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"Testing for Speculative Bubbles - An Empirical Investigation of the Bitcoin Market"

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Abstract

Since its implementation, bitcoin is confronted with the problem of high price volatility. During certain time periods, the exchange rate of the digital currency follows boom and bust patterns which show similarities to speculative bubbles. This thesis aims to empirically investigate whether the bitcoin market experienced such a bubble. The supremum augmented Dickey-Fuller (=SADF) test and its generalized version (=GSADF) are used to check for the presence of speculative bubbles. Both models are derived from the right-tailed augmented Dickey-Fuller (=ADF) test. To determine whether a speculative bubble occurred, the models are applied to the data set which contains the turn of the year 2013/2014. Both the SADF test and the GSADF test give empirical evidence for the presence of a speculative bubble.

Keywords: Bitcoin, digital currency, cryptocurrency, speculative bubble, rational bubble, SADF test, GSADF test

Übersicht

Seit der Entstehung des Bitcoin-Netzwerks im Jahr 2009 zeichnet sich die Digitalwährung durch starke Kursschwankungen aus. Bestimmte Zeiträume sind durch einen rasanten Kursanstieg gekennzeichnet, welcher einem Kurseinbruch folgt. Dieser Verlauf erinnert an eine spekulative Blase. Das Ziel dieser Arbeit ist es empirisch zu erforschen, ob solche Blasen im Bitcoin-Markt erkennbar sind. Dafür wird der Supremum Augmented-Dickey-Fuller (=SADF) Test und die modifizierte Version (=GSADF) angewandt. Beide Modelle basieren auf einem rechtsseitigen Augemented-Dickey-Fuller-Test, kurz auch ADF-Test genannt. Der empirische Teil umfasst einen Datensatz, welcher den Zeitraum zwischen 2013 und 2014 beinhaltet. Sowohl der SADF-Test als auch der GSADF-Test zeigen, dass im Zeitintervall 2013/14 eine spekulative Blase im Bitcoin-Markt präsent war.

Schlüsselwörter: Bitcoin, Digitalwährung, Kryptowährung, spekulative Blasen, SADF-Test, GSADF-Test

Contents

1 Introduction

Speculative bubbles have a long history in financial markets. Their detection most commonly takes place in retrospect after a so-called crash or bubble burst, which is shown by a sudden drop in prices. In recent years, the research field of econometric tests for speculative bubbles flourished (e.g. Homm and Breitung (2012), Phillips, Wu, and Yu(2011), Gürkaynak (2008)). These studies propose various theoretical and measurement models, which do not not only raise empathy about the speculative phenomena but also contribute to deepen the knowledge on how to diagnose a bubble at an earlier stage.

A particularly appealing archetype of financial markets is the bitcoin market. Bitcoin is a decentralized digital currency introduced in 2008 by a person or group under the pseudonym Satoshi Nakamoto (Nakamoto, 2008). Since its first implementation in 2009, bitcoin has experienced a rapid rise which was followed by a sharp decline at the end of 2013. In 2017, the exchange rate of the digital currency is spectacularly increasing, reaching its record high in June. The dramatic boom and bust pattern leads to the following key question: Did the bitcoin market experience a speculative bubble? In order to address this research question, this thesis seeks to empirically test for the presence of speculative bubbles in the bitcoin market.

With regard to investigating this question, the model developed by Philips, Wu and Yu (2011) and the modified approach by Philips, Shi and Yu (2015) are applied. In the first paper, the authors test for explosive behaviour in the NASDAQ stock price index in the 1990s. The method uses the right-tailed augmented Dickey-Fuller (=ADF) test which is repeatedly implemented on a forward expanding sample sequence. The results are obtained as the supremum of the corresponding ADF statistic sequence (=SADF) (Phillips et al., 2011). The second paper proposes the generalized sup ADF (=GSADF) test, which also relies on a right-tailed ADF test but uses flexible window widths in the implementations. The GSADF test outperforms the SADF test when multiple bubbles occur in the data set. The data sets are extracted from the database

Quandl and both tests are applied on the samples in order to check for explosive behaviour.

The thesis is structured as follows: The next section gives an overview on speculative bubbles, in particular rational bubbles which assume rational expectations. Then this thesis reviews the literature on the contextual background of the bitcoin market. Next, the thesis presents both the main model to test for explosive behaviour, developed by Philips, Wu and Yu (2011), and the modified and extended model, developed by Philips, Shi and Yu (2015), which significantly improved the detection of multiple bubbles in the data set. This is followed by the fifth chapter, which illustrates the empirical findings. The sixth chapter discusses the results and suggests various implications and limitations.

2 Speculative Bubbles

2.1 Speculation in Economics

In "A Dictionary of Economics" (2012) the term "speculation" is defined as an economic activity which aims to profit from anticipated price movements of commodities or assets. As opposed to regular trading or investment, the major motive of speculative transactions are the expected capital gains. Speculators buy an asset, intending to sell it at a later date at a higher price due to an anticipated rise in the market value. Or vice versa, they sell an asset to buy it at a later date at a lower price due to an anticipated fall in the market value. (Binswanger, 1999) These financial transactions bear a significant risk because of uncertain future price trends but speculators intend to transform their expectations into capital profits. As a matter of fact, certain markets are more suitable for speculative trading than others. These markets have the following conditions (Aschinger, 1995):

1. Existence of a broad and nearly perfect market, where fully standardized and storable products are traded
2. Sequential trading of products
3. Low transactions costs
4. Uncertainty on size and direction of future price movements which facilitates a higher degree of speculation

These characteristics are fulfilled by financial assets, especially stocks, and goods traded at stock. However, these products are characterized by a higher risk level. Bonds, for instance, are seen as a much safer investment than stocks. Under certain economic conditions, more and more investors participate in speculative trading, expecting to benefit from an increasing price movement. (Binswanger, 1999)

In particular, this is the case during the emergence of speculative bubbles as it will be shown in the following sections.

2.2 Definition of Bubbles

The word "bubble" is associated with a steadily growing object before eventually bursting (Siegel, 2003). A similar image is given in the economic world when defining bubbles. In this case, bubbles implicate a rapid asset price increase followed by a collapse (Durlauf and Blume, 2008). The American economic historian Charles P. Kindleberger defines a bubble in his famous book "Mania, Panics, and Crashes" (1978), which was reprinted after the dot.com bubble, as "an upward price movement over an extended period [...] that then implodes" (Kindleberger and Aliber, 2005, p. 29). In the "New Palgrave Dictionary of Economics" (2008), Kindleberger gives a more precise definition:

A bubble may be defined loosely as a sharp rise in price of an asset or a range of assets in a continuous process, with the initial rise generating expectations of further rises and attracting new buyers - generally speculators interested in profits from trading in the asset rather than its use or earning capacity. The rise is usually followed by a reversal of expectations and a sharp decline in price often resulting in financial crises. (Durlauf and Blume, 2008, p. 583: Bubbles in history)

This definition indicates that during the emergence of a bubble, the market price of an asset cannot be justified solely by its future cash flows, but rather by its expected resale value. In finance, the prevalent approach is to distinguish between the market value, i.e. the current price, and the intrinsic or fundamental value. The fundamental value refers to the price of an asset or commodity obtained by discount rates and cash flows (Siegel, 2003). Bubbles can be seen as large, persistent mispricings of assets, because the market value of a financial or real asset distinctly exceeds its fundamental value. Furthermore, Kindleberger's definition states that the collapse of bubbles results in financial crisis. Because of the severe consequences on the economy, it is of great importance to understand why prices can deviate from their intrinsic value. (Brunnermeier and Oehmke, 2012)

2.3 Rational Bubbles

At first glance it seems that the expression "rational bubble" is a contradiction in terms. Bubbles, which are frequently referred to as "speculative manias", appear to be inconsistent with rationality. Kindleberger (2005) takes a closer look at this misconception.

In economics, the "rational expectations" assumption suggests that prices of goods are based on optimal predictions of future changes using all currently available information. This implies that investors are willing to buy an overpriced asset because they anticipate reselling it at a higher price (Muth, 1961; Brunnermeier and Oehmke, 2012). In contrast, the "adaptive expectations" assumption has a backward-looking view. In this case, prices of goods are determined by trends in the recent past, meaning if asset prices are rising they will continue to rise (Kindleberger and Aliber, 2005).

According to Blanchard and Watson (1982), rationality does not necessarily mean that the asset price and its fundamental value are equal. In fact, there can be deviations which can be interpreted as rational bubbles. These deviations are discussed in detail in chapter 4, where the bubble component is denoted by B_t.

