Bitcoin, gold and the Chinese yuan

A comparison of volatility and correlations

Niels Graveland (U604018)

Tilburg University

Abstract

This paper studies daily returns of Bitcoin, Gold and the CNY/USD exchange rate in order to identify whether these assets differ in variance behaviour. The study is carried out employing an asymmetric GARCH model with a sample period of June 2011 to June 2018. This study shows that based on its volatility and correlation with other financial assets, Bitcoin cannot be seen as a gold like asset nor as a currency. Firstly, the correlations of Bitcoin with other financial assets are analysed and compared to gold and the Chinese Yuan. Based on this analysis, it is concluded that Bitcoin is not correlated to other financial assets, this differs from the correlation of gold and currency pairs that are related to almost all assets in the dataset. Secondly, an asymmetric GARCH model is used to compare the volatility behaviour of Bitcoin, gold and the Chinese Yuan. The results show that Bitcoin, gold and the Chinese Yuan feature fundamentally different volatility behaviour in volatility persistence and asymmetry in volatility behaviour . Bitcoin does not currently reflect any unique properties of gold or currency pairs. However, results of this study suggest that Bitcoin returns are related to returns of the Chinese Yuan what suggest that Bitcoin starts to react to similar variables as currencies. Further research can explore which variables Bitcoin and the Chinese Yuan are both related to.

Keywords: Bitcoin, volatility, cryptocurrency, GARCH

Author:	Niels Graveland
ANR:	U604018
Study:	MSc. Finance
Faculty :	TISEM
Supervisor:	dr. K.K. Nazliben
Second reader:	dr. L.T.M. Baele
Date:	November 2018

Table of Contents

Abbreviations

ARCH	Autoregressive Conditional Heteroscedasticity
BTC	Bitcoin
CNY	Chinese Yuan
CRIX	The CRyptocurrency IndeX
EUR	Euro
GARCH	Generalized Autoregressive Conditional Heteroscedasticity
JPY	Japanese Yen
USD	United States Dollar

1. Introduction

Since (Nakamoto, 2008) introduced Bitcoin as peer-to-peer electronic cash system, its popularity has risen significantly, with a peak of 831 billion US dollar on January, 2018 comparable to the market valuation of a company such as Alphabet. With this rise in popularity and market value, the following question arises: what drives the price of Bitcoin to such levels? Bitcoin originally began as a peer-to-peer electronic cash system, but it appears that Bitcoin is becoming a speculative investment vehicle for investors instead of a means of payment. The extreme increase in market value raises the question as to whether Bitcoin is an investment asset, a store in value such as gold or a currency. (Glaser, 2014) show that the majority of users use Bitcoin's as a speculative assets instead as a means of payment. From this it can be concluded that Bitcoin is mostly used as an investment asset rather than a currency.

Since it is questionable if Bitcoin behaves as a currency, the question arises: what kind of financial asset can Bitcoin be compared to ? Some media and banks label cryptocurrencies and Bitcoin as 'the new digital gold', because both assets share similarities following (Dyhrberg, 2016) states that both Bitcoin and gold derive most of their value from the fact that they are scarce and costly to extract. However, in certain way gold and Bitcoin are different. Gold is used for its store of value and its negative correlation with currencies, which makes its useful for hedging. Such abilities are not certain for Bitcoin. Due to this comparison and the media label as 'the new digital gold', it is interesting to compare Bitcoin, gold and currency pairs from an econometric perspective and focus on the correlation with other assets and the volatility behaviour of these three assets. Therefore, this research will address whether Bitcoin can be classified as 'the new digital gold' or as an established currency based on volatility behaviour and how it correlates with established asset classes as stock indices and currencies.

Because Bitcoin is difficult to define as an financial asset analysing the variance can be informative. The asymmetric GARH model that is used in this thesis can give indications how the variance of Bitcoin behaves compared to other financial assets. This analysis will therefore contribute to defining the economic abilities of bitcoin in portfolio analysis, risk management and currency capabilities. The main focus of this thesis is to apply an asymmetric GARCH model among different financial assets to answer the following research question: *How does the return on Bitcoin behave compared to the gold price and CNY/USD exchange rate when analysing the variance of these assets?*

This thesis will extend the current research of (Baur, Dimpfl, & Kuck, 2017) and (Dyhrberg, 2016a) on the question if bitcoin behaves different compared to gold and currencies when analysing the variance. Current research will be extended with the use of an extended dataset including Chinese variables and the broader cryptocurrency market index CRIX.

The analysis of the results is divided into four parts. First, the correlation of Bitcoin, gold and exchange rates with other assets are analysed. From this analysis, can be concluded that Bitcoin does not behave as a currency or commodity because it is not correlated to other financial assets in the dataset.

Secondly, the volatility behaviour of cryptocurrencies in comparison to stock indices, commodities and currencies is analysed, focusing particularly on the stylized facts of long memory and asymmetry in the variance. The characteristic of long memory in a financial time series is also referred to as volatility persistence (i.e. slowly decaying autocorrelation effects in conditional volatility). This is a common characteristic in financial time series (i.e. stock indices, commodities and foreign exchange rates). The second characteristic, asymmetric volatility, is interpreted by the empirical phenomenon when negative returns are associated with upward conditional volatility and vice versa. This phenomenon is observed in the stock markets and is explained by the leverage effect and the volatility feedback effect. The volatility persistence is the highest for the CRIX index and gold. This thesis finds that Bitcoin, gold and currencies have different reactions on the conditional volatility to positive and negative shocks. Where the volatility of gold and currencies increases more by negative shocks than positive, the opposite is true for Bitcoin. Surprisingly, the findings of Bitcoin are not applicable to the CRIX index. Overall, it may be concluded that Bitcoin, gold and the Chinese Yuan feature fundamentally different volatility behaviour in the volatility persistence and asymmetric volatility.

Thirdly, this research tested if there is a relationship between returns of the US dollar (USD) and the Chinese Yuan (CNY). In comparison with the results of (Baur, Dimpfl, & Kuck, 2017), it was shown that there is no relationship between returns in USD and Bitcoin. However, results suggest that there is a relationship between returns in the CNY and Bitcoin returns in the period between 1st of July 2014 and 1st of June 2018, which may suggests that Bitcoin and the CNY are beginning to react to the same macroeconomic variables.

Finally, the news impact curves present a graphical interpretation of the results shown in the asymmetric GARCH equation. The graphs give an interpretation of the signs of the asymmetric GARCH term, showing that for gold and the CNY, negative returns increase variance more than positive returns and vice versa for Bitcoin. The differences shown in the news impact curves can have substantial implications for portfolio selections and asset pricing. If volatility can be predicted after major news event this can lead to a reduction in risk of holding the assets. Therefore any differences in predicted volatility after good or bad news can lead to important differences in option pricing and dynamic hedging strategies.

The results indicate that Bitcoin cannot be compared to gold or currencies because it is hardly correlated to other financial assets what is prominent feature of gold and currencies. Furthermore, its volatility dynamics do not share similarities with gold or currencies. However, it is possible that Bitcoin is slowly beginning to behave as a currency because there has been a relationship between Bitcoin and CNY in recent years. The findings of this study are interesting for investors helping to determine how Bitcoin behaves compared to other assets. With the results of the study investors do have a better understanding what drives the volatility of cryptocurrencies and how the volatility behaves compared to other assets. The understanding of this properties can be helpful to policy makers and market participants with pricing securities, deciding on the hedging strategy and portfolio selections.

The structure of this paper is as follows: Section 2 describes the current literature regarding cryptocurrencies and volatility analysis of financial assets. Section 3 describes the research question of this thesis. Section 4 presents the data that is used. Section 5 describes the methodologies and hypotheses that are used to answer the research question. Section 6 describes the results. Section 7 discusses the main findings of this thesis and Section 8 concludes the thesis.

2. Literature review

The focus of this study is to determine whether Bitcoin shares similarities with gold and currencies based on statistical properties using GARCH models. The structure of this literature review is therefore as follows. As first the technological part of cryptocurrencies and the blockchain is explained. Secondly, to understand the drivers of Bitcoin's volatility, the current state of the literature on the value drivers of Bitcoin is described. Thirdly, to explore if the relationship with other financial assets has an impact on Bitcoin's volatility, the risk management properties of Bitcoin are described. Fourthly, the current state of the literature on the statistical properties of gold and the correlation of gold with other financial assets is described. Fifthly, the current state of the literature that compares Bitcoin with gold is described. Sixthly, the current state of the literature on the statistical properties of currencies and the correlation with other financial assets is described. Finally, the studies that examine whether Bitcoin behaves as a currency are described.

2.1 Bitcoin and the Blockchain

What is Bitcoin?

Within the popular news media, Bitcoin is discussed as a digital currency that has its own value, and in the past few years has experienced extreme volatility in price from several thousand dollars per Bitcoin to only a few hundred dollars per Bitcoin ((Bjerg, 2016). The reality, however, is that there is much more to understand about Bitcoin than just that it is a digital currency that seems to receive a great deal of attention within the news media. Instead, Bitcoin is better described as a communications protocol that is used to engage in the exchange of virtual currency (Bohme & Christin, 2015). More specifically, a Bitcoin is a chain of digital signatures that are stored on a computer in a digital wallet. It is the digital wallet that generates keys that are used when Bitcoins are sent and received (Bjerg, 2016).

The idea for Bitcoin was developed in 2008 as an online currency that would exist with a decentralized system of peer-to-peer authentication. At first, only a few Bitcoin would be available. In order for more Bitcoins to come into existence, computational puzzles would have to be solved and verified. When people who are known as miners solve computational puzzles, they receive Bitcoins for their efforts (Dwyer, 2015). Once of the criticisms that has arisen regarding the mining of Bitcoins is that the computational puzzles require a great deal of computing power to solve. The computational puzzles are not easy to solve, and as more Bitcoins are created, the puzzles become more difficult. In this regard, miners are using a great deal of energy to solve each puzzle in order to receive just a few Bitcoins (Bjerg, 2016).

The idea that Bitcoin is a decentralized currency is also important in understanding the digital currency. Bitcoin is unlike traditional currency issued by a government because of the way in which the currency is exchanged and traded. With traditional currency, a single government both issues the money and certifies its authenticity. In contrast, Bitcoin is exchanged and traded through the peer-to-peer network. On the peer-to-peer network, there are many nodes that are interconnected through which the virtual currency can be exchanged to make payments or traded (Dwyer, 2015). The information about who owns each Bitcoin is located in multiple records on multiple computers and servers around the world. There is no single source of information about who owns Bitcoins. The information is publicly available for all to see, but it is located on multiple servers and computers rather than a single central computer (Bohme & Christin, 2015).

What is the Blockchain ?

An important part of the existence and use of Bitcoin is what is known as the blockchain. The blockchain is a peer-to-peer database or ledger system that maintains the transaction histories of every Bitcoin in existence (Yli-Huurmo, Ko, & Choi, 2016). The blockchain is freely and publicly available, and can be downloaded on any computer. However, while the transaction histories of every Bitcoin are publicly available, the identities of the people who own the Bitcoins and who engaged in specific transactions are difficult, but not impossible, to determine (Lee, 2015).

The ledger system is called a blockchain because it consists of individual blocks, which are transactions that are collected by the peers on the peer-to-peer network, as well as the miners. The individual transactions are put together as a block and are sent to the peer-to-peer network. If the transactions are verified to be correct, then the block is added to the current last block that is part of the chain. Each newly added block includes a reference to the previous block. It is this process of connecting blocks that reference each other that creates the blockchain. (Conoscenti & De Martin, 2016).The ability of the blockchain to be downloaded to any computer means that it is impossible to block any specific individual or group from engaging in Bitcoin transactions. A bank that controls the process of transactions along its network can prevent a specific individual or entity from using its system. In contrast, the decentralized nature of Bitcoin's blockchain means that transactions can occur without the ability of a single individual preventing another individual or entity from using the online currency (Lee, 2015).

The question might arise as to whether the blockchain is truly accurate given that it is decentralized. The mining work that occurs to create new Bitcoins involves verifying new blocks. Only after the extensive computational work of verifying the information in new blocks has occurred, which results in miners gaining new Bitcoins, are the new blocks added to the existing chain (Yli-Huurmo, Ko, & Choi, 2016).

In this regard, the transaction histories that are part of the blockchain have been verified, and are considered to be accurate.

It should be noted that there can be parts of the blockchain that may not agree with each other in terms of transaction histories. However, over time, miners will perform the work of verifying the data in the blocks in which there is disagreement. Once the miners have performed the extensive work of verifying the transaction histories, the part of the blockchain that is inaccurate will be removed and the correct blocks will become permanent parts of the chain (Conoscenti & De Martin, 2016). In this way, contradictory information in the blockchain is likely to be corrected over time.

To summarize this section, Bitcoin is introduced in 2008 as a peer to peer electronic cash system that is not issued by a central authority or a government. The information who owns Bitcoin's is located in multiple records on multiple computers and servers around the world. The technique that is used to store this information is called the blockchain. The technique of blockchain is used to verify transactions on the peer to peer network.

2.2 Value drivers of Bitcoin

This study focuses on the volatility behaviour of Bitcoin. It is therefore valuable to conduct a literature review to find out what drives the value of Bitcoin, as the value drivers can help to explain the volatility behaviour of Bitcoin.

One of the issues that seems to be poorly understood are the main drivers that impact the price of Bitcoin. (Kristoufek, 2015) investigated the drivers of Bitcoin price. The researcher explained that while it is often argued that Bitcoin is a currency whose value is based on speculation, this is not the case. The researcher found that the same factors that impact the change in traditional currencies drive the value of Bitcoin: the level of usage of the cryptocurrency, the supply of Bitcoin and its price level. In this regard, Bitcoin may be a cryptocurrency, but its value is indeed driven by the same factors that drive traditional currencies.

The question that must be asked, however, is what factors affect the short-term and long-term volatility of cryptocurrency. (Conrad, Custovic, & Ghysels, 2018) examined the short-term and long-term volatility of cryptocurrency by examining the relationship of cryptocurrency volatility to the volatility of the S&P 500 and the Baltic dry index. The researchers found that there was a significant and negative relationship between the realized volatility of the S&P 500 and long-term Bitcoin volatility. Furthermore, the researchers found a significant and positive relationship between the S&P 500 volatility risk premium and long-term Bitcoin volatility. Finally, a significant positive relationship was found between the Baltic dry index and long-term Bitcoin volatility, but the researchers also found a significant and negative relationship with Bitcoin trading volume. Overall, the results showed a negative relationship between risk in the U.S. stock market and Bitcoin volatility.

