0.00999
	(0.0110)
DumICOSK	0.0151
	(0.0124)
DumTradeBan	-0.000127
	(0.00860)
Constant	0.00428
	(0.00628)
Observations	769
Adjusted R-squared	-0.002
r2	0.0187

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Model 3 includes six dummy-variables to the regression of model 1. All variables of model 1 are added as control variables. DumBTG is the introduction of Bitcoin Gold, DumBTC is the introduction of Bitcoin Cash, DumBTP is the introduction of Bitcoin Private, DumICOChina is the dummy for the ICO ban in China, DumICOSK is the ICO ban in South-Korea and DumTradeBan is the foreign exchange trade ban in China.

VARIABLES	(1) Model4NW AbsRetBitc
ΔTransCost	-0.00930
	(0.0330)
ΔDiff	0.0677
	(0.0546)
ΔMinRev	-0.0155
	(0.0400)
ΔNumTrans	0.000610
	(0.0349)
ΔTransVol	0.00817
	(0.0186)
ΔHrate	0.0120
	(0.0240)
GoldReturn	0.312*
	(0.173)
ΔVIX	0.0125
	(0.0130)
WTIReturn	-0.139**
	(0.0615)
DumBR	-0.000149
	(0.000294)
DumBTG	0.0248***
	(0.00602)
DumBTC	0.0111**
	(0.00460)
DumBCP	-0.0171**
	(0.00701)
DumICOChina	0.00895
	(0.00983)
DumICOSK	-0.0176*
	(0.00986)
DumTradeBan	0.00225
	(0.00720)
Constant	0.0237***
	(0.00493)
Observations	769

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Model 4NW includes six dummy variables to model 2NW. Because of the problems with homoscedasticity and serial correlation found in model 2, model 4NW is estimated using Newey-West standard errors.

7.6 Event study

Date	Event	CAR 8-Day	P-Value 8-Day
27/5/2016	Release GeForce GTX 1080	0.082168	0.1948
10/6/2016	Release GeForce GTX 1070	0.025437	0.7245
9/7/2016	Block reward is changed from 25 bitcoins to 12.5 bitcoins	-0.259135	0.0464*
19/7/2016	Release GeForce GTX 1060	-0.028250	0.8265
2/8/2016	Release Nvidia TITAN X	-0.017783	0.6394
5/3/2017	Release GeForce GTX 1080 Ti	-0.072075	0.0652
6/4/2017	Release Nvidia TITAN Xp	0.029390	0.7208
17/5/2017	Release GeForce GT 1030	-0.212940	0.0152*
23/07/2017	Introduction of Bitcoin Cash	0.032214	0.7320
14/8/2017	Release Radeon RX Vega 64	0.116753	0.1964
28/8/2017	Release Radeon RX Vega 56	-0.007352	0.9256
4/9/2017	ICO's Banned in China	0.074575	0.3985
29/09/2017	ICO's banned in South-Korea	0.057001	0.0456*
23/10/2017	Introduction of Bitcoin Gold	-0.022683	0.8188
2/11/2017	Release GeForce GTX 1070 Ti	0.049994	0.2984
4/2/2018	China Banning announcing ban of trading by banning foreign exchanges	-0.000429	0.9954
10/3/2018	Introduction of Bitcoin Private	0.012571	0.7181

The table shows the event study results for the chosen 8-day horizon. The event horizon is two days before the event until 5 days after the event. CAR is the cumulative abnormal return measured in the event horizon. CAR is used in a t-test to test for a statistically significant shock. The corresponding P-values for the t-test are given in the table. Events that are statistically significant at a 5% confidence level are market with an asterisk.

Date	Event	CAR -10 Day	P-Value -10 Day	CAR 15-Day	P-Value 15-Day
27/5/2016	Release GeForce GTX 1080	-0.003136	0.9650	0.075709	0.2477
10/6/2016	Release GeForce GTX 1070	0.010528	0.7847	0.007817	0.9370
9/7/2016	Block reward is changed from 25 bitcoins to 12.5 bitcoins	0.018070	0.7168	-0.217510	0.2453
19/7/2016	Release GeForce GTX 1060	-0.146267	0.3311	0.074181	0.4031
2/8/2016	Release Nvidia TITAN X	0.084014	0.2927	-0.081727	0.0998
5/3/2017	Release GeForce GTX 1080 Ti	-0.015929	0.6150	-0.396665	0.0063*
6/4/2017	Release Nvidia TITAN Xp	-0.077577	0.5987	-0.077514	0.4503
17/5/2017	Release GeForce GT 1030	-0.090118	0.5337	-0.069326	0.6206
23/07/2017	Introduction of Bitcoin Cash	0.064968	0.5961	0.086153	0.5435
14/8/2017	Release Radeon RX Vega 64	0.153227	0.1236	-0.091375	0.3039
28/8/2017	Release Radeon RX Vega 56	-0.132721	0.0470*	0.081288	0.4300
4/9/2017	ICO's Banned in China	-0.017251	0.8260	0.010452	0.9026
29/09/2017	ICO's banned in South-Korea	-0.009186	0.7747	0.261778	0.0447
23/10/2017	Introduction of Bitcoin Gold	0.100270	0.0885	0.028367	0.7993
2/11/2017	Release GeForce GTX 1070 Ti	0.035480	0.7500	-0.010440	0.8672
4/2/2018	China Banning announcing ban of trading by banning foreign exchanges	0.003060	0.9639	0.088953	0.3154
10/3/2018	Introduction of Bitcoin Private	0.069042	0.2355	0.047358	0.4682

This table shows two different event horizons for the event study as a robustness check. The -10 day horizon takes the 10 days prior to the event as the event horizon. The 15-day event horizon takes the 15 days after the event as the event horizon. Statistically significant events are given an asterisk.

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