In this thesis, the represented model assumes rational expectations.

2.4 Minsky's Financial Instability Hypothesis

In 1986, the American economist Hyman P. Minsky published his work "Stabilizing an unstable economy" where he introduced the financial instability hypothesis (Minsky and Kaufman, 2008). At the end of the 2000s - roughly 30 years later - his theory attracted a great deal of attention in the media during the subprime mortgage crisis, even leading to the catch phrase "The Minsky Moment" ((Whalen, 2007; Cassidy, 2008)). Minsky referred to his theory as "an interpretation of the substance of Keynes's 'General Theory' " (Minsky, 1992) which interpreted the financial instability as endogenous variable of market economies.

The financial instability hypothesis distinguishes between three income-debt relations which are labelled as hedge finance, speculative finance and Ponzi finance. In the so-called hedge-case, the firm is able to pay back the interest and reduce its indebtedness. A speculative financing unit can pay back the interest but cannot repay the principal solely from income cash flows. A firm belongs to Ponzi finance if its cash flows are not sufficiently large to pay the interest or the principal on the due dates. Therefore, these firms must either increase their indebtedness or sell assets. (Minsky, 1992; Kindleberger and Aliber, 2005)

Minsky's first theorem of the financial instability hypothesis states that the economy has stable financing structures, such as hedge finance, and unstable financing structures, which include speculative finance and Ponzi finance. The second theorem claims that over a prolonged period of economical prosperity, the economy has the tendency to shift from a stable financing scheme to an unstable one (Minsky, 1992). The core of the Minsky's hypothesis can be summed up as ”stability is destabilizing”. In times of flourishing economy, capitalists are more optimistic about the future and more risk-loving. Consequently, they are more likely to invest in financial assets with higher risks. This leads to financial structures which are dominated by speculative finance and Ponzi finance, causing economic instability. (McCulley, 2009)

2.5 Pattern of a Bubble

Minsky's theory helps to explain the boom and bust pattern of speculative bubbles. Kindleberger and Aliber (2005) use Minsky's model to outline a framework of five different phases of a typical bubble cycle: displacement, boom, euphoria, profit taking and panic. In this subsection, a closer look at each of these five stages is taken.

A displacement is an exogenous shock in the macroeconomic system, such as an innovative technology or historically low interest rates. After an extensive shock, capitalists anticipate profit opportunities and invest in the technology or country. The rapid expansion leads to increasing optimism among the investors. More and more business firms and individuals enter the market, which paves the way for the boom phase. This phase is usually driven by an expansion of credit and lending, allowing people to invest more than they would have been able to otherwise. After some time, the effective demand for goods and services is higher than the market can offer, which boosts market prices. The euphoria phase develops at this stage. The rapid rise attracts even more investors because they are anticipating further increases in the prices. During the euphoric phase, new explanations and proofs are given to justify the enormous rise of prices. As the speculative boom continues, few insiders who purchased the assets at an earlier stage resell them and make profit. This short phase is called profit taking. The specific signal that predicts the burst of a bubble may be a minor event. An increasing number of investors realizes the decline in prices and tries to sell the assets before making an even bigger loss. The continuing sharp fall in prices and rising doubts whether the prices will recover lead to panic, the final phase. Investors will try to liquidate their assets at any price. Consequently, supply exceeds demand, leading to downward sloping prices. (Kindleberger and Aliber, 2005)

The historical speculative bubbles which are presented in the next section all follow those phases.

2.6 Historical Bubbles

2.6.1 Tulipmania

One of the first documented speculative bubbles is the tulipmania in the Netherlands from 1636 to 1637. In this period, the prices for tulip bulbs, especially for rare varieties, experienced an enormous rise which was then followed by a sudden collapse. (Van der Veen, 2012)

The tulip which originated in Turkey was imported to Western Europe in the middle of the sixteenth century. The Dutch dominated the tulip market and facilitated the creation of unique patterned flowers which yielded high prices

(Garber, 1989, 1990). Until the early 1630s, wealthy merchants were mostly involved in trading the bulbs. However, this changed after sales had started taking place throughout the year (Van der Veen, 2012). An increasing number of people from all classes entered the tulip market and the rising prices attracted speculators. From November 1636 to January 1637, peak prices were paid for the tulip bulbs, setting up the speculative bubble. After this three-month period, the prices suddenly collapsed. Even rare tulip bulbs could not be sold at ten percent of their previous value (Garber, 1989, 1990). The decline in prices led to a distress in the Dutch economy (Kindleberger and Aliber, 2005).

2.6.2 The dot.com Bubble

At the turn of the century, the U.S. stock market faced a speculative bubble related to the growing popularity of the Internet. Therefore, the bubble is famously known as the "dot.com bubble".

In the late 1990s, Internet use grew rapidly and the demand for new technologies connected to the Internet sector experienced a spectacular rise. More and more market enthusiasts were willing to buy stocks in Internet-based companies which promised high returns. The boom phase quickly turned into euphoria as newly created Internet businesses emerged on a daily basis. It was believed that the new technologies would revolutionize the existing corporate landscape. During the run-up phase, many people invested in firms without being fully aware of the produced products and services. At the end of March 2000, the dot.com-bubble burst. During 2000 and 2002, the NASDAQ index dramatically dropped and many Internet stocks went out of business. (Rapp, 2014; Wheale and Amin, 2003)

3 Bitcoin

In this thesis, the term "bitcoin" without capitalization refers to both the technology and the currency as it is suggested in the Oxford Dictionary of English (2010).

3.1 History

In 2008, a research paper called "Bitcoin: A Peer-to-Peer Electronic Cash System" (Nakamoto, 2008) was published by a person or a group of people using the pseudonym "Satoshi Nakamoto". To this day, the identity of the creator or creators is a well-kept secret [1]

In the opening sentence, the author or authors define bitcoin as "*a purely peer-to-peer version of electronic cash [that] would allow online payments to be sent directly from one party to another without going through a financial institution*" (Nakamoto, 2008, p. 1). This implies that no intermediary, such as a bank, is needed and that the currency has a solely digital representation - making bitcoin the world's first decentralized digital currency. (Brito and Castillo, 2013)

At the beginning of 2009, the open-source code was implemented and the very first bitcoins were generated (Vigna and Casey, 2015). Open-source software is an efficient way of improving programming codes. Anyone is able to modify and redistribute the source code free of charge (Bonaccorsi and Rossi, 2003). Famous examples include the operating system Linux and the web browser Mozilla Firefox (Franco, 2015).

However, the vision of a digital currency did not arise from Nakamoto's work. Two decades before the implementation of bitcoin, Milton Friedman stated in an interview, "*The one thing that's missing but that will soon be developed, is a reliable e-cash, a method whereby on the Internet you can transfer funds*

[1] Over the years, there have been lots of speculations about the true identity of Satoshi Nakamoto. In 2016, an Australian entrepreneur claimed that he was the founder of bitcoin which was seriously taken into consideration by the BBC and The Economist. However, the self-proclaimed Mr Nakamoto has not yet offered conclusive evidence. (Source: `http://www.economist.com/news/briefings/21698061-craig-steven-wright-claims-be-satoshi-nakamoto-bitcoin` Accessed: 12-04-2017

from A to B, without A knowing B or B knowing A [. . .]. That kind of thing will develop on the Internet." (National Taxpayers Union, 1999, 14:40 - 15:07) During this time, b-money, an anonymous peer-to-peer cash-system, was published by Dai (1998). Dai was a member of Cypherpunks, a group of activists guided by the goal to maintain anonymity in the digital era. The "b-money" paper was referenced in Nakamoto's work and set the course for cryptocurrencies such as bitcoin. Cryptocurrency - as the name implies - is based on cryptography which enables secure communication by using asymmetrical cryptosystems. This method, which is often referred to as "public-key cryptosystem", relies on mathematical algorithms. (Franco, 2015; Singh, 1999)

Before the invention of bitcoin, DigiCash was the most promising digital money protocol to be put into practice. DigiCash was created by David Chaum, one of the most influential cryptographers in the 1990s, and represented a cryptographic digital currency system. Its structure of anonymity was asymmetrical, allowing one side of the transaction, in this case the payer, to hide his or her identity whereas the other side, the payee, could be identified if necessary. This stands in contrast to bitcoin's approach of anonymity where both parties of a transaction are anonymous. Another important difference between the two cryptocurrencies is DigiCash's government- and bank-oriented strategy, while bitcoin on the other hand needs no third party. In the mid-1990s, a number of world's major banks expressed their interest in this new digital form of money. Deutsche Bank and Advance Bank of Australia launched pilot projects with DigiCash. However, the slow growth of the digital currency did not meet the banks' expectations, forcing DigiCash to file for bankruptcy a few months later. (Vigna and Casey, 2015)

Since bitcoin's implementation, a wide range of new cryptocurrencies have emerged. At the time of writing, there are 690 digital currencies with bitcoin taking the lead with a share of almost 68 % (`https://coinmarketcap.com/currencies/views/all/`, Accessed: 14-04-2017).