It is important to note that while the results of the study conducted by (Conrad, Custovic, & Ghysels, 2018) provided information about the factors that impacted the long-term volatility of Bitcoin, the data that were examined in the study were over a relatively short period of time. Similarly, other researchers have noted that the price of Bitcoin is affected by long-term fundamentals, such as equity market indices, exchange rates, and supply and demand, but the idea of long-term was defined as being over a year (Bouoiyour S. , 2016). In this regard, the idea of what constitutes a long-term analysis of value drivers for Bitcoin might be over a relatively short term because Bitcoin is fairly new. A true long-term analysis of Bitcoin may not be possible for several years, until the cryptocurrency becomes more widely used.

(Bouoiyour & Selmi, 2015) argued that it is difficult to determine the long-term drivers of Bitcoin. Instead, they concluded that the value of Bitcoin is still largely determined by speculation and that its long-term prospects as a respected and trusted currency for trade is unclear. In this regard, there is ambiguity within the academic literature as to whether Bitcoin is indeed driven by the same factors that impact the value of physical currencies or whether it is speculation that largely continues to drive the value of the cryptocurrency.

To summarise this section, although (Kristoufek, 2015) concluded that Bitcoin is driven by the same factors as traditional currencies, (Bouoiyour & Selmi, 2015) show the opposite and argue that the value of Bitcoin is largely determined by speculation. In this regard, there is ambiguity within the academic literature. (Conrad, Custovic, & Ghysels, 2018) showed that there is a negative relationship between risk in the U.S. market and Bitcoin's volatility drivers.

2.3 Risk management properties of Bitcoin

The previous section provided an overview of the academic literature concerning potential factors determining the value and volatility of Bitcoin. This section will provide an overview of the risk management properties of Bitcoin. If Bitcoin has some risk management properties, this may explain its volatility; it is therefore valuable to add this section to the literature review.

Another issue that has been raised is whether Bitcoin is a safe haven during times of economic uncertainty and volatility in other investments. (Selmi, 2017) investigated whether Bitcoin can serve as a safe haven against the U.S. stock market. The researchers found that the ability of Bitcoin to serve as a safe haven has varied over time. However, over both the short term and the long term, Bitcoin has been a weak safe haven against changes in the value of the U.S. stock market. (Bouri, Gupta, Tiwari, & Roubaud, 2017) conducted a study to determine if Bitcoin could be used to hedge against global uncertainty by using the first principal component of the Volatility Index (VIX) of developed stock markets around the world. The researchers found that Bitcoin was a hedge against global market uncertainty over shorter time periods.

From a critical perspective, the studies regarding whether Bitcoin can be used as a safe haven and hedge against global market volatility and uncertainty indicate that Bitcoin can indeed be a safe haven and hedge, but only over the short term. Investors who are seeking a short-term hedge against market volatility may find Bitcoin to provide a safe haven; however, it appears that Bitcoin should not be viewed as a long-term safe haven or hedge against market volatility. (Urquhart & Zhang, 2018) provide further evidence for the use of Bitcoin only as a safe haven in specific circumstances. The researchers investigated using Bitcoin as a hedge against volatility in the French Franc, Euro, British Pound, Australian Dollar, Canadian Dollar and the Japanese Yen. They found that Bitcoin could be used as an intraday currency hedge in periods of extreme turmoil, but only for the currencies of the Canadian Dollar, French Franc and the British Pound. They concluded that Bitcoin is a hedge for certain currency investors and high frequency investors.

Based on these results, it seems appropriate to argue that Bitcoin is a safe haven, but only for investors who need a short-term safe haven as opposed to investors who may be more cautious and who are looking for a long-term hedge against market volatility. One of the reasons for the short-term nature of Bitcoin as a safe haven may be related to the nature of cryptocurrencies as an asset class. (Bianchi, 2017) investigated the relationship between cryptocurrencies and standard asset classes with regard to the factors that drive market activity. The researcher found only a slight relationship between returns on commodities such as gold and energy and returns on cryptocurrencies. Furthermore, the relationship between the returns on commodities and the returns on cryptocurrencies did not result in volatility spill-over effects. Instead, the trade volume of cryptocurrencies was affected by the previous returns of the cryptocurrencies rather than by macroeconomic factors. In this regard, the conclusion may be made that cryptocurrencies are indeed largely driven by speculation rather than the larger macroeconomic factors and conditions that generally drive the volatility and prices of other asset classes.

Given the findings of the studies that have been reviewed that Bitcoin and other cryptocurrencies may only serve as short-term safe havens because they continue to be driven by investor speculation, as opposed to larger macroeconomic conditions over the long-term one may ask whether should Bitcoin be part of a portfolio diversification strategy. (Eisl, Gasser, & Weinmayer, 2015) examined the impact of Bitcoin on investment portfolios that are already highly diversified and concluded that including Bitcoin provided additional diversification improvement. However, the researchers noted that the addition of Bitcoin increased the conditional value at risk of the portfolio, but such risk was compensated by high returns. This caveat is important because it raises the question of whether the increased conditional value at risk for an investment portfolio when Bitcoin is added is acceptable in periods when the price of Bitcoin declines. The risk of adding Bitcoin to an investment portfolio may be acceptable when Bitcoin's price is experiencing a continued period of increase, but may be unacceptable when the price of the cryptocurrency is experiencing a period of decline.

In a similar study about the impact of Bitcoin on portfolio diversification, (Briere, Oosterlinck, & Szafarz, 2015) concluded that adding Bitcoin to well-diversified investment portfolios improved the portfolios' risk-return trade-off. However, the data for the study was from 2010 through 2013, which was a period in which the price of Bitcoin increased steadily. If the same study were conducted during a period in which Bitcoin experienced a significant decline in value, the results may have shown that including Bitcoin even in a well-diversified portfolio is harmful to the risk trade-off of the portfolio.

In fact, (Briere, Oosterlinck, & Szafarz, 2015) noted that the results of their study may have been due to the behaviour of Bitcoin during the period in which data were examined. This certainly raises the issue that the short-term benefits of Bitcoin when the price of cryptocurrency is increasing may not remain over the long term, particularly given that Bitcoin still seems largely driven by speculation rather than any relationship to larger macroeconomic market conditions. This is an indication that in order to understand the longer-term relationship of Bitcoin to other assets such as gold or major currencies, more current research and investigation is needed, particularly given the large decline in the price of Bitcoin that has occurred in recent months. The past behaviour of Bitcoin in which its price increased dramatically over a fairly short amount of time may not be indicative of longer-term behaviour, especially as sentiment about the cryptocurrency changes among those who may have previously traded Bitcoin based on speculation of major price increases.

Instead of risk management properties, another group of studies focused on the volatility changes in the Bitcoin markets and how these changes can be explained.

(Bouri, Azzi, & Dyhrberg, 2017) concluded that before the price crash of December 2013, positive shocks increase volatility shocks more than negative shocks. After the price crash of December 2013, no significant relation is shown. The inverted asymmetric reaction of Bitcoin is contrary to what is shown in equities. Where the volatility feedback effect and leverage effect do not explain this inverted asymmetric reaction, the authors propose that this effect can be explained by the safe haven effect.

(Bouoiyour S. , 2016) also examined the changing volatility in Bitcoin prices. Using a GARCH model the authors analysed if Bitcoin's volatility change over time. The results show that volatility is the highest in the period 2010-2015 when it is compared to data from the first half of 2015. Furthermore the asymmetric reaction in the variance is statistical significant in both sub periods. Suggesting that bitcoin were drive more by negative shocks compared by positive shocks.

(Bouri, 2017) examined whether Bitcoin can act as a hedge and safe haven for major world stock indices, bonds, oil, gold, the general commodity index and the USD index. With a data span from July 2011 to December 2015 and using a dynamic conditional correlation model, the authors came to the following conclusions: the empirical results indicate that Bitcoin is a poor hedge and is suitable for diversification purposes only. However, Bitcoin can serve as a strong safe haven against extreme down movements in Asian stocks. Furthermore, the study shows that Bitcoin hedging and safe haven properties vary between horizons.

2.4 Bitcoin as 'the digital gold'

Because this research will compare statistical properties between Bitcoin and gold, this part of the literature review will discuss current research comparing Bitcoin and gold as financial assets.

One of the first studies that compared Bitcoin with gold is (Yermack, 2015), which examined the correlation of Bitcoin against gold and different currency pairs. The author concluded that the pairwise correlations between gold, currencies and Bitcoin are not significantly different from zero. (Yermack, 2015) states that Bitcoin is a poor hedge and safe haven and cannot be compared to gold and currencies.

In addition to (Yermack, 2015), (Ennis, 2013) also focused on gold's role as hedge and safe haven for equity, bonds and currencies. (Ennis, 2013) investigated whether Bitcoin has the same properties as gold and can act as a hedge and safe haven for equity, bonds and currencies. Using a GARCH model, (Ennis, 2013) found that Bitcoin can act as a hedge for the Euro and not for the dollar. Furthermore, results suggest that Bitcoin can act as a hedge against European equity markets. For US equity markets, Bitcoin can act as a diversifier and not as a hedge or a safe haven. Finally, Bitcoin can act as a hedge for both the European and US bond markets. Therefore, (Ennis, 2013) concludes that Bitcoin and gold do have similarities.

In addition to (Yermack, 2015) and (Ennis, 2013) (Dyhrberg, 2016) also compared Bitcoin with gold and the USD based on the risk management properties using an extended research period compared to (Yermack, 2015) and (Ennis, 2013). The results proved opposite to the conclusion of (Yermack, 2015).

To test the hedging capabilities of Bitcoin (Dyhrberg, 2016) used an asymmetric GARCH model. Results of this study suggest that Bitcoin can be used as a hedge against stock indices as the FTSE. However, Bitcoin can also be used as a short term hedge against the American dollar. Due to this hedging capabilities the authors conclude that Bitcoin does have the same hedging capabilities as gold and can be included in investment portfolio as a hedge against market specific risk.

Another study by (Dyhrberg, 2016) examined whether Bitcoin shares (statistical) properties with gold and currencies using a asymmetric GARCH model. Based on the results of the asymmetric GARCH model (Dyhrberg, 2016) concluded that Bitcoin shares statistical properties with gold and currencies and therefore Bitcoin can be classified as something in between gold and the American dollar. Furthermore, Bitcoin may be useful in risk management and helpful for the risk-averse investor in anticipation of negative shocks to the market.

However, (Baur, Dimpfl, & Kuck, 2017) questioned the results of (Dyhrberg, 2016) and did a replication and extension study. Based on the same sample as (Dyhrberg, 2016) and using an asymmetric GARCH model, this study showed some different results. The findings show that Bitcoin exhibits distinctively different returns, volatility and correlation characteristics compared to other assets including gold and the USD. The authors therefore concluded that Bitcoin cannot be compared with gold or the USD. Furthermore, they concluded that there is no relationship between the volatility of the USD and Bitcoin.

Whereas (Dyhrberg, 2016) and (Baur, Dimpfl, & Kuck, 2017) focused on comparing Bitcoin with gold and the US dollar, (Klein, Pham, & Walther, 2018) focus particularly on comparing Bitcoin with gold. The results of this study correspond to the results of (Baur, Dimpfl, & Kuck, 2017) in showing that there are few similarities between these assets. First, the conditional variance properties of Bitcoin and gold as well as other assets were analysed. The authors found that Bitcoin's volatility has an asymmetric effect that is comparable with gold and silver. Furthermore, they found that Bitcoin has a significantly long memory effect in the variance but that it is as persistent as gold and silver. Secondly, the time-varying conditional correlation was analysed using a BEKK-GARCH model. The results showed that gold plays an important role in financial markets with flight-to-quality in times of market distress. Furthermore, the results showed that Bitcoin behaves as the exact opposite and positively correlates with downward markets. The authors concluded that Bitcoin and gold feature fundamentally different properties to assets and linkages to equity markets. These results hold for the broad cryptocurrency index CRIX.

To summarise, the current literature disagrees as to whether Bitcoin can be compared with gold. (Dyhrberg, 2016) concludes that Bitcoin behaviour is somewhere in between gold and the US Dollar while (Baur, Dimpfl, & Kuck, 2017) and (Klein, Pham, & Walther, 2018) conclude that Bitcoin cannot be compared to gold or currencies.

2.5 Statistical properties of gold

Since this study compares the statistical properties of Bitcoin with gold and currencies, it is valuable to describe the current state of literature on the statistical properties of gold and the correlation of gold with other financial assets. This knowledge may be used to make an effective comparison between Bitcoin and gold as financial assets. Due to the similarities between these assets described in Section 2.3, it is possible that theories that explain gold's volatility are applicable to explain the volatility of Bitcoin.

Using an asymmetric GARCH model (Baur, 2011) examined the volatility behaviour of gold. The results suggest that gold exhibits: *an inverted reaction to positive and negative shocks (i.e. positive shocks increase the volatility by more than negative shocks).* The authors suggest that this effect can be explained by a safe haven hypothesis. The hypothesis states that investors interpret positive changes in gold prices as a signal future uncertainty in financial asset markets. This leads to uncertainty in the gold market and therefore to higher volatility.

(Byers & Peel, 2001) use a different approach to investigate the drivers of volatility in gold returns. The main research objective is to determine whether gold has an long memory effect in the variance. The long memory effect in the variance would imply that shocks to the variance are long lived. The results show that gold has an long memory effect in the variance.

Another group of studies focuses on the relationship of gold with other financial assets and if it can serve as a hedge or safe haven. (Baur & Lucey, 2010) tried to answer the question if gold can be used as a hedge or safe haven against stocks indices and bonds. To answer this question the authors calculated the dynamic conditional correlations between gold returns and US, UK and German stock and returns. A hedge is defined as financial asset that is uncorrelated with stock indices and bonds on average and a safe haven is defined as a financial asset that is uncorrelated with stock and bonds returns in a market crash. Results show that gold can be used as a hedge against stocks and as a safe haven in times of a market crash. However, a portfolio analysis shows that the safe haven property of gold is short-lived.

Whereas (Baur & Lucey, 2010) focused on the relationship of gold with stocks and bonds, (Capie, 2005) examined gold as a possible hedge asset in relation to currency portfolios. The authors examined if gold can be used as a hedge against currency pairs. Especially as a hedge against Yen/USD and Sterling/USD exchange rates. The authors concluded that in some periods gold can act as hedge against currencies, however the hedging ability varies over time and is based on unpredictable political and economic events. The theory that is given why gold is a hedge against the dollar is that it seems sensible when the dollar is losing value, investors may exchange their dollars for gold what leads to a rise in gold price on average.