3.2 Decentralization

One of the most revolutionary components of bitcoin is its decentralized structure. No trusted third parties, including the government and financial intermediaries, are needed. Contrary to the still most common currencies of today such as fiat money including euro and U.S. dollar, where third parties are directly involved. Fiat money is not backed by a physical commodity such as gold or other precious metals and therefore has no intrinsic value. The confidence in the currency's value is created by the issuing government and the supply managing central bank. (Yermack, 2013; Franco, 2015)

Due to its need of a central authority, fiat money is dependent on trust. Central banks must be trusted to manage the money supply carefully. Banks must be trusted to responsibly deal with the customer's money. If faith in financial institutions vanishes, fiat money becomes valueless. (Vigna and Casey, 2015)

Nakamoto [2] tackles this issue, *"What is needed is an electronic payment system based on cryptographic proof instead of trust, allowing any two willing parties to transact directly with each other without the need for a trusted third party"* (Nakamoto, 2008, p. 1). Bitcoin was introduced in the time of the financial crisis of 2008. The crises impacted the global economy severely, leading to recession and losses for billions of people. Confronted with the flaws of the existing financial system, the cryptographic digital currency offered an alternative. This leads to the conclusion that the decentralized aspect of bitcoin constitutes an essential part of its rapid development. (Sornette and Woodard, 2010; Vigna and Casey, 2015)

3.3 Technology

One of the major challenges of digital money is that it runs the risk of double-spending. In contrast to physical money, it can be spent twice or even more. Consequently, a trusted third party was needed to avoid this possible

[2] For simplicity reasons, Satoshi Nakamoto will from now on refer to a single male person in this thesis.

fraud. However, bitcoin's main technological breakthrough offers a solution to this problem: the blockchain. (Franco, 2015)

3.3.1 Blockchain

The blockchain is a database collecting all bitcoin transactions since its implementation. It is a chronologically expanding chain of blocks. New transactions are grouped into a block, which is then added to the end of the chain. Each block is linked to the previous one in the chain. Therefore, the length of the blockchain increases with every new group of transactions. The length of the chain plays an essential role in determining the correct blockchain, which is the longest one.

Each computer running the bitcoin software, commonly referred to as node, has a full copy of the blockchain. The blockchain, which is publicly accessible, is used to validate the transactions and that is crucial in order to prevent double-spending.

In a centralized database, the double-spend problem is easily solved because the identities and financial histories of all users are known. Yet there is a major drawback: the central database system represents a "single point of failure". If the server is attacked, the whole system will be shut down. This potential threat does not appear in the case of a decentralized database. In bitcoin's peer-to-peer network, attacks are only successful if a great majority of the network is controlled by malicious nodes. This kind of attack is called "51% attack" and requires, as the name suggests, more than half of the computational power of the network in order to abuse double-spending. Still there is the question, if an attacker is willing to invest this huge amount of computational power in committing this fraud instead of using it to generate new bitcoins. Nakamoto (2008) points out that playing by the rules would be more profitable for the attacker.

The blockchain enables a payment system which eliminates the need for trusting traditional financial institutions. (Franco, 2015)

3.3.2 Transactions

As discussed in the previous section, all bitcoin transactions that have ever taken place are stored in the blockchain. They are public which distinguishes bitcoin from closed digital currency systems like PayPal. However, the public transactions do not reveal the true identity of the involved parties. In order to protect the user's anonymity, bitcoin addresses are used. These addresses appear as strings with 26 to 34 characters consisting of random digits as well as uppercase and lowercase letters. (Franco, 2015; Vigna and Casey, 2015)

Since bitcoin belongs to the category of cryptocurrencies, cryptography is used to ensure secure transactions. More precisely bitcoin relies on asymmetric cryptography, better known as public-key cryptography. This cryptosystem uses different keys for encryption and decryption. With the help of the private key, the public key is computed. This public key can be accessed by any interested party and is used to encrypt the secret message. The encrypted message can only be decrypted by the party who has the private key. Note that knowing the public key does not give any insights into the private message. Without the private key, no valuable information can be gained. (Singh, 1999; Franco, 2015)

For a better understanding of the public-key cryptography, the following padlock analogy is used: Anybody can lock a padlock but only the person with the key can open it. In this case, the open padlock represents the public key. Only the party with the correct key can unlock the padlock and access the secret data. This key can be interpreted as the private key. (Singh, 1999)

Basically, bitcoin addresses can be seen as public keys. Each of these addresses can be shared with the public without revealing the owner's true identity. Each public key has its corresponding private key. In order to undertake a transaction, the public key must be signed with its associated private key. (Franco, 2015; Vigna and Casey, 2015)

3.3.3 Mining

Mining is the process of adding new blocks to bitcoin's blockchain. A person who contributes his or her computational power to confirm new transactions is called ”miner”. In the peer-to-peer system, miners are of great importance for securing the blockchain. In return, the network rewards them with new bitcoins and collected fees from the transactions. (Franco, 2015; Vigna and Casey, 2015)

The term ”mining” is derived from mining precious metals. Classical mining requires a great deal of effort to mine valuable resources such as gold. In the digital world this effort resembles the computational power which is needed to gain new bitcoins. However, this analogy does not apply all the time. An increasing investment in digital mining does not increase the number of bitcoins in circulation, which is contrary to gold mining. This is because the amount of rewarded bitcoins per block is predefined. (Franco, 2015; Nakamoto, 2008)

As of April 2017, the block mining reward is set to 12.5 bitcoins. Initially, 50 bitcoins were remunerated per block but the number of generated coins is halved every 210,000 blocks which is approximately every four years. This limits the total amount of bitcoins in circulation to roughly 21 million. At the time of writing, around 16 million bitcoins are in circulation (Source: `http://www.bitcoinblockhalf.com/`, Accessed: 24-04-2017). Each block is mined every 10 minutes. In order to keep this time interval, the block mining difficulty is adjusted every 2,016 blocks, which is equivalent to every two weeks. Therefore, the creation of new blocks is independent of computational power changes in the network, such as an increasing number of miners. (Franco, 2015)

Since bitcoin is a peer-to-peer network, new participants are allowed to enter the network at any time and generate their own rewards for mining. At the end of 2010, so-called mining pools started to form in the bitcoin market. Those mining pools are connected groups of miners who unite their computational power and share the gained rewards. (Franco, 2015)

Vigna and Casey (2015) point out that the strength of bitcoin is its reward system. The network does not enforce commitment of its peers through punishment but rather through remuneration. According to Nakamoto (2008), miners are more likely to stick to the rules with this approach as it would be more profitable to invest the computational power in generating new bitcoins instead of attacking the system.

3.3.4 Wallet

A wallet is a software that manages the balances of the user's funds. The choice of the word "wallet" gives the impression that it is the counterpart to a wallet in real life. But strictly speaking, this is incorrect as bitcoins are not stored in the wallet. Instead, private keys which give users access to a transaction are contained in the wallet. Losing the private key causes that those funds are no longer accessible. Although the funds are still in the blockchain, the private key is needed to sign the transaction. As a result, the funds are considered to be lost. Consequently, backups of the private keys are crucial and most software wallets provide this feature. Furthermore, many wallets are able to generate new addresses, i.e. public keys, for each transaction in order to enhance secure payment. (Dwyer, 2015; Franco, 2015)

There are different types of wallet implementations. The most secure wallet is the one that keeps a complete copy of the blockchain because users do not need to rely on any third party. However, the drawback is that not every computer is suitable to store the whole distributed database. At the time of writing, the size of the blockchain reaches almost 114 GB (Source: `https://blockchain.info/charts/blocks-size`, Accessed: 05-05-2017). An alternative wallet is the lightweight wallet. In this implementation, third parties are needed to send and receive transactions. Due to its limited size, these wallets are more suitable for devices, such as smartphones. But there is a trade-off: the security risk increases because of the reliance on a third party. The third type of wallet is the web wallet. The structure of a web wallet is similar to existing online banking services. The company controls the funds and manages the private keys on behalf of the user. However, this bears an enormous risk because web services could be hacked or even steal the user's funds themselves. In both cases, the user would lose his or her funds. (Franco, 2015)

3.4 Criminal Activity

One of the strongest features of cryptocurrencies is maintaining the user's anonymity. In bitcoin's case, all transactions are publicly accessible in the blockchain, but the real identity of both the payer and the payee is hidden. However, government agents and fiscal authorities have expressed concerns at the rise of digital currencies. They fear that criminals might exploit the anonymous characteristics of cryptocurrencies for illegal transactions and money laundering because detecting suspicious activities in this cryptographic framework becomes more difficult (Federal Bureau of Investigation, 2012; Ogunbadewa, 2013). A report on virtual currency schemes published by the European Central Bank in 2012 concludes that the lack of regulation increases the incentive for criminals to use this new form of digital money for illegal purposes (European Central Bank, 2012). The argument holds in the case of the famous "Silk Road" website. (Meiklejohn et al., 2013)

Silk Road was an anonymous online marketplace which was launched in early 2011. It used the Tor network, an encrypted web browser that makes it nearly impossible to trace the user's internet activity, to ensure anonymous communication and accepted only bitcoin as a trading currency. These two aspects protected the identities of both buyers and sellers. Theoretically, all products could be traded at the online marketplace but due to its guaranteed anonymity its central products quickly became illegal goods, including narcotics and weapons. According to Christin (2013), the four most popular categories which have been traded at Silk Road were linked to drugs. In October 2013, after two and a half years of operating, Silk Road was shut down by the Federal Bureau of Investigation. The FBI referred to the website as "the most sophisticated and extensive criminal marketplace on the Internet, serving as a sprawling black-market bazaar" (Source: `https://www.fbi.gov/contact-us/field-offices/newyork/news/press-releases/ross-ulbricht-the-creator-and-owner-of-the-silk-road-website-found-guilty-in-manhattan-federal-court-on-all-counts`, Accessed: 09-05-2017). It is estimated that during a period of more than 2 years Silk Road generated sales of 9.5 million bitcoins.

Despite Silk Road's criminal history, it played a crucial role in developing bitcoin. Silk Road was the first big business to use the cryptocurrency as a medium of exchange and bitcoin's community significantly grew during this time. (Christin, 2013; Vigna and Casey, 2015)

3.5 Classification

Bitcoin's goal is to create a functioning currency without the need of a government or a financial authority. Naturally, the question arises how well bitcoin serves as money (Lo and Wang, 2014). According to Mankiw (2014), money is composed of the following three functions:

- **Medium of exchange:** An item that enables a person to purchase goods and services.
- **Unit of account:** The economic value of goods and services is measured in money unit.
- **Store of value:** An item that can be used to transfer purchasing power from the present to the future.

These three functions will be discussed in detail to give an understanding of whether bitcoin is or is not a currency.

Bitcoin as Medium of Exchange

Bitcoin must be accepted by a large number of businesses to show its usefulness as a medium of exchange. Only if this is the case, consumers will be willing to accept the new digital currency as payment because they are confident that enough others will do the same. In the last years, the acceptance of bitcoin has increased among companies. The first major online retailer that started accepting bitcoin was Overstock.com at the beginning of 2014 (Source:

https://www.overstock.com/bitcoin, Accessed: 24-05-2017). Few weeks later, TigerDirect, an online electronics merchant, adapted bitcoin as a payment method as well. Several other businesses followed, for the most part online companies, such as online travel booking agency Expedia.

Bitcoins steady rise is also reflected in the increasing number of daily transactions. At the time of writing, the transactions per day surpassed 300,000. Within two years, the daily transactions have tripled from 100,000 to 300,000, as can be seen in figure 1.

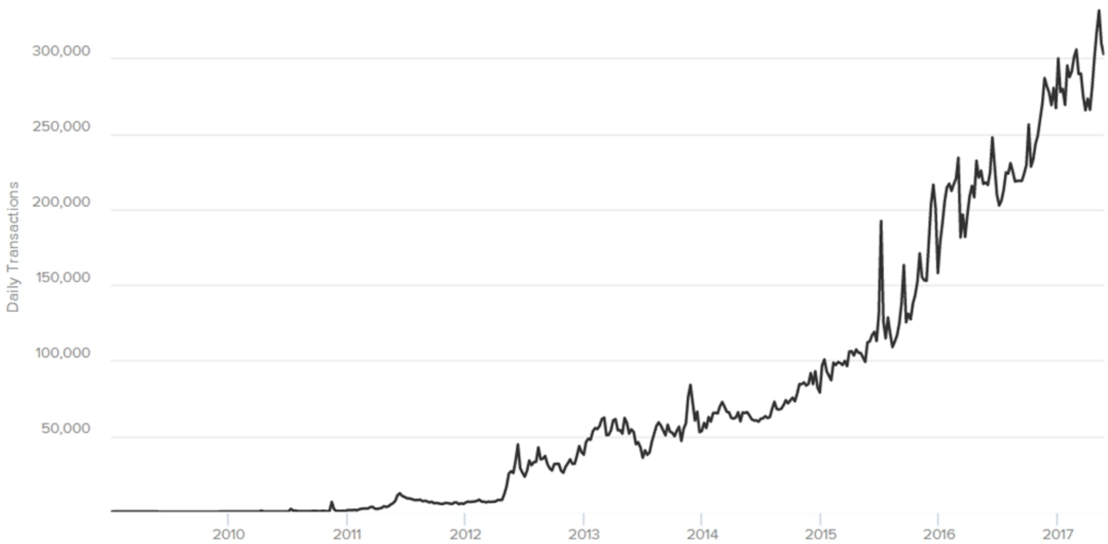

Figure 1: Bitcoin transactions per day from 2009 to 2017 (Source: http://www.coindesk.com/data/bitcoin-daily-transactions/, Accessed: 24-05-2017)

Despite this growth, the number of transactions is still low in comparison to other payment methods. Furthermore, bitcoin's user base is considered to be small among most economists. To become a customarily used medium of exchange, bitcoin must reach a stage where a sufficient large number of people thinks it is worth adapting the new technology.

Using bitcoin as a payment method represents a cost advantage. Since there are no intermediary institutions involved, transaction fees can be kept very low compared to credit card fees. Moreover, transactions are settled almost instantly and are final. The question that arises is how to deal with returns because bitcoin transactions cannot be cancelled. Most merchants offer refunds in the item's U.S. dollar value. Expedia states in its "Terms and Conditions", "Your refund will be converted from USD to Bitcoin based on an exchange rate set by Coinbase at the time you initiate the refund through our Website" (Source: `http://www.expedia.com/Checkout/BitcoinTermsAndConditions`, Accessed: 27-05-2017). Note that Coinbase is an exchange company specialized in digital currencies. Expedia's statement implies that customers might receive more or less bitcoins than they paid at the time of purchase because of the fluctuating exchange rate. This reveals a major drawback of bitcoin: price volatility. Since bitcoin's implementation, the digital currency has experienced drastic price changes. Lo and Wang (2014) investigated the price of two goods offered at Overstock and TigerDirect. While the U.S. dollar price of the products was constant, the bitcoin price remained valid for only a short time. Although they chose a relatively short sample period of two weeks, the obtained results showed a crucial disadvantage of the cryptocurrency. Bitcoin's price volatility will be discussed in detail in the next section. (Lo and Wang, 2014; Franco, 2015)

Bitcoin as Unit of Account

In general, bitcoin is not considered to be a good unit of account. Most businesses that accept the cryptocurrency as payment do not quote the prices in bitcoin due to its high price volatility. Instead, they choose standard currencies, such as dollars or euros. Supporters of the new digital money argue that merchants will start posting prices in bitcoin as soon as the price stabilizes. (Lo and Wang, 2014; Franco, 2015)

Bitcoin as Store of Value

Digital currencies with their frontrunner bitcoin serve as well as stores of value, such as fiat money, precious metals or real estates. Bitcoin's advantages with respect to these other assets are its uncomplicated transportation and limited supply, which creates scarcity. Private keys which are necessary to access bitcoins are easily moved even in large quantities. But also in this case, bitcoin's high volatility represents a drawback. Critics even argue that bitcoin resembles a speculative investment rather than a stable store of value. There are several benefits of investing into bitcoin in comparison to other investments with similar risk profiles, the main one being its low correlation with other assets. (Lo and Wang, 2014; Franco, 2015)

In summary it can be said that bitcoin is a functioning medium of exchange and a risky store of value. However, it is a bad unit of account. But the connection of the three functions of money is getting more and more questioned among economists. They argue that it is possible to unbundle these functions because of the usage of new technologies. From this point of view, it will not make a difference whether it fulfils all the functions right away or it fulfils some of the functions and will achieve the remaining ones in the future. (Dourado, 2014; Franco, 2015)

Japan's government made its decision: In April 2017, the country passed a law to accept bitcoin as legal currency. This legalisation had major impact on the recent rise of bitcoin to its all-time high. (Source: `http://www.cnbc.com/2017/04/12/bitcoin-price-rises-japan-russia-regulation.html`, Accessed: 31-05-2017)

3.6 Volatility

Looking at the data starting from bitcoin's implementation in 2009 until now shows that bitcoin is a volatile asset.