To summarise this section, several academic papers have concluded that gold has an inverted asymmetric reaction to positive and negative shocks (i.e. positive shocks increase the volatility by more than negative shocks). Furthermore, several academic papers have concluded that gold has a long memory effect in the variance. Regarding the correlation of gold with other financial assets, it can be concluded that gold can be used as a hedge against stock and bond markets and as a safe haven in extreme market conditions.

2.6 Bitcoin as a currency

This section provides a summary of the academic literature concerning whether Bitcoin can be considered a currency. This is valuable to assess if Bitcoin shares statistical properties with currencies, because this research aims to determine whether Bitcoin can be considered a currency or an alternative asset.

A question that different researchers tried to answer is whether Bitcoin is a real currency or rather it is merely an asset that is traded based on speculation and owner sentiments as opposed to macroeconomic data. A research by (Lynch, 2013) noted that an important issue facing Bitcoin that impacts its ability to be treated as a real currency is the high level of volatility in its value. The research explained that the high volatility in the value of Bitcoin is an indication that Bitcoin's value is based primarily on speculation. In turn, the large volatility in the value of Bitcoin reduces the desire of people to accept it as a currency due to the fear that its value will significantly change, and particularly if its value declines, from day to day or week to week.

(Badev & Chen, 2014) concluded from their research of Bitcoin that the cryptocurrency has a fairly low transaction volume as compared to the overall volume of transactions in the payment system of the United States. In this regard, Bitcoin is not being widely used as a means of conducting day to day transactions. From a critical standpoint, it could be argued that the low transaction volume of Bitcoin is a further indication that it is more of a speculative investment rather than a serious currency that users can trust for making daily purchases. People who own Bitcoin are not acquiring the cryptocurrency with the intention of using it in place of U.S. Dollars or other currencies. Instead, they are acquiring Bitcoin to attempt to take advantage of its high volatility as a means of making money as would occur with any other asset.

The idea that Bitcoin is being acquired with the intent of generating profits rather than replacing existing currencies was found to be occurring in the research conducted by (Glaser, 2014) in which data regarding Bitcoin was examined in order to determine if it can be viewed as a currency or an asset. An important finding in the study was that new users of Bitcoin generally traded it as a speculative investment rather than used it as a daily currency for making purchases. The argument could be made that if people truly viewed Bitcoin as a new currency that they trusted more than the U.S. Dollar or other major currencies around the world, they would acquire Bitcoins and use them in place of other currencies. Instead, it seems that new owners of Bitcoin are more engaged in attempting to taking advantage of the change in value of Bitcoin as a means of generating returns and profits.

(Yermack, 2015) also explained from an economic examination of Bitcoin that the cryptocurrency behaves more like an investment in which owners are engaged in speculation than as a currency. The researcher further explained that Bitcoin faces the threat of theft due to hacking, and does not have the same protections from banks, such as deposit insurance, as other currencies. Even more, Bitcoin is not used as a means of providing credit to consumers or loan contracts. In this regard, Bitcoin does not have the strength as currencies, and people who use Bitcoin do not have the same protections that they have with other currencies.
A different research method for analysing the characteristics of Bitcoin is to analyse transaction data instead of return data. (Baur, Hong, & Lee, 2018) examined if Bitcoin is a medium of exchange or a speculative asset. Analysing the statistical properties of Bitcoin's returns, the authors conclude that Bitcoin is uncorrelated with conventional asset classes as stocks, bonds and commodities. From the analyse of the transaction data of Bitcoin accounts the authors conclude that Bitcoin is used as speculative investment rather as an currency and medium of exchange.

Based on these studies, it seems that Bitcoin cannot be viewed as a currency. Instead, Bitcoin is still a speculative investment that is purchased and exchanged almost entirely for the sake of generating profits. The large volatility in the value of Bitcoin makes it difficult to use as a currency because people have a lack of trust that the value of Bitcoin will be stable from one day to the next.

2.7 Statistical properties of currencies

Because this study compares the statistical properties of Bitcoin with gold and currencies, it is valuable to describe the current state of literature on the statistical properties of currencies and the correlation of currencies with other assets. Due to the similarities between these assets, it is possible that theories that explain currency's volatility are applicable to explaining the volatility of Bitcoin.

(Wang, 2006) examined if bilateral exchange rates and trade-weighted indices have an asymmetric return volatility relationship. The authors conclude that there is a statistical significant asymmetric volatility in the daily volatilities of the AUD, GBP and JPY against the USD. The asymmetry per currency is stable and do not differ over a period of several years. (McKenzie, 2002) attempted to find an explanation for the presence of asymmetric shocks in the variance of exchange rates. For stock indices this phenomenon is explained by the leverage effect. However, for exchange rates, there is no economic reason for the asymmetric shocks in the variance. Therefore, the authors tested a hypothesis that the asymmetric responses in exchange rate volatility is due to the intervention of central banks. Empirical evidence showed support of this hypothesis and suggest that intervention is the economic reason for asymmetric volatility in exchange rate markets.

To summarize, (Wang, 2006) concludes that there is an asymmetric return volatility relationship in different currency pairs. (McKenzie, 2002) argues that the asymmetric volatility in exchange rates can be explained by the intervention activities of central banks.

3. Data and Descriptive statistics

This section presents the data that are used in the empirical analyses of this thesis.

Bitcoin

The daily Bitcoin data is collected from Coindesk. Coindesk shows the Bitcoin Price Index (BPI), which is the price of one BTC in USD and uses an average from the world's leading Bitcoin exchanges. This offers an advantage over using data from one exchange, which can create a bias. The data available ranged from January 3, 2011 to June 30 2018, which consisted of 1924 observations. The Bitcoin price chart during this time period can be seen in Figure 1.

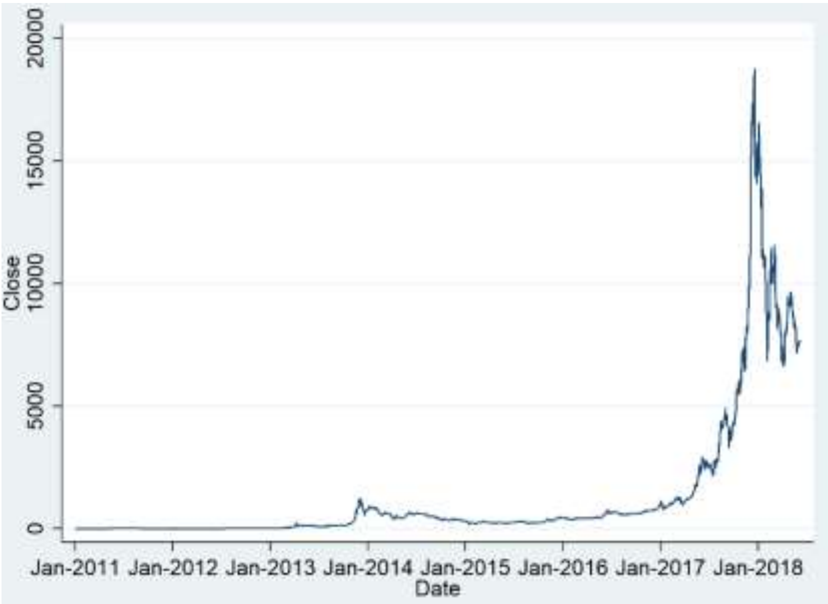


Figure 1: Bitcoin price

From this price chart, we can conclude that Bitcoin exhibited an abnormal price path. The period between January 2017 and June 2018 particularly shows abnormal returns and volatilities. There is no consensus on the economic explanation for the price increase during this period.

Currencies

In order to determine which variables to use to compare Bitcoin's volatility and analyse the correlation, the countries in which Bitcoin is traded most frequently must be considered. To determine in which countries Bitcoin is traded most frequently, the currencies in which Bitcoin is traded were analysed. To analyse this, data was taken from Bitcoinity[1] and the results of the traded volume can be seen in the appendix in Figures 2 and 3.

As can be seen in Figures 2 and 3 in the appendix, the CNY has dominated Bitcoin trading in recent years. The second most traded currency is USD, which is then followed by EUR and JPY. As a result, it can be assumed that China is the most significant external country that influences Bitcoin's volatility, followed by

[1] https://data.Bitcoinity.org/markets/volume/

the United States, the European Union and Japan. As substantiation, (Woo, 2017) shows that the global market share of Chinese exchange trading of Bitcoin before 2013 was negligible and up to 20% rose to a 60% market share in 2014 and 2015. Therefore, this research uses data from China and the United States to analyse the correlation and volatility behaviour. It is possible that the inclusion of Chinese variables will lead to different results compared to current research that focuses on macroeconomic variables from the United States (Baur, Dimpfl, & Kuck, 2017). Therefore, the currency pairs that are used are USD/EUR and CNY/USD.

CRIX Index
In order to test if the results hold for other cryptocurrencies beside Bitcoin, the broad market-weighted cryptocurrency index CRIX (Trimborn, 2016) is included in the dataset of the research. The CRIX price of the CRIX index consists of the top 10 cryptocurrencies in market capitalisation. The CRIX index was retrieved from July 1, 2014 to June 30, 2018 from the website crix.hu.berlin.de.

Gold prices
On top of these variables, this research will use the price of gold because of its shared qualities with Bitcoin and to compare the volatility of Bitcoin and gold. As proxy for the gold returns, the gold price in USD per ounce is used. In order to test if the results hold for silver prices as well, silver prices are also included in the research. As a proxy of the silver returns, the price of silver in USD per ounce is used.

Stock indices
To compare the correlation of bitcoin, gold and currencies the stock indices the S&P 1500 index, the Shanghai composite index and the MSCI world index are included in the dataset.

In conclusion, a dataset of nine time series were collected: the cryptocurrency Bitcoin; the market-weighted cryptocurrency index CRIX; the currency pairs USD/EUR and CNY/USD; the commodities gold and silver; and stock indices the S&P 1500 index, the Shanghai index and the MSCI world index. All of the explanatory variables have missing observations since financial markets are closed during the weekends and holidays.

Using the time series data, the log returns were calculated. The use of log returns is well-documented in empirical finance literature. The log returns are calculated by dividing the price at time *t* by the price on previous day:

$$r_t = \log (P_t / P_{t-1})$$

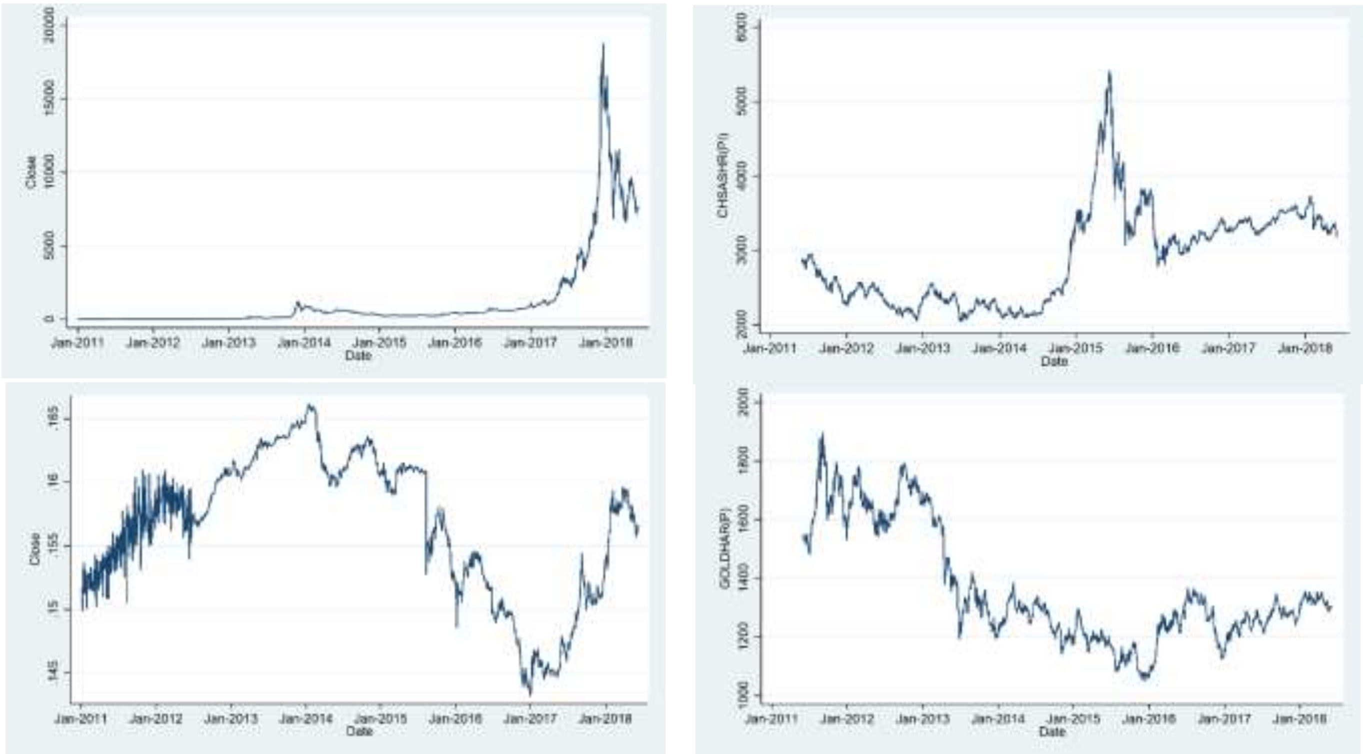


Figure 2: Price development of Bitcoin, Shanghai A Share Index, CNY/USD and gold

Figure 2 shows the price development of Bitcoin, Shanghai Index, CNY/USD and gold. The assets exhibit very different price paths during the research period. Where Bitcoin prices rise significantly to a high of $17.527 on 6th January 2018, gold prices decreased in this period to a price of $ 1,300.70 USD per ounce on 1st June 2018. The CNY/USD exchange rate exhibited a volatile price path during this period; particularly during the period between January 2011 and January 2012, the price CNY/USD fluctuated heavily. During the period between January 2015 and January 2017, the value of the Chinese Yuan decreased to a value of $0.14325 on 29th December 2016. This can be explained by the decline of the Chinese economy during this period. This economic downturn is also shown in the price path of the Shanghai A Share Index, which declined in this same period.