As figure 2 shows, bitcoin's exchange rate is wildly fluctuating. On the 19^{th} of August 2013 the price of one bitcoin surpassed 100 U.S. dollars. Not even half a year later, on the 28^{th} of November 2013, bitcoin's price increased tenfold reaching the 1,000 U.S. dollars mark. This was followed by a sharp decline few weeks later where the price was approximately halved. At the time of writing, bitcoin's value is on a spectacular rise. On the 2^{nd} of March 2017 the price of one bitcoin surpassed the value of one ounce gold (Source: https://www.forbes.com/sites/laurashin/2017/03/02/1-bitcoin-is-now-worth-more-than-an-ounce-of-gold/#2645129850f4, Accessed: 13-06-2017) and it did not stop there. Few months later, on the 20^{th} of May 2017, bitcoin was worth more than 2,000 U.S. dollars for the first time in history. The impressive increase continued: on the 11^{th} of June 2017 the price of one single bitcoin crossed the 3,000 U.S. dollars mark.

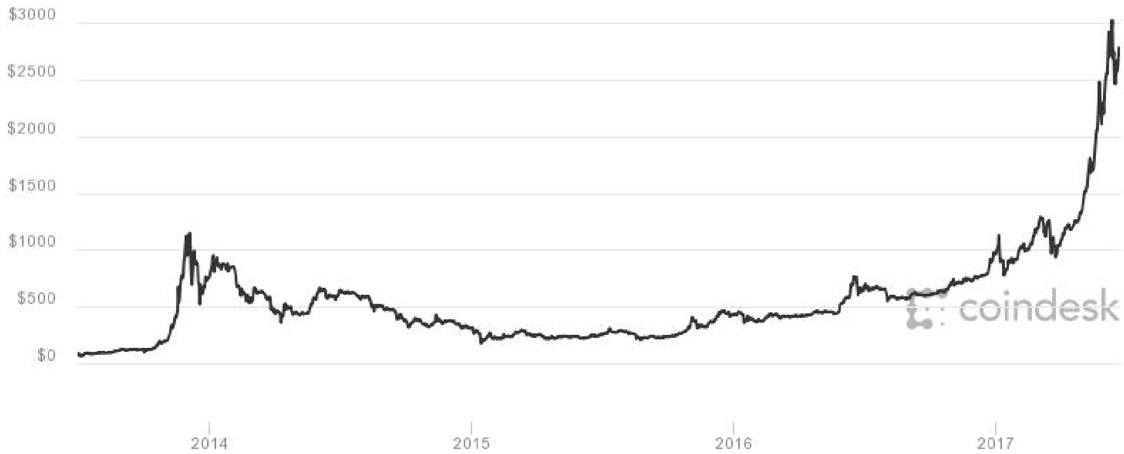

Figure 2: Bitcoin's price movement from July 2013 to June 2017 (Source: http://www.coindesk.com/price/, Accessed: 22-06-2017)

The first real-world transaction using bitcoin is considered to be pizza. Laszlo Hanyecz, a programmer, paid 10,000 bitcoins in exchange for two pizzas on the 22^{nd} of May 2010 (Source: https://bits.blogs.nytimes.com/2013/12/22/disruptions-betting-on-bitcoin/?_r=1, Accessed: 14-06-2017). Since then, this day is also known as the "Bitcoin Pizza Day" where bitcoin fans celebrate the anniversary of the probably most expensive pizza in history (Source: http://www.coindesk.com/bitcoin-pizza-day-celebrating-pizzabought-10000-btc/, Accessed: 14-06-2017). Back in 2010, the two pizzas were worth around 25 U.S. dollars. By today's exchange rate, it would be worth more than 27.8 million U.S. dollars.

There were several events that played an important role in bitcoin's price development. The starting point of bitcoin's rise is often considered to be the bail-in of Cyprus' banks in March 2013. For the first time in eurozone's history, uninsured depositors had to take a loss on their holdings in order to recapitalize the banking system. This harsh bail-in clearly showed bitcoin's benefits. The cryptocurrency was seen as safe haven from the threat of government confiscation. (Michaelides, 2014; Vigna and Casey, 2015)

Bitcoin profited of its growing acceptance and a growing number of people started investing in it. Not even the arrest of Silk Road-creator Ross Ulbrecht by the Federal Bureau of Investigation in October 2013 changed bitcoin's upward spiral. One month later the price of one bitcoin surpassed the 1,000 U.S. dollars mark. The price skyrocketed due to two reasons: The first one were promising comments about digital currencies' future made by the U.S. government. The second one was driven by Chinese speculators. In November 2013, the Chinese bitcoin market was on a phenomenal rise. BTC China, based in Shanghai, became the world's largest bitcoin exchange by trading volume surpassing the leading bitcoin intermediary Mt. Gox. The price of the cryptocurrency reached its peak at 1,147 U.S. dollars on the 4^{th} of December 2013 (Source: http://www.coindesk.com/price/, Accessed: 19-06-2017). However, this was followed by a sharp decline. People's Bank of China declared that bitcoin was not a real currency and the Chinese government restricted the use of digital money. These restraints diminished China's leading role in the bitcoin market. Only a few days after bitcoin's record high, the price started to fall dramatically and was down to almost 700 U.S. dollars. (Mullany, 2013; Vigna and Casey, 2015)

In February 2014, bitcoin's exchange rate experienced a further drop. Mt. Gox, once the worldwide leader of bitcoin exchange, had to file for bankruptcy and declared that it lost 650,000 bitcoins which were worth around 500 million U.S. dollars at the time. (Vigna and Casey, 2015)

After these dramatic highs and lows in the bitcoin market, the willingness to invest in bitcoin shrunk. From the beginning of 2015 to autumn of the same year, the price of the virtual currency was fluctuating around 250 U.S. dollars as illustrated in figure 2. This corresponds to less than a quarter of bitcoin's peak one year earlier. But in 2016, the cryptocurrency started to recover and the price steadily increased.

The new year started good for Satoshi Nakamoto's invention: On the 3^{rd} of January 2017, bitcoin's price crossed once again the 1,000 U.S. dollars mark for the first time in three years. The enormous rise led to mass coverage in the media, including The Guardian (Source: `https://www.theguardian.com/technology/2017/jan/02/bitcoin-tops-1000-for-first-time-in-three-years-as-2017-trading-begins`, Accessed: 20-06-2017) and CNBC (Source: `http://www.cnbc.com/2017/01/02/bitcoin-breaks-1000-level-highest-in-more-than-3-years.html`, Accessed: 20-06-2017) which drove up the price even further.

In March 2017, the E.T.F., short for exchange-traded fund, was rejected by the U.S. Securities and Exchange Commission. Tyler and Cameron Winklevoss, twin brothers who are best known for their legal battle with facebook-founder Marc Zuckerberg, worked on the E.T.F for four years, which would allow to trade bitcoin like a common stock. The bitcoin market reacted to the decision of the S.E.C. quickly. At the beginning of March, a single bitcoin was worth more than an ounce of gold. The enormous rise was mainly driven by the anticipation that the cryptocurrency could be approved by the U.S. Securities and Exchange Commission. But the negative outcome affected bitcoin's exchange rate which lost around 15 percent versus the U.S. dollar. The price quickly recovered though. (Popper, 2017; Roberts, 2017)

In April 2017, Japan accepted bitcoin as a legal payment method (Source: `http://www.cnbc.com/2017/04/12/bitcoin-price-rises-japan-russia-regulation.html`, Accessed: 21-06-2017). As a result, an increasing number of Japan's retailers started accepting the digital currency, such as one of the country's biggest electronics retailers Bic Camera Inc. (Source:

http://www.japantimes.co.jp/news/2017/04/05/business/tech/retailers-japan-accept-virtual-currency/#.WUpEY-vyjIU, Accessed: 21-06-2017).

Driven by the euphoria, bitcoin's value skyrocketed in the last months. In May 2017, the price of a single bitcoin surpassed the 2,000 U.S. dollars mark, which was followed by the 3,000 U.S. dollars mark just a few weeks later. After its historic peak, bitcoin's price decreased and is worth approximately 2,600 U.S. dollars in June 2017.

4 Testing for Speculative Bubbles

Campbell, Lo and MacKinlay (1997) state the following expectational difference equation

$$P_t = \frac{1}{(1+R)} \mathrm{E}_t[P_{t+1} + D_{t+1}], \tag{1}$$

where P_t is the asset price at period t, R is the constant risk-free interest rate, $\mathrm{E}_t[*]$ denotes the expected value conditioned on the available information at time t and D_{t+1} is the dividend obtained in period $t+1$.

The difference equation can be solved by forward iteration and by using the Tower property $\mathrm{E}_t[\mathrm{E}_{t+1}[Y]] = \mathrm{E}_t[Y]$. For k-periods this yields the following result

$$P_t = \left(\frac{1}{1+R}\right)^k \mathrm{E}_t[P_{t+k}] + \sum_{i=1}^{k} \left(\frac{1}{1+R}\right)^i \mathrm{E}_t[D_{t+i}]. \tag{2}$$

Letting k go to infinity, we obtain

$$P_t = \sum_{i=1}^{\infty} \left(\frac{1}{1+R}\right)^i \mathrm{E}_t[D_{t+i}]. \tag{3}$$

Note that in this case the first term of equation (2) goes to zero. This is due to the transversality condition which assumes that the expected asset price will shrink to zero for increasing k (Campbell et al., 1997; Homm and Breitung, 2012)

$$\lim_{k\to\infty} \mathrm{E}_t\left[\left(\frac{1}{1+R}\right)^k P_{t+k}\right] = 0. \tag{4}$$

This result ensures that equation (3) is the unique solution solving the expectational difference equation. In fact, P_t is equal to the fundamental price which is denoted by F_t. However, this assumption can be relaxed for rational bubbles which allows for infinitely many solutions.

If equation (4) does not hold, the solution can take the following form

$$P_t = F_t + B_t, \tag{5}$$

where B_t is often referred to as bubble component (Phillips et al., 2015) which satisfies the submartingale property

$$\mathrm{E}_t[B_{t+1}] = (1 + R)B_t \geq B_t. \tag{6}$$

The last equation can be interpreted as follows: A rational investor who is willing to buy an asset at price P_t anticipates that the bubble component B_t is as well present in the next period and grows at rate R. Due to this expected upward price movement, it seems to be profitable to invest in the asset, because the investor expects that she will be able to sell it at an even higher price in the next period. Note that this behaviour is consistent with the rational expectations assumption. (Homm and Breitung, 2012)

The absence of a bubble which is given by $B_t = 0$ yields $P_t = F_t$, where the asset price depends on the dividend component which follows a martingale. In the presence of a bubble, which means $B_t > 0$, the process displays a more explosive behaviour. In this case, the asset price P_t and the bubble component B_t are not stationary and grow rapidly according to equation (6). These properties can be used to test for bubble phenomena. (Phillips et al., 2011, 2015)

4.1 Detecting Bubbles

The following approach is applied by Phillips, Shi and Yu (2015) to identify explosive behaviour. As a starting point, the authors use right-sided unit root tests. It turns out that this type of tests are particularly suitable for real time bubble detection processes because the main focus is on the explosive alternative as opposed to left-sided unit-root tests, where the main focus is on the stationary alternative. This provides information on mildly explosive behaviour and submartingale characteristics in the data. (Phillips et al., 2014, 2015)

Using the notation of Phillips, Shi and Yu (2015), the null hypothesis is given by a random walk process with an asymptotically negligible drift

$$y_t = \frac{d}{T^\eta} + y_{t-1} + \epsilon_t, \quad \text{with a constant } d \tag{7}$$

where η is a localizing parameter which affects the magnitude of the drift as the sample size T goes to infinity and the error term is $\epsilon_t \overset{iid}{\sim} (0, \sigma^2)$.
This type of model is particularly handy because it allows for a more realistic picture, since financial data commonly displays a mild drift.
Backward substitution for equation (7) yields $y_t = \frac{dt}{T^\eta} + \sum_{j=1}^{t} \epsilon_j + y_0$ which gives the deterministic drift dt/T^η. We can distinguish between the following cases:
For $\eta > 1/2$, the effect is negligible because the drift component is dominated by the stochastic trend. In contrast, the drift part plays a central role for $\eta \leq 1/2$. For the special case $\eta = 1/2$, the standardized output $y_t/T^{1/2}$ follows asymptotically a Brownian motion with drift. (Phillips et al., 2014)
The test statistic is based on the following regression model

$$\Delta y_t = \alpha + \beta y_{t-1} + \sum_{i=1}^{k} \psi_i \Delta y_{t-i} + \epsilon_t \tag{8}$$

where y_t denotes the asset price, α is the intercept, k is the number of lags and the error term is $\epsilon_t \sim N(0, \sigma^2)$.
The null hypothesis is

$$H_0 : \beta = 0$$

which means that y_t is a unit root process. The right-tailed alternative hypothesis is given by

$$H_1 : \beta > 0$$

which implies explosive behaviour. (Shi et al., 2010)

4.2 The SADF Test

Phillips, Wu, and Yu (2011) introduce the sup ADF (=SADF) test which they use to empirically check for explosive behaviour in the NASDAQ stock price index in the 1990s. The test is derived from the right-tailed ADF statistic which is repeatedly implemented on a forward expanding sample sequence leading to a hypothesis test based on the sup value of the corresponding ADF statistic sequence. (Phillips et al., 2015)

Consider the regression sample which is normalized by the total sample size T starting at the r_1^{th} fraction of the total sample and ending at the r_2^{th} fraction. The window size of the regression r_w is defined by $r_w = r_2 - r_1$. For the SADF test, the starting point r_1 of the forward expanding sample sequence is set to 0. Consequently, the window size r_w equals the endpoint r_2 and expands from the smallest initial value r_0 to 1. (Phillips et al., 2015; Shi et al., 2010)

The SADF statistic is denoted by

$$SADF(r_0) = \sup_{r_2 \in [r_0, 1]} ADF_0^{r_2}, \tag{9}$$

where $ADF_0^{r_2}$ is defined as the ADF statistic for a sample going from 0 to r_2. The method of SADF test is shown in the following figure.

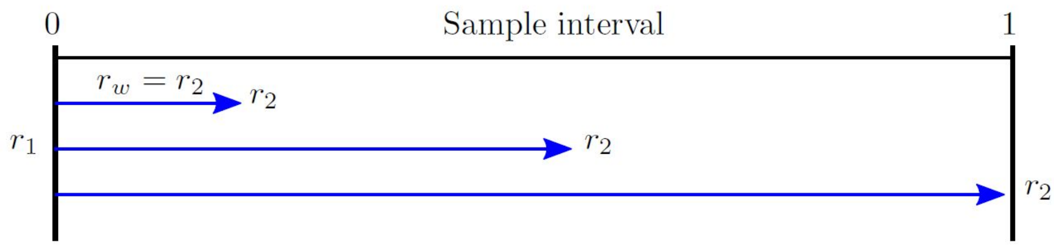

Figure 3: Illustration of the forward expanding sample sequence for the SADF test (Caspi, 2013)

There are several methods to test for speculative bubbles (e.g. Campbell and Shiller (1988); Diba and Grossman (1988) who use co-integration based tests; Frömmel and Kruse (2012) who apply fractionally integrated models). Homm and Breitung (2012) compare different approaches to detect explosive behaviour in financial data. In practice, the model constructed by Phillips, Wu and Yu (2011) has its strength in finding periodically collapsing bubbles. Therefore, Phillips, Shi and Yu (2015) focused on the model's superiority compared to alternative methods.

4.3 The GSADF Test

Phillips, Shi and Yu (2015) point out that the SADF test may show its weakness when it comes to implementing a long historical time series which experienced multiple boom and bust phases. In the worst case, the test would fail to reveal the existence of a speculative bubble. Therefore, the authors introduced a modified version of the SADF test: the generalized sup ADF (=GSADF) test.

The GSADF test relies as its predecessor on recursive right-tailed ADF tests but the starting point is not fixed. This means that not only the end point of the regression varies, but also the starting point can change within a feasible range. This flexibility of the window widths enables a better detection of multiple bubbles in comparison to the SADF test.