Table 1: Descriptive Statistics

Variables	Obs	Mean	Std.Dev.	Min	Max	p1	p99	Skew.	Kurt.
Bitcoin	1924	.463	6.221	-44.326	54.037	-18.669	21.293	.322	13.734
CRIX	1384	.41	7.348	-25.334	19.85	-12.113	11.161	22.536	715.531
CNY/USD	1576	.001	.546	-2.927	4.514	-1.903	1.952	.533	16.123
USD/EUR	1723	.006	.566	-2.962	2.948	-1.408	1.502	.075	4.804
MSCI	1629	.028	.816	-5.256	4.112	-2.317	2.182	-.612	8.452
Shanghai A	1629	-.001	1.28	-7.934	5.599	-4.14	3.392	-.808	9.667
SP1500	1629	.043	.908	-6.896	4.632	-2.548	2.373	-.524	8.59
Silver	1629	-.053	1.771	-12.997	7.576	-5.337	4.504	-.755	8.613
Gold	1629	-.014	1.051	-9.596	4.839	-2.856	2.557	-.659	10.333

The descriptive statistics show that Bitcoin and the CRIX index behave very differently compared to gold, the currencies and indices such as the MSCI World index. Bitcoin has the highest daily mean return of 0.463%, followed by the CRIX index with 0.41%. The standard deviation provides a similar picture and puts the CRIX index and Bitcoin at the top with a standard deviation of 7.348% and 6.22% followed by silver with 1.77% and the Shanghai Composite Index with 1.28%. The high standard deviation of Bitcoin and CRIX is also shown in the minimum and maximum returns. Bitcoin and CRIX tend to have more extreme values compared to the other financial assets..

4. Research Question

This section will introduce the main research question of this research and how this research question relates to the current scientific research.

It may be concluded from the literature review that Bitcoin was introduced as a currency but that the majority of users treat their Bitcoin investment as a speculative asset rather than a means of payment (Glaser, 2014). Furthermore, Bitcoin has been compared to gold, as the two have many similarities such as limited quantity, easy transportation, easily division, the inability to counterfeit and acceptance as a barter. Furthermore, *neither of them has a nationality or is controlled by a government, and both Bitcoin and gold derive most of their value from the fact that they are scarce and costly to extract* (Dyhrberg, 2016). As it is difficult to define whether Bitcoin is a currency or a commodity (such as gold), an analysis of the variance of Bitcoin, gold and currency pairs will help to define if Bitcoin behaves similarly to well-known financial assets or as something entirely different. A question that should be answered is therefore if Bitcoin behaves as a well-known financial asset or as something in between a currency and commodity.

Research that attempted to answer this question was conducted by (Dyhrberg, 2016) by applying the GARCH framework popular among finance and asset research. Two models were used to investigate the similarities between Bitcoin, gold and the dollar. (Dyhrberg, 2016) used a GARCH model with explanatory variables. The equation that is used is presented in the appendix. To investigate the asymmetrically effect (Dyhrberg, 2016) used an exponential GARCH model as presented in the appendix.

Using this methodology, (Dyhrberg,2016) concluded that Bitcoin has many similarities to both gold and the dollar. For example, its medium of exchange characteristics are clear and Bitcoin has a significant reaction to the federal funds rate, which points to Bitcoin acting like a currency; however, due to the fact that Bitcoin is decentralized, it will never behave exactly like a currency. (Dyhrberg, 2016) concludes that Bitcoin can be compared to gold in that they react to similar variables in the GARCH model, possess similar hedging capabilities and the conditional variance reacts symmetrically to positive and negative returns. The overall conclusion of (Dyhrberg, 2016) *is that Bitcoin is somewhere in between a currency and a commodity due its decentralized nature and limited market size.*

However, (Baur, Dimpfl, & Kuck, 2017) do not agree with following the methodologies chosen by (Dyhrberg, 2016). (Baur, Dimpfl, & Kuck, 2017) conclude: *'since the two GARCH models are estimated for Bitcoin returns, the results cannot yield any information about the volatility of gold or any asset included as explanatory variable. A meaningful comparison is therefore impossible. All other interpretations are also potentially incorrect due to the use of non-stationary data'. Furthermore, the results do not show that "Bitcoin may also be useful for hedging against the dollar". Since the levels of two highly correlated exchange rates are used, it is unlikely that such an effect can be identified from the present results.'*

Due to the shortcomings in the research methodologies chosen by (Dyhrberg, 2016), (Baur, Dimpfl, & Kuck, 2017) proposed an alternative analysis with a sample extended until July 14, 2017 to conclude on the main research objective: *"If Bitcoin behaves like a well-known financial asset or as something in between a commodity and a currency"*. (Baur, Dimpfl, & Kuck, 2017) proposed to answer the research question using the asymmetric GARCH model of (Glosten, Jagannathan, & Runkle, 1993).

In contrast to (Dyhrberg, 2016), (Baur, Dimpfl, & Kuck, 2017) studied returns and volatility separately for each asset class. This allowed the authors to separately compare statistical properties across assets.

The main findings of their research suggest that Bitcoin cannot be compared to either a commodity nor a currency. The findings suggest that Bitcoin has unique risk-return characteristics, follows a different volatility process when compared to other assets and is uncorrelated with other assets. Furthermore, the findings suggest that Bitcoin is not related to changes of the USD. These conclusions are in stark contrast to the findings of (Dyhrberg, 2016).

This thesis will extend the research of (Dyhrberg, 2016) and (Baur, Dimpfl, & Kuck, 2017) on this topic to analyse whether the results still hold if Chinese variables and the CRIX index are added to the dataset. Because the methodology used by (Baur, Dimpfl, & Kuck, 2017) proved to be superior compared to the methodology of (Dyhrberg, 2016), this research will use the methodology used by (Baur, Dimpfl, & Kuck, 2017) to answer the main research question.

Since the Chinese market has a significant influence (Woo, 2017) on Bitcoin price formation, it would be interesting to see if the results of the current research hold if Chinese macroeconomic variables are added into the dataset. Thus, whereas current research focuses on the comparison between Bitcoin and EUR/USD as a currency pair, this research will focus on the comparison between Bitcoin and CNY/USD as currency pair.

The main research question that will be answered in this research is as follows: *How does the return on Bitcoin behave compared to the gold price and CNY/USD exchange rate when analysing the variance of these assets?*

Where current research focusses on the variables Bitcoin, USD/EUR exchange rate, gold and US indices this research will extend this dataset with the CNY/USD exchange rate, the broader cryptocurrencies market index CRIX, silver prices and Chinese indices. This extension of the dataset will lead to new insights in the comparison of Bitcoin with other assets and correlation with other assets. Especially, if the results of earlier research hold with Chinese variables. Furthermore, the inclusion of the CRIX index will give insights of current findings are also applicable to other cryptocurrencies. Where there is currently no scientific research that answers this question these extensions will make this research question scientific relevance to help to define cryptocurrencies as a financial asset. The results of this research can help policy makers and market participants with pricing securities, deciding on the hedging strategy and portfolio selections.

5. Methodology and Hypotheses Development

This section will describe the methodologies that are used in the empirical analysis and the hypotheses that are tested with the empirical analysis.

5.1 Theory ARCH/GARCH models

The OLS model in econometrics is called the "great workhorse" (Engle, 2001). Econometricians frequently are asked to figure out how one variable changes in relation to another variable. However they are also asked to forecast the size of the errors of the model, and to analyze the errors. To analyze and forecast the errors the ARCH and GARCH are the main models. This is because OLS models operates on the assumption that when squared, the expected value of all error terms would be the same at any given point. This is called 'homoscedasticity" and it is the basis of the OLS model. When variances in the error terms are not equal, and some ranges are larger or smaller than others, this is called heteroscedasticity.

When heteroscedasticity is present, regression coefficients on the ordinary least squares regression remains unbiased. However, a false sense of exactness is engendered when the standard errors and confidence intervals produced by the conventional procedures are used. Rather than look at heteroscedasticity as a problem that should be fixed, ARCH models simply consider heteroscedasticity a variance, and one that can be modelled ((Engle R. , 2001). In this way, the least squares deficiencies are corrected. In addition, it is possible to make a prediction for the variances of the error terms, through computation. For financial time series, this is a particularly helpful process.

It is widely known that financial time series have some stylized features: (I) the future value depend on their own lagged what is called (autoregressive), (II) financial time series are dependent on past information (conditional) and (III) exhibit a non-constant variance called (heteroscedasticity). Furthermore the variance of financial time series exhibit two main properties: changes of volatility over time (volatility clustering) and asymmetric effects of conditional volatility to positive and negative shocks.

The ARCH model that was introduced by (Engle, 1982) assumed that conditional volatility is depended on the conditional volatility measured as a linear function of the past squared error terms. However, one shortcoming of this linear ARCH model is the need for a long lag (q) length. Therefore (Bollerslev, 1986) extended the ARCH model and called it the Generalized Autoregressive Conditional Heteroscedasticity or GARCH model. The same as the ARCH model the GARCH model allows the conditional volatility to be a function of past period squared error term, but it includes the past conditional variance as well. Due to this extension it is not necessary to include many lags (q) length.

After the GARCH model was introduced many extensions are created. For example, (Glosten, Jagannathan, & Runkle, 1993) (GJR) that improved the GARCH model in modelling asymmetric shocks to the volatility. Financial time series tend to have an asymmetric response of the conditional variance to positive and negative returns. For stock indices negative returns increase the conditional variance more than positive returns what is known as leveraging effect. Where the ARCH and GARCH models cannot deal with this difference the results of this models can be biased.

News impact curves are used to illustrate the response of conditional variance to positive and negative lagged returns. The positive and negative returns are plotted on the horizontal axis and the conditional variance on the vertical axis. The curve that is shown explains the difference in magnitude of the impact of positive returns and the impact of negative returns. For stock indices generally the negative side is steeper than the positive side. An example of a news impact curve for a stock indices is shown below.

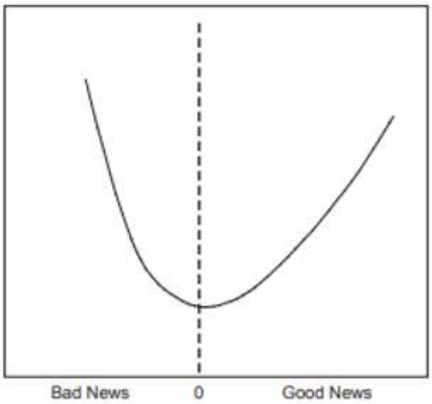


Figure 3: Example of news impact curve

5.2 Application of GARCH models

The research is carried out on the cryptocurrency Bitcoin; the market-weighted cryptocurrency index CRIX; the currency pairs USD/EUR and CNY/USD; the commodities gold and silver; and stock indices the S&P 1500 index, the Shanghai index and the MSCI world index.

Before the asymmetric GARCH (1,1) model is estimated, two statistical preconditions are investigated: clustering volatility and an ARCH effect in the residual. To test this, the residuals of the financial assets are plotted. Graphically, can be confirmed that all assets have clustering volatility in the residuals.

The second precondition that must be tested is whether there is an ARCH effect in the residuals. The presence or absence of an ARCH effect determines whether there is serial correlation of the heteroscedasticity. In order to test this precondition, an ARCH test was conducted. The null hypothesis is that there is no ARCH effect and the alternative hypotheses is the opposite. The results of the ARCH test suggest that for all the assets there is evidence that there is an ARCH effect for all assets in the dataset.

Where the preconditions to run a GARCH model are met the asymmetric GARCH (1,1) model is given below:

$r_t = \alpha + b r_{t-1} + e_t$ (1)

$\sigma_t^2 = \omega + \alpha e^2_{t-1} + \beta\sigma^2_{t-1} + \gamma I(e^2_{t-1})$ (2)

The mean equation is specified in Equation (1) and Equation (2) specifies the variance equation. The mean equation that is used is a function of a constant with a previous day's return and an error term.

The dependent variable of the variance equation is the conditional variance (σ_t^2). This is the one period ahead forecast variance based on past information, also known as the conditional variance. The conditional variance equation is a function of four parameters:

(1) ω is the constant and represents the weighted average long-run variance;

(2) αe^2_{t-1} represents the lagged squared residual return ARCH term;

(3) $\beta\sigma^2_{t-1}$ the influence of previous period's variance on today's volatility (GARCH term);

(4) $\gamma I(e^2_{t-1})$ I is the indicator that takes on a value of 1 if previous error terms are positive and zero otherwise. This parameter (γ) captures whether there is an asymmetric effect in the reaction to positive and negative return to volatility. If there is no asymmetric effect on lagged shocks on the volatility, this parameter is zero or not significant. However, if lagged negative return increase volatility more than lagged positive returns, this parameter will be negative and significant. If lagged positive shocks increase volatility more than lagged negative shocks, this parameter will be positive and significant.

Equation 2 is used to calculate the ARCH term, GARCH term and asymmetric GARCH term. Based on the results of this equation the majority of the hypotheses will be tested. To test the significance of the parameter it is assumed that the conditional error distributions in the GARCH is: the Gaussian (normal) distribution.

The (1,1) in the GARCH (1,1) is a standard notation where the first numbers specifies the number of autoregressive lags/ARCH terms that are used in the equation , and the second number specifies how many moving average lags (GARCH terms) are used in the equation. The GARCH (1,1) is the most commonly used model in financial research.

The size of the parameters of α and β can help to explain the dynamics of the volatility of the return series. This property reflects the mean-reverting characteristic of the GARCH model and therefore a higher $\alpha + \beta$ can be treated as higher volatility persistence level. For example $\alpha + \beta$ is relatively small, the forecast of volatility will converge quicker to the unconditional long run variance. Therefore, the sum of the ARCH and GARCH terms is used to tell how quickly large volatilities decay after a shock. The higher the sum of the ARCH and GARCH term the higher the volatility persistence of an asset. The asymmetric GARCH equation will be regressed for all assets separately to detect the differences in parameters in the financial assets.

5.3 Hypotheses

This section will describe the hypotheses that are tested to answer the research question of this thesis.

To answer the research question, several aspects of the price volatility of Bitcoin, gold and CNY/USD were analysed. Firstly, the correlations between gold prices, Bitcoin prices, currencies and stock prices were calculated to detect any relationships between the different assets.

The hypothesis that will be tested using the correlation analysis is:

Hypothesis 1: Bitcoin is not correlated to other financial assets in the dataset where gold and currencies are related with the other financial assets in the dataset. The differences will indicate that Bitcoin does not behave as a currency or a commodity.

H 1: ϱ between BTC and the assets (CNY/USD, USD/EUR, MSCI, Shanghai A, SP1500, Silver, Gold) is <0.05.
H 0: ϱ between BTC and (CNY/USD, USD/EUR, MSCI, Shanghai A, SP1500, Silver, Gold) is > 0.05

Secondly, an asymmetric GARCH model was used to detect differences among the financial assets in the volatility processes across assets. The equation that is used to detect differences among financial assets is:
$\sigma t^2 = \omega + \alpha_1 e_{t-1^2} + \beta_1 \sigma^2 t{-1} + \gamma I\ (e^2{}_{t-1})$.

The hypothesises that are tested with the results of this equation are:

Hypothesis 2: The hypotheses is that Bitcoin and gold differ from the CNY in that these assets have a positive significant asymmetric GARCH term and CNY has a negative significant asymmetric GARCH term. The difference will indicate that Bitcoin behaves as investment asset like gold instead of a currency.

H 1: asymmetric term (γ) for Bitcoin and Gold is positive and statistical significant at 0.05 level. What means that for Bitcoin and Gold positive returns increase the conditional variance more than negative returns.
H 0: asymmetric term (γ) for Bitcoin and Gold are negative and/or not statistical significant at 0.05 level.

Hypothesis 3: The volatility persistence measured by the sum of $\alpha + \beta$ for Gold and Bitcoin will be the most persistent compared to the other assets in the dataset. The differences will indicate that Bitcoin behaves more as an investment asset instead of a currency.

H 1: Volatility persistence measured by $\alpha + \beta$ will be higher for Bitcoin and Gold than other assets in the dataset
H 0: Volatility persistence measured by $\alpha + \beta$ will be lower for Bitcoin and Gold than other assets in the dataset

The hypothesis that will be answered with adding the returns of the US Dollar to the mean equation is:

Hypothesis 4: There is not a statistical significant relation between the lagged returns of Bitcoin and returns of the US Dollar. This hypothesis will be answered with the following regression: $rt = \alpha + br_{t-1} + usdr + e_t$

H 1: The parameter USD is not statistical significant at the 0.10 level.
H 0: The parameter USD is statistical significant at the 0.10 level.

The hypothesis that will be answered with adding the returns of the Chinese Yuan to the mean equation is:

Hypothesis 5: There is a statistical significant relation between the lagged returns of Bitcoin and returns of the Chinese Yuan. This hypothesis will be answered with the following regression: $rt = \alpha + br_{t-1} + cnyr + e_t$

H 1: The parameter CNY is statistical significant at the 0.10 level.
H 0: The parameter CNY is statistical insignificant at the 0.10 level.

Finally, the news impact curves are defined by the functional relationship between variance and lagged returns holding all other variables constant. The hypothesis that are answered with the news impact curves is:

Hypothesis 6: For Bitcoin and Gold the positive side of the news impact curve will be steeper comparing it with the negative side. For the CNY/USD the opposite is shown.

H 1: For Bitcoin and Gold the positive side of the news impact curve will be steeper comparing it with the negative side. For CNY/USD the opposite is shown.
H 0: For Bitcoin and Gold the positive side of the news impact curve is not steeper comparing it with the negative side. For CNY/USD the opposite is shown.

6. Results

Table 2: Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Bitcoin	1.000								
(2) Crix	0.732*	1.000							
(3) CNY/USD	0.058*	-0.003	1.000						
(4) USD/EUR	-0.018	-0.002	-0.280*	1.000					
(5) MSCI	0.035	-0.028	0.264*	-0.323*	1.000				
(6) Shanghai A	0.022	-0.017	-0.020	-0.006	0.170*	1.000			
(7) SP1500	0.040	-0.022	0.248*	-0.235*	0.914*	0.099*	1.000		
(8) Silver	0.002	0.001	0.052*	-0.220*	0.213*	0.080*	0.082*	1.000	
(9) Gold	0.044	0.051	0.039	-0.210*	0.087*	0.063*	-0.016	0.692*	1.000

* shows significance at the .05 level

Hypothesis 1:
Table 4 represents the correlations of Bitcoin returns with all other returns. It shows that Bitcoin's returns are only correlated with CRIX and the CNY-USD exchange rate. The correlation with CRIX was expected due to the high correlation among different cryptocurrencies. The statistically significant correlation at the .05 level of Bitcoin and CNY-USD exchange rate do not confirm the expectation that Bitcoin is not related to other financial assets. The results show that is valuable to include the CNY/USD exchange rate in the dataset. The poor correlation between Bitcoin and CNY/USD implies that Bitcoin reacts partially to the same variables as the CNY/USD exchange rate. If Bitcoin reacts to the same variables as an established currency pair, one could argue that Bitcoin is beginning to behave as a currency. Due to the fact that the trading volume of Bitcoin in the Chinese Yuan differs per period, it is interesting to test if the correlation between CNY/USD is present in the entire period of the dataset. Therefore, the correlation was calculated for two different periods in the dataset. A subset is created for the period January 1, 2011 until December 31, 2015 and a subset if created for the period January 1, 2016 until June 30, 2018. Results are shown in Table 5 and Table 6 in the Appendix. The results show that the correlation between Bitcoin and CNY/USD decreased slightly in the second subset.

Where Bitcoin is only correlated to CRIX and CNY/USD, the correlation analysis suggests that Bitcoin is not related to gold, the US dollar or stock markets. In comparison gold, is negatively correlated with the USD/EUR exchange rate and positively correlated with the MSCI world and Shanghai Composite Index. If the correlations of Bitcoin and gold are compared, it may be concluded that Bitcoin behaves differently than gold. The only similarity observed is that gold and the Standard and Poor's 1500 are mostly uncorrelated as well, but this alone does not qualify Bitcoin as being similar to gold.

If the correlation of Bitcoin is compared to the correlation of traditional currency pairs, it is remarkable that Bitcoin is not related to the other financial assets in the dataset. In contrast with Bitcoin, the USD/EUR exchange rate is correlated with all the other assets except for Bitcoin, CRIX and the Shanghai Composite Index. In addition to the USD/EUR exchange rate, the CNY/USD is also correlated with all other assets except for the Shanghai Composite Index and gold prices. Hence, as exchanges rates are correlated with almost all other classes with the exception of Bitcoin, Bitcoin appears to behave differently from traditional currencies.

To conclude, the results do not completely confirm the hypothesis that Bitcoin is not related to the other assets due the correlation with the CNY/USD exchange rate. However, this analysis suggest that Bitcoin returns do not behave like a well-known asset or as something in between a commodity and a currency.

6.1 Comparing volatility processes across assets

This section describes and discusses the estimated results of the asymmetric GARCH model. The main findings of the asymmetric GARCH model are presented in Table 3. This table shows the estimated coefficients and standard errors of the asymmetric GARCH model specified in equation 1 and 2. To detect differences among the financial assets the GARCH model is specified for all assets separately.

Table 3: Regression results Asymmetric GARCH model

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Bitcoin	CRIX	CNY	EUR	MSCI	Shanghai	SP1500	Silver	Gold
AR(1)	.0560**	-0.002	0.106***	-0.021	0.088***	0.015	-0.049**	-0.037	0.009
	(.024)	(0.029)	(0.028)	(0.024)	(0.024)	(0.026)	(0.022)	(0.023)	(0.029)
Constant	0.338***	0.226***	-0.003	0.007	0.028**	0.018	0.039**	-0.038	-0.010
	(0.090)	(0.079)	(0.007)	(0.011)	(0.014)	(0.022)	(0.016)	(0.037)	(0.022)
Variance:									
α (ARCH)	0.076***	0.193***	0.179***	0.014***	0.225***	0.050***	0.288***	0.030***	0.044***
	(0.007)	(0.015)	(0.021)	(0.004)	(0.024)	(0.005)	(0.029)	(0.003)	(0.005)
γ (AGARCH)	0.068***	0.019	-0.053**	0.021***	-0.195***	0.002	-0.310***	-0.006	-0.017***
	(0.009)	(0.020)	(0.023)	(0.005)	(0.024)	(0.007)	(0.029)	(0.006)	(0.004)
B(GARCH)	0.898***	0.815***	0.814***	0.973***	0.848***	0.948***	0.822***	0.968***	0.956***
	(0.004)	(0.010)	(0.010)	(0.005)	(0.014)	(0.004)	(0.016)	(0.004)	(0.004)
α + B	0.974	1.008	0.993	0.987	1.073	0.998	1.11	0.998	1.00
Constant	0.182***	0.295***	0.004***	0.001***	0.017***	0.005***	0.034***	0.015***	0.009***
	(0.025)	(0.033)	(0.000)	(0.000)	(0.002)	(0.001)	(0.004)	(0.004)	(0.002)
Observation	1924	1383	1800	1926	1826	1826	1826	1826	1826

Standard errors are in parenthesis *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ $\sigma t^2 = \omega + \alpha_1 e_{t-1}^2 + \beta_1 \sigma^2_{t-1} + \gamma I\ (e^2_{t-1})$

From the mean equation, it can be concluded that Bitcoin and CRIX do have the highest average returns of all assets. More specifically, the constant terms of the mean equation of Bitcoin and CRIX are 0.338 and 0.226, whereas the constant terms of the other assets vary between -0.003 and -.0.010. Furthermore, from the mean equation it can be concluded that for Bitcoin, CNY/USD and the MSCI index, lagged returns are a statistically significant predictor of future returns.

The volatility equation demonstrates that Bitcoin and CRIX exhibit highly volatile processes compared to the other assets: the constant in the volatility equation is the highest, confirming that Bitcoin and CRIX returns are the most volatile. The lowest constant in the volatility can be found for the exchange rates CNY/USD and EUR/USD, confirming that these currencies are the least volatile.

All variables have a statistically significant α ARCH coefficient. This shows that for all the variables, the former's day conditional volatility is a predictor for current conditional volatility.

Hypothesis 2:
The asymmetric GARCH term (γ) of Bitcoin shows a statistically significant positive coefficient which is in stark contrast to all other assets' asymmetric effects. This conforms to our expectations in the hypothesis, in which we concluded that for Bitcoin, positive shocks increase the conditional volatility by more than negative shocks whilst for currencies and stock indices we concluded the opposite. However, gold shows a statistically significant negative sign. This is different than expected in the hypothesis where is concluded that for gold positive shocks increase the variance more than negative shocks . The results show that that positive shocks increase the volatility more than negative shocks for Bitcoin whilst this asymmetry is the opposite for all the other assets in the dataset. It is remarkable that this finding is different for the CRIX index. It was expected that the CRIX index would also have statistically significant positive coefficient and that these findings would be applicable to other cryptocurrencies as well.

The difference in these findings may be due to the fact that the CRIX index represents a different time period. The CRIX index represents the period from July 1, 2014 to June 30, 2018 whereas the Bitcoin was obtained for the period from January 1, 2011 to June 30, 2018. To test if these findings were due to a difference in time period, the asymmetric GARCH term of Bitcoin was calculated for two different subsets of the dataset. The first subset consists of returns between January 1, 2011 to June 30, 2014 and the second subset consist of Bitcoin returns between July 1, 2014 to June 30, 2018. Results are shown in the Appendix in Tables 7 and 8.

These findings show that the difference between CRIX and Bitcoin is not due to the difference in time period. In both sub periods, there is a statistically significant asymmetric GARCH term. This shows that the findings are not applicable to all cryptocurrencies.

Based on both subsets, we find that Bitcoin is not similar to gold based on the variance behaviour. For Bitcoin, positive shocks tend to increase volatility more than negative shocks. This contradicts the findings of (Dyhrberg, 2016), who does not find a significant asymmetric effect. However, for gold returns, the opposite is shown. Gold tends to have a higher volatility if the former day's residual was negative. This contradicts with the literature review, where it was concluded that gold tends to have a higher volatility if the former day's residual was positive. This difference in findings may be due to the chosen time period, which differs from the time periods used for the research in the literature review.

To conclude, the results do not confirm the hypothesis that both Bitcoin and Gold do have an statistical significant negative asymmetric GARCH term. All variables have a statistically significant GARCH term. This was expected due to the fact that all variables have an significant ARCH effect.. This shows that the previous day's volatility of Bitcoin does influence today's volatility of Bitcoin (GARCH).

Hypothesis 3:
The test for volatility persistence the sum of $\alpha + \beta$ is used. The results of this sum can be found in the Table 6 regression results. The estimates show that CRIX, gold and the stock indices SP1500 and the MSCI world do have the highest volatility persistence where the value is equal or higher than 1. For all other variables, the respective sum is equal to or smaller than one. These results suggest that Bitcoin cannot be compared to gold and behaves more similar to the Chinese yuan. This results does not hold for the CRIX index that tends to have a same volatility persistence as gold. To conclude, the results do not confirm the hypothesis that Bitcoin and Gold have the highest volatility persistence.

Hypothesis 4:
To analyse if the variables are related to changes in value of the USD, the USD/EUR exchange rate was added to the main equation. The results of the GJR-GARCH (1,1) with the USD/EUR added in the mean equation can be found in Table 4.

Table 4 : Regression results with USD/EUR

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Bitcoin	CRIX	CNY	MSCI	Shanghai	SP1500	Silver	gold
Mean eq:	$rt = \alpha + br_{t-1} + usdr + e_t$							
AR(1)	0.056**	0.120***	-0.143***	0.103***	0.014	-0.035	-0.041*	0.007
	(0.025)	(0.039)	(0.018)	(0.021)	(0.026)	(0.024)	(0.024)	(0.029)
USD	-0.042	0.117	-0.054***	-0.337***	-0.034	-0.201***	-0.772***	-0.432***
	(0.132)	(0.244)	(0.009)	(0.021)	(0.042)	(0.018)	(0.058)	(0.033)
_cons	0.302***	0.202	-0.012*	0.021	0.017	0.036**	-0.038	-0.014
	(0.092)	(0.160)	(0.007)	(0.014)	(0.022)	(0.016)	(0.037)	(0.022)
Variance eq:	$\sigma t^2 = \omega + \alpha_1 e_{t-1}^2 + \beta_1 \sigma^2_{t-1} + \gamma I\ (e^2{}_{t-1})$							
A (ARCH)	0.090***	0.512***	0.616***	0.236***	0.054***	0.305***	0.037***	0.064***
	(0.009)	(0.083)	(0.059)	(0.026)	(0.006)	(0.031)	(0.004)	(0.005)
γ (AGARCH)	0.058***	-0.241***	-0.374***	-0.244***	0.006	-0.333***	-0.000	-0.025***
	(0.010)	(0.085)	(0.053)	(0.027)	(0.008)	(0.031)	(0.007)	(0.006)
B (GARCH)	0.890***	0.439***	0.567***	0.856***	0.941***	0.819***	0.958***	0.942***
	(0.005)	(0.104)	(0.025)	(0.014)	(0.004)	(0.016)	(0.004)	(0.004)
Constant	0.217***	4.430***	0.011***	0.017***	0.006***	0.033***	0.016***	0.009***
	(0.030)	(1.457)	(0.001)	(0.002)	(0.002)	(0.004)	(0.005)	(0.002)
Observation	1918	779	1751	1802	1802	1802	1802	1802

The coefficient estimated shows that Bitcoin returns are not related to changes of the USD, while the other assets in the dataset (except for Shanghai A Share index and CRIX) exhibit a statistical significant relationship the changes in value for the USD. More particularly, the estimated parameter is -0.042 for Bitcoin returns and between -0.054 and -0.772 for the other assets, indicating that the returns of the USD are negatively related to all assets except for Bitcoin and CRIX. This finding is in line with (Baur, Dimpfl, & Kuck, 2017), who conclude that Bitcoin is the only asset that is not related to changes in the USD. A possible explanation for this result is that the high volatility of Bitcoin returns influence any movements in USD that can create a relationship between those two variables. To conclude, the results confirm the hypothesis that there is no significant relationship between the returns of USD and bitcoin. The coefficients estimated in the variance equation further show that the inclusion of the US Dollar in the mean equation does not lead to major qualitative changes of the results.