The GSADF statistic is defined as

$$GSADF(r_0) = \sup_{\substack{r_2 \in [r_0, 1] \\ r_1 \in [0, r_2 - r_0]}} ADF_{r_1}^{r_2} \tag{10}$$

where $ADF_{r_1}^{r_2}$ represents the ADF statistic for a sample going from the starting point r_1 to the end point r_2. The GSADF statistic is the largest ADF statistic ranging from r_1 and r_2. (Phillips et al., 2015)

The following figure shows the method of the GSADF statistic.

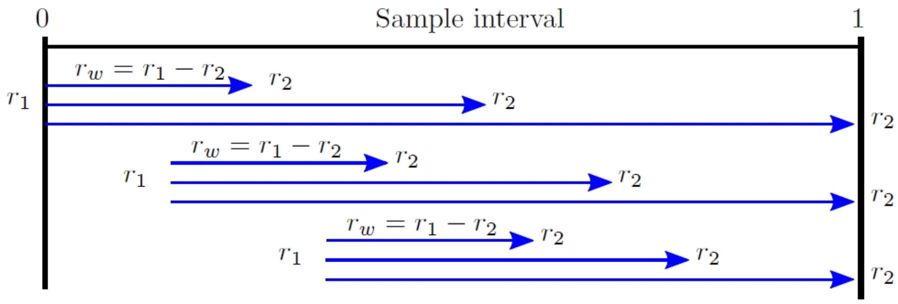

Figure 4: Illustration of the sample sequence for the GSADF test (Caspi, 2013)

5 Empirical Findings

5.1 Data

Due to the topicality of the bitcoin field, a lot of open source data is available. In this work, the used database is Quandl, a data platform that offers data sets from hundreds of publishers (http://www.quandl.com). The sample consists of daily exchange rates between bitcoin prices and U.S. dollar. In order to test for presence of speculative bubbles in the bitcoin market, the logarithmic time series of the exchange rates are used.

Two data sets are chosen: the first one which includes the turn of the year 2013/2014 and a second one which includes bitcoin's enormous increase in 2017.

5.2 Results

In the first data set, the window size is set to 10% for the SADF test and the critical values are obtained from 1,000 Monte-Carlo replications. Since the GSADF test requires higher computational power compared to the SADF test, the window size corresponds to 30% for the first data set. The second data set uses the same window size, namely 10%, for both tests. The critical values are again obtained by Monte-Carlo simulations with 1,000 replications. For all data sets the lag order k is set to 0 as it is recommended by Phillips, Shi and Yu (2015) to choose a fixed lag length in order to reduce distortion.

1) First Data Set

The chosen time period ranges from the 1^{st} of April 2013 to the 31^{st} July 2014, giving 487 observations. The results for both tests are shown in table 1.

Test critical values	SADF	GSADF
	2.088310	5.175967
99%-quantile	2.004959	2.211287
95%-quantile	1.453440	1.761576
90%-quantile	1.165373	1.486354

Table 1: Results of the SADF and GSADF test from April 2013 to July 2014

Taking a look at figure 5 and 6, explosive behaviour can be detected in the time period from November 2013 to January 2014. Both SADF and GSADF test exceed the critical value which gives strong evidence for presence of a speculative bubble.

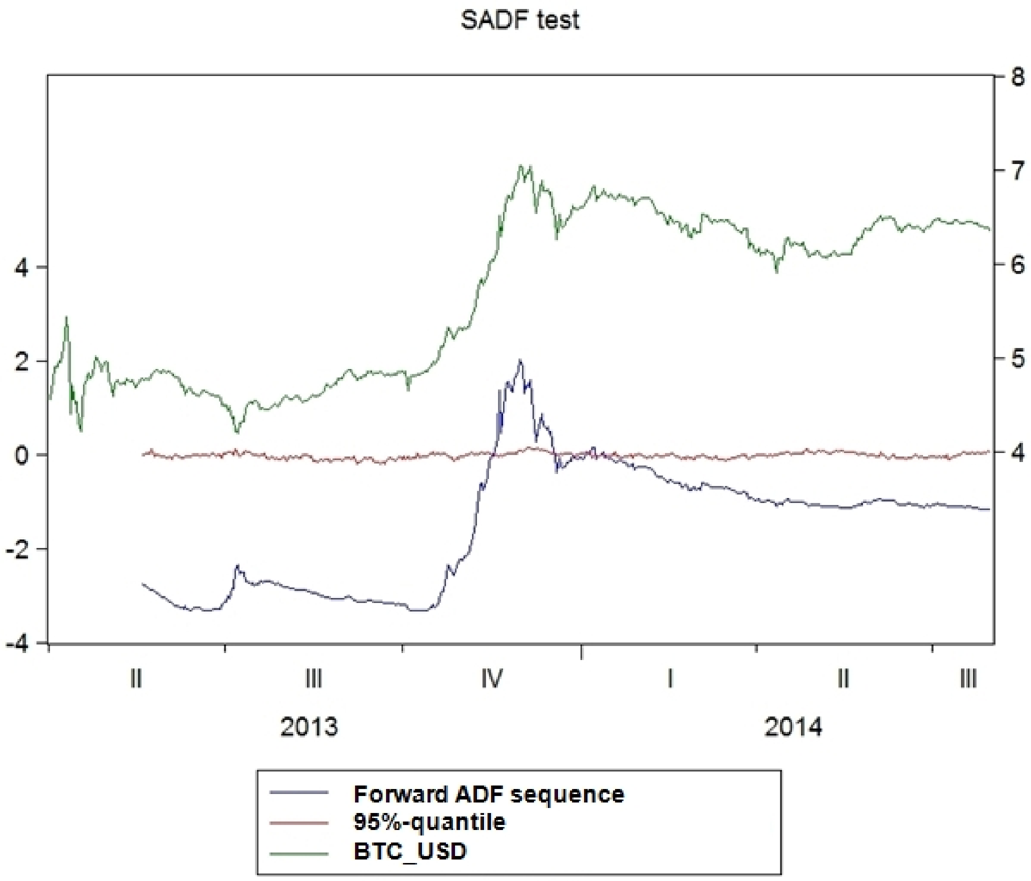

Figure 5: SADF test for the time period from April 2013 to July 2014

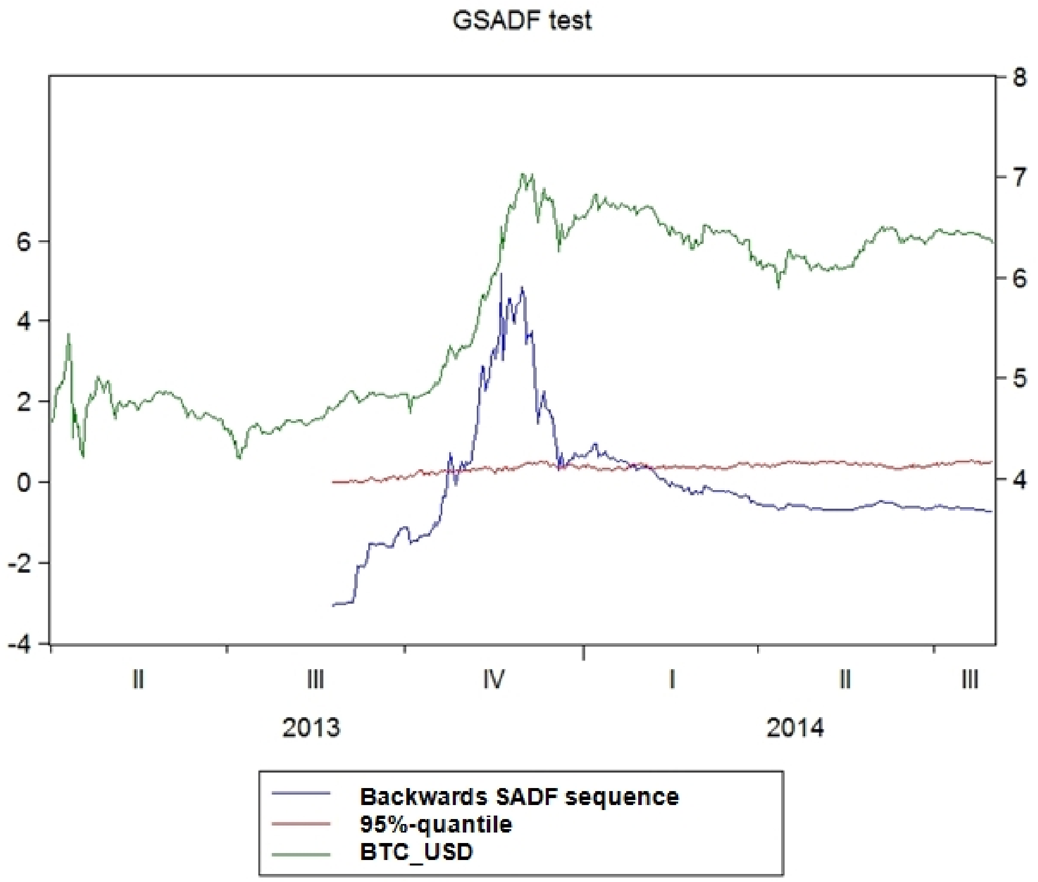

Figure 6: GSADF test for the time period from April 2013 to July 2014

2) Second Data Set

The data set ranges from the 24^{th} of March 2017 to the 11^{th} of June 2017. This time period of almost three months includes 80 observations. The results for both tests are shown in table 2.