Hypothesis 5:
Due to high trading volume in the CNY, I concluded that China dominated Bitcoin trading during the timespan of the research. Therefore, it is interesting to analyse if Bitcoin is related to changes in value of the CNY. To test this, the CNY/USD exchange rate is added to the main equation. The results of the GJR-GARCH (1,1) with the CNY/USD added in the mean equation, can be found in Table 5.

Table 5: Regression results with CNY/USD in the mean equation

	(1) Bitcoin	(2) EUR	(3) CRIX	(4) MSCI	(5) Shanghai	(6) SP1500	(7) Silver	(8) gold
Mean eq:	$rt = \alpha + br_{t-1} + cnyr + e_t$							
AR(1)	0.064**	-0.012	-0.002	0.128***	0.025	-0.021	-0.051*	0.001
	(0.028)	(0.024)	(0.036)	(0.025)	(0.027)	(0.023)	(0.029)	(0.028)
CNY	-0.110	-0.307***	-0.697*	0.361***	-0.017	0.305***	0.342***	0.347***
	(0.158)	(0.026)	(0.367)	(0.035)	(0.052)	(0.034)	(0.067)	(0.043)
Constant	0.293***	0.007	0.231*	0.016	0.017	0.038**	-0.052	-0.011
	(0.097)	(0.012)	(0.119)	(0.015)	(0.023)	(0.017)	(0.041)	(0.024)
Var. eq:	$\sigma t^2 = \omega + \alpha_1 e_{t-1}^2 + \beta_1 \sigma^2_{t-1} + \gamma I\ (e^2_{t-1})$							
α	0.137***	0.012***	0.196***	0.229***	0.054***	0.312***	0.168***	0.028***
	(0.011)	(0.004)	(0.021)	(0.023)	(0.006)	(0.031)	(0.020)	(0.003)
Γ	0.078***	0.019***	0.056*	-0.245***	0.000	-0.362***	-0.127***	-0.013***
	(0.015)	(0.005)	(0.029)	(0.023)	(0.008)	(0.032)	(0.032)	(0.003)
Β	0.844***	0.976***	0.788***	0.857***	0.944***	0.816***	0.109	0.974***
	(0.007)	(0.004)	(0.015)	(0.015)	(0.004)	(0.015)	(0.120)	(0.003)
Constant	0.368***	0.001***	0.633***	0.022***	0.006***	0.041***	2.351***	0.005***
	(0.049)	(0.000)	(0.085)	(0.003)	(0.001)	(0.004)	(0.355)	(0.002)
Observation	1793	1800	918	1697	1697	1697	1697	1697

Standard errors are in parenthesis
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The coefficient estimated shows that Bitcoin returns (in agreement with the USD) are not related to changes of the CNY. More specifically, the coefficient estimated is (-0.110) and not statistically significant. However, the CRIX index is related to the changes in CNY/USD exchange rate. More specifically, the coefficient estimated is -0.697 and statistically significant at the 0.10 level. This finding may be due to the difference in time period or it is possible that other cryptocurrencies in the CRIX index are related to the CNY/USD and Bitcoin is not. To test if the difference was due to a difference in time period, the regression results were estimated for two different time periods. The first subset consists of the time period January 1, 2011 to June 30, 2014 and the second subset consisted of data between July 1, 2014 to June 30, 2018. The results are shown in Tables 9 and 10 in the appendix.

Based on these tables, it may be concluded that the difference in findings is due to the difference in time period. Whereas in the first subset there is no significant relationship between Bitcoin and CNY, in the second subset there is a negative significant coefficient estimated at the 0.05 level.

The results show that Bitcoin is statistically significant related to changes in the CNY/USD exchange rate in the second subset. The begs the question as to what drives this relationship. A possible explanation is that Bitcoin reacts to the same variables as CNY/USD, which may be an indication that it starts to behave as a currency. This indicates that Bitcoin is beginning to react to the same variable as the CNY. The coefficients estimated in the variance equation further show that the inclusion of the Chinese Yuan in the mean equation does not lead to major qualitative changes of the results.

To conclude, the results confirm the hypothesis that there is a statistical significant relation between the lagged returns of Bitcoin and returns of the Chinese Yuan. However, it is not present in the complete time period of the research.

Hypothesis 6:
The news impact curves give a simple way to identify the impact of recent shocks on next periods conditional volatility. This provides a way to illustrate the differences in volatility behaviour between gold, Bitcoin and CNY/USD in more detail and in a graphical way. The relation between lagged returns and the conditional variance of a given asset is demonstrated in figures 5-7 with the news impact curves for gold, bitcoin and CNY denominated in USD. The lagged returns are shown on the horizontal axis and the conditional volatility is shown on the vertical axis; the curve is based on the parameter estimates of the asymmetric GARCH model.

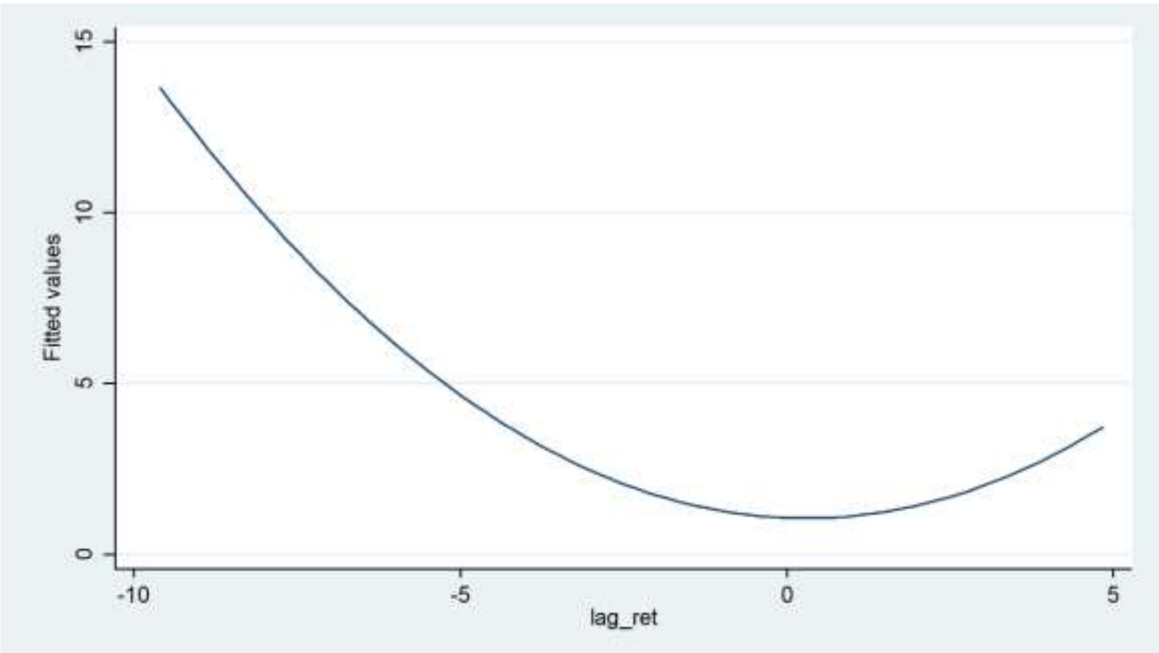


Figure 5: Gold impact returns

Figure 5 demonstrates that negative returns of gold have a larger impact on the conditional volatility than positive returns. The graphical representation demonstrates the magnitude of the asymmetric effect in terms of volatility change. For example, the conditional volatility of the daily gold return in USD is 0.05 for shocks equal to -5% and 0.04 for shocks equal to 5%. Therefore, on average, the increase in volatility is higher when previous returns are negative compared to when a previous return is positive. It is clear to see that for the negative returns there is a steeper line than for positive returns. This is different as expected in hypothesis 6 where the opposite is expected.

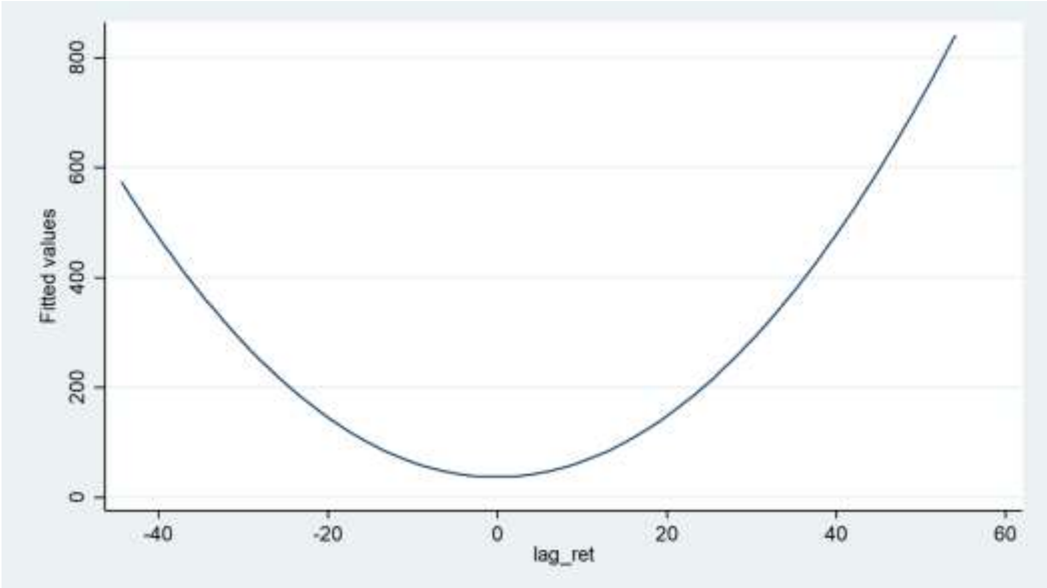


Figure 6: Bitcoin impact curve

The values on the horizontal axes show that Bitcoin exhibits more extreme price movements than gold. The values shown begin at -40 and end at +60. The values on the vertical axes show that the conditional volatility of Bitcoin is also larger compared to gold. The graph illustrates that positive returns of Bitcoin have a larger impact on its volatility than negative returns. However, as shown in Figure 6, the difference between positive and negative returns are more difficult to detect in the graph due to the more extreme values in the returns. Thus, although it is concluded Table 4 that the asymmetric term is statistically significant, the news-impact curve shows that the difference between the positive and negative returns on the variance is difficult to present graphically due to the extreme returns. However, based on the curve can be concluded that positive shocks increase the conditional volatility by more than negative shocks.

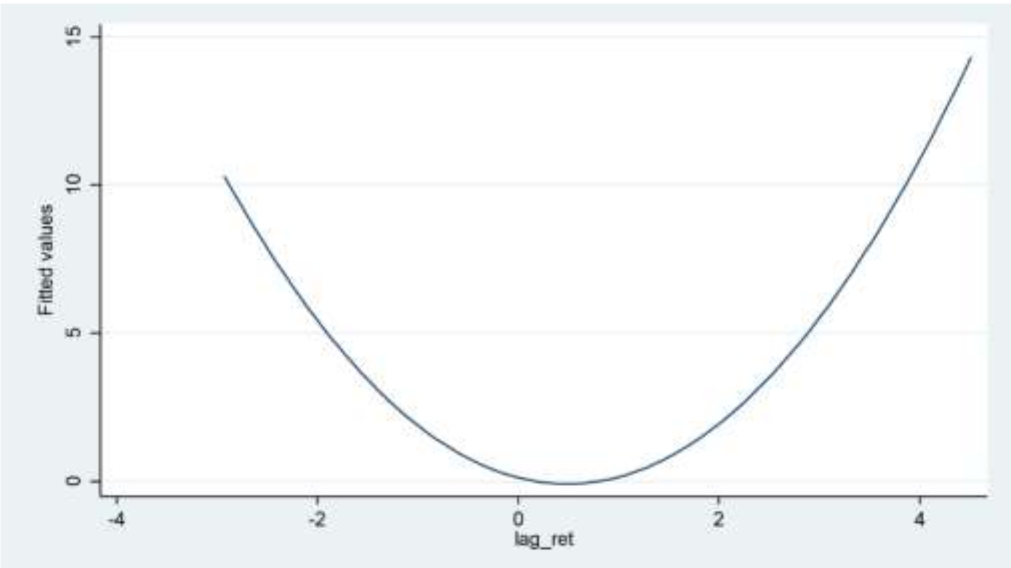


Figure 7: CNY/USD

The graph of CNY/USD shows most clearly the difference in reaction to positive and negative shocks compared to the other graphs. This is also caused by the small distribution of the returns. The graphs of CNY/USD illustrate that negative returns have a large impact on the conditional volatility of the CNY/USD exchange rate than positive returns. More specifically, a decrease of 2% in returns leads to a rise in conditional volatility of 5% and a rise of 2% in returns leads to a rise in conditional volatility of 2.5% on average. For the CNY/USD it is clearly that for negative shocks the line is steeper than for positive returns. This confirms the hypothesis 6 that for the CNY/USD exchange rate the negative returns do have a bigger influence on the conditional variance as positive returns.

The news impact curves help to give a graphical representation of the asymmetric GARCH term presented in Table 4. While it is clear that CNY/USD negative returns have a larger effect on the conditional variance, for Bitcoin the differences between positive and negative shocks are harder to detect due to the higher standard deviations of returns. Finally, for gold, the differences are easier to detect and show that negative returns have a larger effect on the variance compared to positive effects. The results of the news impact curves confirm the results from Table 4, where it is concluded that for Bitcoin positive returns have a larger impact on volatility compared to negative returns.

The differences shown in the news impact curves can have substantial implications for portfolio selections and asset pricing. If volatility can be predicted after major news event this can lead to a reduction in risk of holding the assets. Therefore any differences in predicted volatility after good or bad news can lead to important differences in option pricing and dynamic hedging strategies.

To conclude, the results of this section do not confirm the hypothesis that for Bitcoin and Gold the positive side of the news impact curve will be steeper comparing it with the negative side. For CNY/USD the opposite is shown. Because for gold the negative side of the news impact curve is steeper and this differs from the expected outcome.

7. Discussion

This section discusses and compares the findings with the current literature.

The hypotheses tested with the empirical analysis are that Bitcoin and gold differ from the CNY in that Bitcoin and gold have a positive significant asymmetric GARCH term and CNY has a negative significant asymmetric GARCH term. However, the results showed that Bitcoin is the only asset in this time period that has an positive and significant asymmetric GARCH parameter. This results indicates that in the time period of the research Bitcoin behaves a unique assets and cannot be compared to gold neither the CNY exchange rate.

Furthermore the analysis of volatility persistence gave some surprising findings. Where was expected that both Bitcoin and Gold would differ from the other assets with a higher volatility persistence. The results showed that the highest volatility persistence is shown for CRIX, gold and the stock indices. This results suggest that Bitcoin cannot be compared to Gold and behaves more similar to the Chinese Yuan.

Where there is still not much scientific research on Bitcoin and cryptocurrencies the findings of this study are interesting for investors helping to determine how Bitcoin behaves compared to other assets. With the results of the study investors do have a better understanding what drives the volatility of cryptocurrencies and how the volatility of cryptocurrencies behaves compared to other assets. This helps to define if bitcoin behaves as a currency or commodity. The definition of cryptocurrencies as financial asset can be valuable information for investors whether to include cryptocurrencies into an investment portfolio. Where this thesis concludes that Bitcoin does not behave as a currency neither a commodity but as a speculative asset. It is advised to investors not to include cryptocurrencies into an investment portfolio. Due to uncertain definition of Bitcoin as a financial asset, holding Bitcoin in an investment portfolio comes with great risk because it is hard to predict how it will behave in the near future.

The findings of this study are also interesting for the Commodity Futures Trading Commission (CFTC). The CFTC has officially declared Bitcoin a commodity such as gold or silver. However, this thesis concludes that Bitcoin behaves different compared to commodities as gold and silver. Therefore, it is questionable if it is justified that the CFTC declared Bitcoin as a commodity.

The findings of this thesis confirms the findings of (Yermack, 2015) and (Baur, Dimpfl, & Kuck, 2017), which concluded that Bitcoin cannot be compared with gold or fiat currencies based on statistical properties. The findings also correspond with (Klein, Pham, & Walther, 2018), who concluded that Bitcoin and gold cannot be compared based on statistical properties. This thesis also confirmed the finding of (Cermak, 2017) that Bitcoin is related to the Chinese Yuan and suggests that Bitcoin is beginning to react to the same variables as the CNY. However, the findings of this thesis disagrees with the findings of (Dyhrberg, 2016), which concluded that Bitcoin is something in between a currency and a commodity. The study disagrees with the findings of (Baur, 2011), because the results does not find a significant positive asymmetric GARCH term for gold returns. Whereas (Baur, 2011) finds a positive asymmetric GARCH term for gold returns and uses this as an explanation for the safe haven hypothesis, this study does not find support to substantiate this statement.

This thesis also disagrees with (Bouri, Azzi, & Dyhrberg, 2017) that states the positive asymmetric GARCH of Bitcoin can be explained by the safe haven property. As Bitcoin is not related to stock indices, this suggests that the safe haven hypothesis cannot explain the asymmetric GARCH term of Bitcoin.

8. Conclusion

Based on recent data up to June 2018, we revisited the conditional volatility modelling of Bitcoin returns and updated the results of previous applications of GARCH-class models on Bitcoin and gold prices performed by (Baur, Dimpfl, & Kuck, 2017) and (Dyhrberg, 2016). The method used by (Baur, Dimpfl, &

Kuck, 2017) was followed, which led to the use of a correlation analysis and the asymmetric GARCH model proposed (Glosten, Jagannathan, & Runkle, 1993). Our results indicate that the inclusion of CNY/USD as a currency pair with the dataset and the CRIX index as a robustness check is a valuable extension of the dataset and offers interesting findings. From the correlation analysis, it may be concluded that there is a statistically significant correlation at the .05 level of Bitcoin and CNY-USD. This confirms our expectation that Chinese macroeconomic parameters have an influence on Bitcoin's price formation. Furthermore, the correlation analysis provides evidence that Bitcoin behaves entirely differently than gold or the CNY/USD exchange rate. Whereas gold is related to different stock indices and currency pairs, Bitcoin is only weakly related to the CNY/USD exchange rates. Furthermore, although the CNY/USD is related to almost all other financial assets in the dataset, Bitcoin is not related to stock indices and gold prices. Therefore, the correlation analysis suggests that Bitcoin behaves differently compared to gold and the CNY/USD exchange rate.

From the asymmetric GARCH model, it may be concluded that the asymmetric GARCH term (γ) of Bitcoin shows a statistically significant positive coefficient, which is in stark contrast to other assets' asymmetric effects. This means that for Bitcoin, positive shocks increase the volatility by more than negative shocks, whilst for the other financial assets the opposite is concluded. Furthermore, gold shows a statistically significant negative coefficient. For the CNY/ USD exchange rate, a negative and significant sign is shown. This corresponds with the expectation from the literature review where research shows that this is a well-known characteristic of established currencies.

Based on the asymmetric reaction to positive and negative shocks, it may be concluded that Bitcoin cannot be compared either to gold nor to CNY/USD as it is the only asset where positive shocks increase the volatility by more than negative shocks. It is remarkable to see that these results do not hold for the broad market-weighted index CRIX. It was expected that the CRIX index would have the same reaction on positive and negative shocks as Bitcoin due to the high correlation among different cryptocurrencies. The division of data in subsets shows that these differences in findings are not due to the difference in time period but that these findings are not applicable to the CRIX index. From this finding, it may be concluded that the reaction of the variance on positive and negative shocks is not applicable to all cryptocurrencies. The inclusion of USD returns in the mean equation does not lead to surprising findings. In line with (Baur, Dimpfl, & Kuck, 2017), no significant relationship was found between Bitcoin and the USD returns, whereas almost all other assets are related to changes in the USD. However, the inclusion of CNY returns in the mean equation does lead to interesting findings. A significant relationship between changes in CNY and the CRIX is shown in the results. For Bitcoin, no significant relationship with changes in CNY was found. The division of data into different subsets shows that this difference is due to the difference in time periods and that there is a significant relationship between Bitcoin and CNY returns in the time period between July 1, 2014 to June 30, 2018. This significant relationship tells us that Bitcoin and the CRIX index have begun to react to the same variables as the CNY, especially due to the fact that this relation is present

in the second subset and not in the first subset. These results confirm that the inclusion of Chinese variables in the dataset is a valuable extension to the research of (Baur, Dimpfl, & Kuck, 2017) and (Dyhrberg, 2016) and leads to interesting findings.
The analysis of the volatility persistence shows that the volatility persistence is the highest for the CRIX index, stock indices and gold. Based on the volatility persistence Bitcoin cannot be compared to gold but behaves more similar to the Chinese yuan.

To answer the research question, Bitcoin cannot currently be compared to any of the financial assets in the dataset from an econometric perspective, as it behaves entirely differently than conventional financial assets. This also applies for the broader market index CRIX and for different time periods. Results of this thesis show that Bitcoin behaves very differently compared to gold and currencies. These results may be surprising given Bitcoin's intention as a digital currency. However, due to the excess returns and high volatility, Bitcoin behaves as a speculative asset rather than a commodity or a currency. Nevertheless, the empirical evidence suggests that Bitcoin has begun to react to the same economic variables as the Chinese Yuan. This may be a sign that Bitcoin has begun to behave as a currency. Nevertheless, I believe that Bitcoin and other cryptocurrencies will remain highly volatile in the coming years due to the highly speculative character of these assets. As long as this highly volatile behaviour will not change, cryptocurrencies are not suitable as a viable currency for the long run. The volatile price movements are mainly caused by speculative investors, regulatory decisions and cyber-attacks. As long as these factors exist, Bitcoin cannot act as a viable currency.

8.3 Recommendations & Limitations

This section will describe the recommendations and limitations of this study. First the data will be discussed, followed by the methodologies and results.

The sample selected was all the available Bitcoin data at the time of writing. One may argue that including the first years of Bitcoin is not relevant due to the small trading volume in these years. Therefore, this thesis tested if results differ by dividing the sample into two different subsets. Future research may perform the same research for each year separately and test whether findings change over time. Furthermore, future research may take different cryptocurrencies separately instead of the CRIX index to test if findings differ per cryptocurrency. In addition, one may argue that the sample size is too small to base conclusions on. Given the relatively young markets, the research may be repeated once cryptocurrency markets are more matured.

This thesis uses a dataset of eight different assets. One may argue that this provides a general view regarding the volatility behaviour and correlations between assets. Future research may extend the dataset using other currency pairs and other variables such as government bonds and inflation-linked bonds.

During the sample period of this study, Bitcoin prices experienced high volatility, which may suggest that volatility behaviour changes over time. It should be noted that the time span of this research includes around 89% of the same dates as (Baur, Dimpfl, & Kuck, 2017) and 61% of the same dates as (Dyhrberg, 2016).

The model chosen to answer the main research question was the asymmetric GARCH model of (Glosten, Jagannathan, & Runkle, 1993). One may argue that as a robustness check, the same research can be performed using the E GARCH model of (Nelson, 1990). Further research may use this model to test if results differ from the GJR GARCH model.

This study uses a conditional correlation matrix to draw conclusion as to the correlation between different assets. One may argue that is more appropriate to use a dynamic conditional correlation to test if the correlation changes over time. Future research may extend this thesis by using a dynamic conditional correlation analysis to test if the results differ over time.

One may argue that adding the news impact curves into the thesis does not add value to drawing the main conclusions on the research question. However, adding the news impact curves helps with understanding the asymmetric GARCH term and helps to interpret the coefficient of the signs.

This study rejects the hypothesis that the asymmetric GARCH term of Bitcoin is due to the safe haven capabilities proposed by (Bouri, Azzi, & Dyhrberg, 2017). However, this study fails to come up with a valid economic explanation for this phenomenon. Further research should investigate if there is a valid explanation for this phenomenon, as exists for stock indices.

The results of this study suggest that Bitcoin and the Chinese Yuan have begun to react to the same economic variables. However, the economic variables that are related to Bitcoin as well the CNY were not examined. Further research should examine the macro-economic variables related to Bitcoin as well as to the CNY.

References

Alstyne, V. (2014). Why Bitcoin Has Value. *Communications of the ACM*, 30-32.

Andersen, T. G., Bollerslev, T., Diebold, X., & Labys, P. (2001). The Distribution of Realized Exchange Rate Volatility. *Journal of the American Statistical 96*, 42-55.

Badev, A., & Chen, M. (2014). Bitcoin: Technical Background and Data Analysis. *Finance and Economics Discussion Series Divisions of Research & Statistics and Monetary Affairs Federal Reserve Board*.

Batten, J., Ciner, C., & Lucey, B. (2010). The macroeconomic determinants of volatility in precious metals markets. *Resources Policy*, 65-71.

Baur, D. (2011). Asymmetric Volatility in the Gold Market. *Journal of Alternative Investments*, pp. 26-38.

Baur, D., & Lucey, B. (2010). Is Gold a Hedge or a Safe Haven? an Analysis of Stocks, Bonds and Gold. *Financial Review*, 217-229.

Baur, D., Dimpfl, T., & Kuck, K. (2017). Bitcoin, gold and the US dollar–A replication and extension. *Financiel Review*, 85-92.

Baur, D., Hong, K., & Lee, A. (2018). Bitcoin: Medium of Exchange or Speculative Assets? *Journal of International Financial Markets*, 177-189.

Bianchi, D. (2017). Cryptocurrencies as an asset clas: An empirical assesment. *WBS Finance Group Research Paper*.

Bjerg, O. (2016). How is Bitcoin money? *Theory, Culture & Society 33*, 53-72.

Black, F. (1976). Studies of stock price volatility changes . *Business and Economics Section* , 177-181.

Bohme, R., & Christin, N. E. (2015). Bitcoin: Economics, tecnology, and governance. . *Journal of Economic Perspectives 29*, 13-38.

Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics*, 307-327.

Bollerslev, T., Andersen, T., Diebold, F., & Vega, C. (2007). Real-time price discovery in global stock, bond and foreign exchange markets. *International Finance Discussion Papers 871*, 251-277.

Bouoiyour, & Selmi. (2015). What does Bitcoin look like? *Annals of Economics & Finance*, 449-492.

Bouoiyour, S. (2016). Bitcoin: A beginning of a new phase? *Economics Bulletin 36*, 30-40.

Bouri, Azzi, & Dyhrberg. (2017). On the return-volatility relationship in the Bitcoin. pp. 1-16.

Bouri, E., Gupta, R., Tiwari, A., & Roubaud, D. (2017). Does Bitcoin hedge global uncertainty? Evidence from wavelet-based quantile-in-quantile regressions. *Finance Research Letters 23*, 85-95.

Briere, Oosterlinck, & Szafarz. (2015). Virtual currency, tangible return: Porfolio diversification with bitcoin. *Journal of Asset Management*, 365-373.

Byers, J., & Peel, D. (2001). Volatility persistence in asset markets: long memory in high/low prices. *Applied Financial Economics 11*, 253-260.

Cai, F., Cheung, Y., & Wong, M. (2001). What Moves the Gold market? *Journal of Futures Markets*, 257-278.

Campbell, J., & Hentschel, L. (1992). No news is good news: An asymmetric model of changing volatility in stock returns. *Journal of financial Economics*, 281-318.

Campell, J., & Hentschel, L. (1992). No news is good news: An asymmetric model of changing volatility in stock returns. *Jounal of Financial Economics* , 281-318.

Capie, F. M. (2005). Gold as a hedge against the dollar. *Journal International Financial Markets 15*, 343-352.

Cermak. (2017). Can Bitcoin become a viable alternative to fiat currencies? An empirical analysis. *Skidmore College - Department of Economics*.

Chan, S., Chu, J., Nadarajah, S., & Osterrieder, J. (2017). A statistical analysis of cryptocurrencies. *Journal of Risk Financial Management*, 30-60.

Christie, A. (1982). The stochastic behavior of common stock variances: Value, leverage and interest rate effects. *Journal of financial Economics*, 50-62.

Conoscenti, M. V., & De Martin, J. (2016). Blockchain for the Internet of Things: A systematic literature review. *International Conference of Computer Systems* , 1-6.

Conrad, C., Custovic, A., & Ghysels, E. (2018). Long-and short-term cryptocurrency volatility components: A GARCH-MIDAS analysis. *Journal of Risk and Financial Management*, 23-44.

Duffee, R. (1995). Stock returns and volatility A firm-level analysis . *Journal of Financial Economics 37*, 399-420.

Dwyer, G. (2015). The economics of Bitcoin and similair private digital currencies. *Jounal of Financial Stability* , 81-91.

Dyhrberg. (2016a). Bitcoin, gold and the dollar – A GARCH volatility analysis. *Finance Research Letters*, 85-92.

Dyhrberg. (2016b). Hedging capabilities of bitcoin. Is it the virtual gold? *Finance Research Letters*.

Eisl, A., Gasser, S., & Weinmayer, K. (2015). Does Bitcoin improve portfolio diversification.

Engle, R. (1982). Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation. *Econometrica*, 987-1007.

Engle, R. (1993). Measuring and Testing the Impact of News in Volatility. *Journal of Finance*, 1749-1778.

Ennis. (2013). Is Bitcoin like Gold? An examination of the Hedging and Safe Haven Properties of the Virtual Currency. .

Glaser, F. (2014). Bitcoin - Asset or Currency? Revealing Users' Hidden Intentions. *ECIS 2014* , 14-28.

Glosten, Jagannathan, & Runkle. (1993). On the Relation between the Expected Value and the Volatility of the Nominal Excess Return. *The Journal of Finance*, 1779-1801.

Klein, T., Pham, H., & Walther, T. (2018). Bitcoin is not the New Gold - A Comparison of Volatility, Correlation, and Portfolio Performance.

Kristoufek, L. (2015). What are the main drivers of the Bictoin price? Evidence from wavelet coherence analysis . *PloS one*, 1-19.

Lee, L. (2015). How Bitcoin's technology could reinvent the stock market. . *Hasting Bus*, 81-132.

Ling, & McAleer. (2002). Stationarity and the existence of moments of a family of GARCH processes. *Journal of Econometrics*, 109-117.

McKenzie, M. (2002). The economics of exchange rate volatility asymmetry. *International Journal Of Finaance Economics* .

Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system.

Nelson, D. (1990). Conditional heteroskedasticity in asset returns: A new approach. *Econometrica*, 347-370.

Pukthuanthong, K., & Roll, R. (2011). Gold and the Dollar (and the Euro, Pound, and Yen). *Journal of Banking & Finance*, 2070-2083.

Selmi. (2017). Are Trump and Bitcoin Good Partners?

Trimborn, S. H. (2016). CRIX an Index for blockchain based Currencies.

Tully, E., & Lucey, B. (2007). A power GARCH examination of the Gold market. *Research in International Business and Finance*, 316-325.

Urquhart, A. (2017). Price clustering in Bitcoin . *Economics Letters 159*, 145-148.

Urquhart, A., & Zhang, H. (2018). Is Bitcoin a Hedge or Safe-Haven for Currencies? An Intraday Analysis. *Finance Research Letters*, 1-7.

Wang, J. (2009). Asymmetric volatility in the foreign exchange markets. *Journal of International Financial Markets, Institutions and Money*, 597-615.

Wang, J., & Yang, M. (2006). Asymmetric Volatility in the Foreign Exchange Markets. *Journal of International Financial Markets, Institutions and Money*, 597-615.

Woo, W. (2017). *Estimating the true Bitcoin trading volumes in China, a data-driven approach.*

Yermack, D. (2015). Is Bitcoin a Real Currency? An Economic Appraisal. *Bitcoin, Innovation, Financial Instruments, and Big Data*, 31-43.

Yli-Huurmo, J., Ko, D., & Choi, S. (2016). Where is current research on blockchain technology? - a systematic review. *Plos one 11*, 1-27.

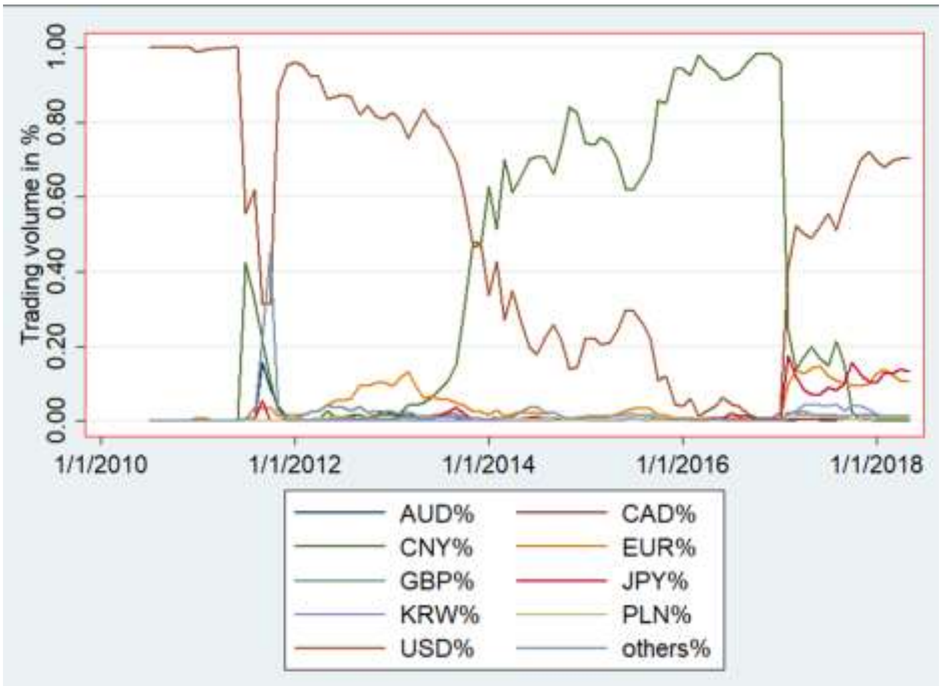
Appendix

A.1 Figures

Figure 2: Trading volume by currency total

Note: Using data from bitcoinity this graph shows the trading volume per currency for the time-period 01-01-2010 to 30-06-2018

Figure 3: Trading volume by currency per period



Note: Using data from bitcoinity this graph shows the trading volume per currency for the time period between 01-01-2010 and 30-06-2018.

A.2 Tables

Table 6 Correlation 01-01-2011/ 31-12-2015

Variables	(1)	(2)
(1) Bitcoin	1.000	
(2) CNY/USD	0.061*	1.00

Table 5 Correlation 01-01-2016/30-06-2018

Variables	(1)	(2)
(1) BITCOIN	1.000	
(2) CNY/USD	0.051*	1.00

Note: shows the correlation between Bitcoin and the CNY among two different subsets.

Table 7: Asymmetric ARCH period 1

ret_btc_usd	Coef.	St.Err	t-value	p-value	Sig.
L.ret_btc_usd	0.054	0.031	1.75	0.080	*
_cons	0.627	0.171	3.67	0.000	***
L.arch	0.029	0.007	4.02	0.000	***
L.tarch	0.093	0.010	9.20	0.000	***
L.garch	0.931	0.005	203.00	0.000	***
_cons	0.110	0.037	2.93	0.003	***

Mean dependent var	0.870	SD dependent var	7.858
Number of obs	840.000	Chi-square	3.069
Prob > chi2	0.080	Akaike crit. (AIC)	5474.076

Note: Table 7 shows the asymmetric GARCH model for the time period 01-01-2011 until 30-06-2014.

Table 8: Asymmetric ARCH period 2

ret_btc_usd	Coef.	St.Err	t-value	p-value	Sig.
L.ret_btc_usd	0.070	0.037	1.91	0.056	*
_cons	0.197	0.106	1.85	0.064	*
L.arch	0.124	0.015	8.55	0.000	***
L.tarch	0.039	0.018	2.19	0.029	**
L.garch	0.853	0.010	81.77	0.000	***
_cons	0.358	0.060	5.96	0.000	***

Mean dependent var	0.262	SD dependent var	4.401
Number of obs	1083.000	Chi-square	3.664
Prob > chi2	0.056	Akaike crit. (AIC)	6023.730

*** p<0.01, ** p<0.05, * p<0.1

Note: Table 8 shows the asymmetric GARCH model for the time period 01-07-2014 until 30-06-2018.

Table 9: Regression results period 01-01-2011 until 30-06-2014.

	(1) Bitcoin	(2) EUR	(3) gold	(4) MSCI	(5) Shanghai	(6) SP1500	(7) Silver
L.ret_btc_usd	0.076**	0.050	0.178***	0.015	0.044	-0.041	0.004
	(0.038)	(0.033)	(0.034)	(0.039)	(0.032)	(0.045)	(0.052)
ret_cyn_usd	0.180	-0.303***	0.427***	-0.097*	0.399***	0.206**	0.058
	(0.211)	(0.031)	(0.042)	(0.056)	(0.041)	(0.090)	(0.060)
_cons	0.539***	-0.008	0.024	-0.036	0.032	-0.071	-0.027
	(0.185)	(0.016)	(0.026)	(0.040)	(0.027)	(0.072)	(0.046)
Variance eq:							
α	0.096***	0.015***	0.226***	0.081***	0.292***	0.231***	0.140***
	(0.015)	(0.005)	(0.038)	(0.028)	(0.042)	(0.039)	(0.022)
Γ	0.104***	-0.007	-0.245***	-0.112***	-0.361***	-0.220***	-0.112***
	(0.018)	(0.007)	(0.038)	(0.033)	(0.046)	(0.049)	(0.019)
Β	0.873***	0.991***	0.864***	0.850***	0.841***	0.150	0.817***
	(0.009)	(0.003)	(0.022)	(0.049)	(0.020)	(0.162)	(0.022)
Constant	0.353***	-0.001***	0.023***	0.156***	0.043***	2.825***	0.154***
	(0.085)	(0.000)	(0.005)	(0.053)	(0.007)	(0.610)	(0.024)
Observation	833	840	742	742	742	742	742

Standard errors are in parenthesis
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

$$h_t = \omega + \alpha e_{t-1}^2 + \gamma I(e_{t-1} > 0)e_{t-1}^2 + \beta h_{t-1}$$

Note: Table 9 shows the asymmetric GARCH model for the time period 01-01-2011 until 30-06-2014. .

Table 10 : Regression results period 01-07-2014 until 01-06-2018

	(1) Bitcoin	(2) EUR	(3) CRIX	(4) MSCI	(5) Shanghai	(6) SP1500	(7) Silver	(8) gold
L.ret_btc_usd	0.067	-0.091***	-0.002	0.082**	0.028	-0.087**	-0.100***	-0.026
	(0.041)	(0.033)	(0.036)	(0.039)	(0.037)	(0.034)	(0.032)	(0.035)
ret_cyn_usd	-0.934**	-0.420***	-0.697*	0.271***	0.132	0.105	1.056***	0.809***
	(0.399)	(0.050)	(0.367)	(0.077)	(0.129)	(0.079)	(0.140)	(0.049)
Variance Eq.								
_cons	0.146	0.014	0.231*	0.011	0.042	0.040*	-0.046	-0.005
	(0.115)	(0.018)	(0.119)	(0.019)	(0.030)	(0.022)	(0.049)	(0.025)
Variance eq:								
Α	0.184***	0.008*	0.196***	0.233***	0.066***	0.329***	0.031***	0.018***
	(0.022)	(0.004)	(0.021)	(0.033)	(0.009)	(0.043)	(0.009)	(0.004)
Γ	0.025	0.017***	0.056*	-0.262***	0.021	-0.368***	0.015*	-0.000
	(0.025)	(0.006)	(0.029)	(0.035)	(0.015)	(0.044)	(0.009)	(0.006)
Β	0.808***	0.980***	0.788***	0.848***	0.925***	0.793***	-0.908***	0.981***
	(0.016)	(0.005)	(0.015)	(0.021)	(0.006)	(0.021)	(0.026)	(0.003)
Constant	0.493***	0.001	0.633***	0.025***	0.006***	0.041***	4.203***	0.000
	(0.086)	(0.001)	(0.085)	(0.004)	(0.002)	(0.005)	(0.136)	(0.001)
Observation	960	960	918	955	955	955	955	955

Standard errors are in parenthesis
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

$$h_t = \omega + \alpha e_{t-1}^2 + \gamma I(e_{t-1} > 0)e_{t-1}^2 + \beta h_{t-1}$$

Note: Table 10 shows the asymmetric GARCH model for the time period 01-07-2014 until 01-06-2018.

A.3 Equations

$$\Delta lnprice_t = \beta_0 + \beta_1 lnprice_{t-1} + \beta_2 Fed_{t-1} + \beta_3 USDEUR_{t-1} + \beta_4 USDGBP_{t-1} + \beta_5 FTSE_{t-1} + \beta_6 Gold\ Future_{t-1} + \beta_7 GoldCash_{t-1} + \varepsilon_t \quad (3)$$

$$\ln\left(\sigma_t^2\right) = \lambda_0 + \lambda_1 Fed_{t-1} + \lambda_2 USDEUR_{t-1} + \lambda_3 USDGBP_{t-1} + \lambda_4 FTSE_{t-1} + \lambda_5 GoldFuture_{t-1} + \lambda_6 GoldCash_{t-1} + \alpha(\varepsilon_{t-1}/\sigma_{t-1}) + \gamma\left(|\varepsilon_{t-1}/\sigma_{t-1}| - \sqrt{2/\pi}\right) + \delta ln\left(\sigma_{t-1}^2\right) \quad (4)$$

Note: equation that is used by Dyhrberg (2016) (GARCH model with explanatory variables).

$$\Delta lnprice_t = \beta_0 + \beta_1 lnprice_{t-1} + \beta_2 lnprice_{t-2} + \beta_3 Fed_{t-1} + \beta_4 USDEUR_{t-1} + \beta_5 USDGBP_{t-1} + \beta_6 FTSE_{t-1} + \beta_7 Gold\ Future_{t-1} + \beta_8 GoldCash_{t-1} + \varepsilon_t \quad (1)$$

$$\sigma_t^2 = \exp(\lambda_0 + \lambda_1 Fed_{t-1} + \lambda_2 USDEUR_{t-1} + \lambda_3 USDGBP_{t-1} + \lambda_4 FTSE_{t-1} + \lambda_5 GoldFuture_{t-1} + \lambda_6 GoldCash_{t-1}) + \alpha\varepsilon_{t-1}^2 + \beta_{\sigma_{t-1}^2} \quad (2)$$

Note: equation that is used by Dyhrberg (2016) (exponential GARCH model)