Test critical values	SADF	GSADF
	1.309753	3.788783
99%-quantile	2.082109	3.978364
95%-quantile	1.419269	2.764297
90%-quantile	1.085177	2.285552

Table 2: Results of the SADF and GSADF test from from March to June 2017

Similar to the evaluation of the first data set, the GSADF test gives empirical evidence for the presence of speculative bubbles in the Bitcoin-USD exchange rate at the 5-% significance level since $3.789 > 2.764$. In the case of the SADF test, the results change though. Since $1.310 < 1.419$ the SADF test does not exceed the critical value at the 5% significance level. However, at the 10% significance level, the null hypothesis is rejected since $1.310 > 1.085$. Figure 7 and figure 8 show the time interval of mildly explosive behaviour where the corresponding statistic is larger than the 95%-quantile.

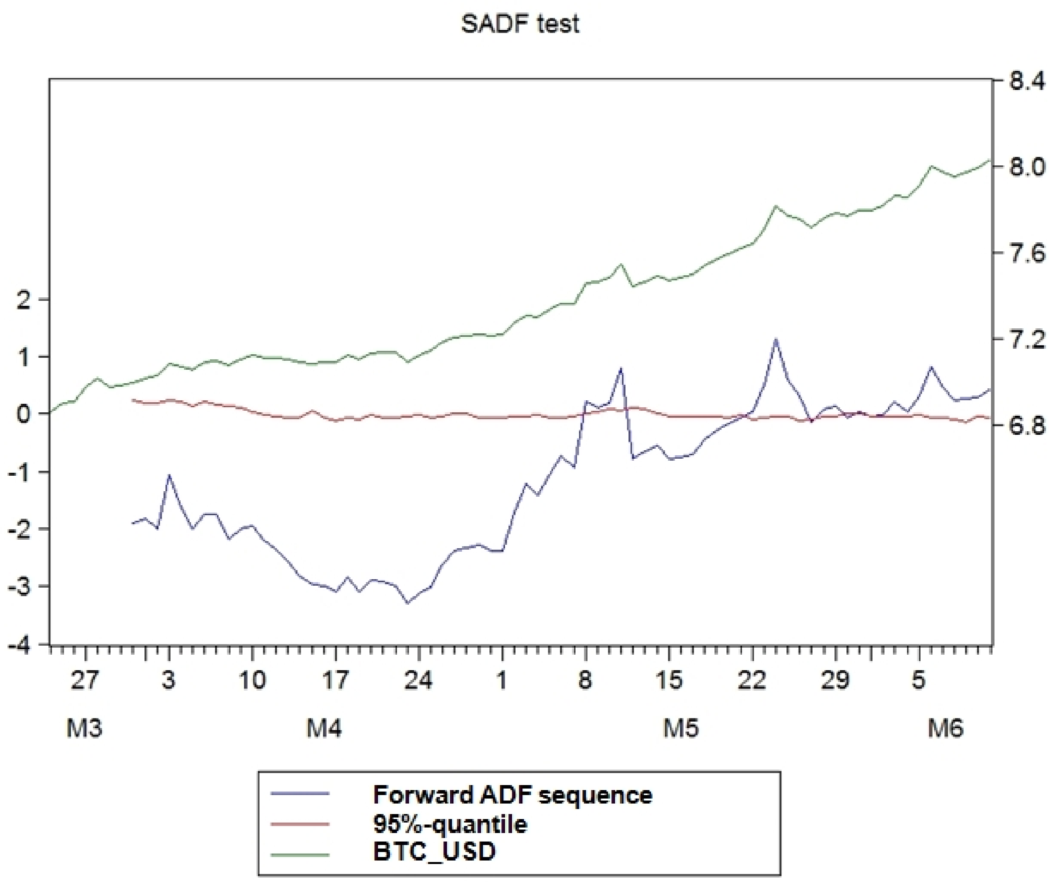

Figure 7: SADF test for the time period from March to June 2017

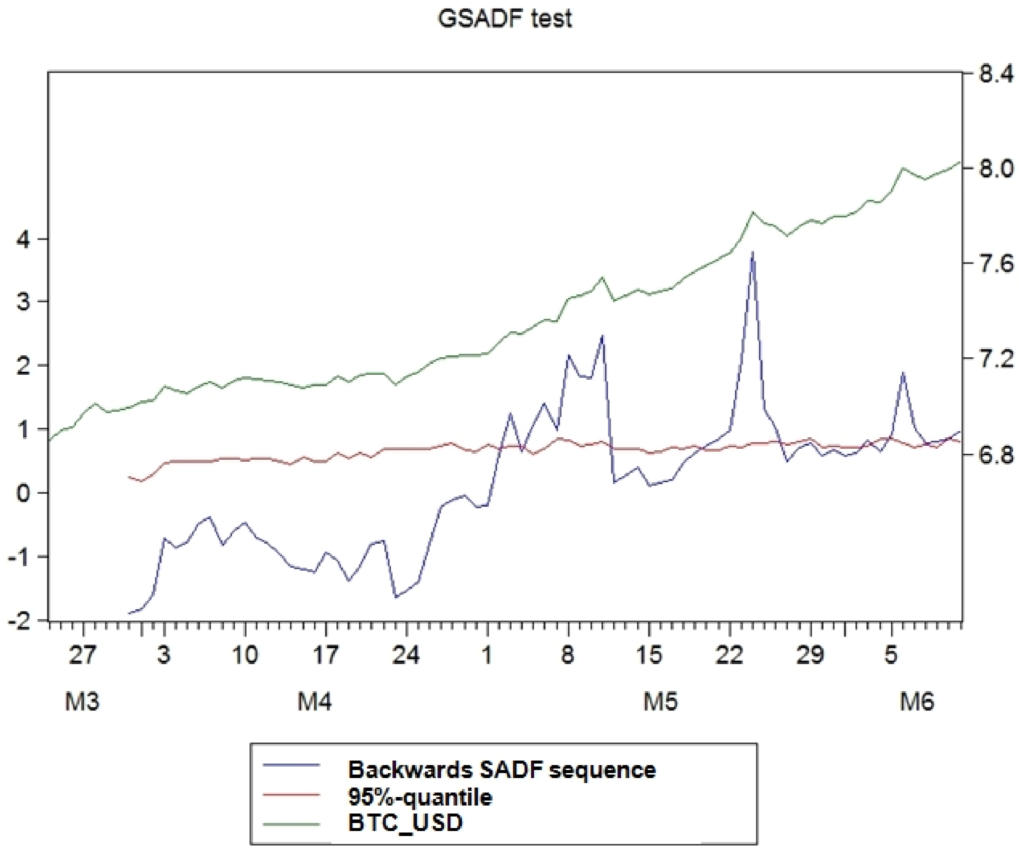

Figure 8: GSADF test for the time period from March to June 2017

6 Discussion

Since its implementation in 2009, bitcoin experienced rapid increases which were followed by sharp declines in less than a decade. In particular, the period between November 2013 and January 2014 is characterized by a boom and bust pattern which fuels speculations of a bubble. This thesis empirically investigates if the bitcoin market experienced a speculative bubble. With regards to answering this research question, the SADF test developed by Philips, Wu and Yu (2011) and the modified version, the GSADF test by Philips, Shi and Yu (2015), were applied. In the time period from April, 2013 to June, 2014 both SADF and GSADF tests give empirical evidence for the presence of a speculative bubble in the bitcoin market. For the second data set which includes bitcoin's historic peak, the GSADF test yields statistically significant results for the existence of an additional bubble.

The time interval of the first data set was chosen due to its boom and bust pattern. At the end of 2013, bitcoin's exchange rate experienced an enormous rise reaching the 1,000 U.S. dollars mark. Two factors played an important role in driving up bitcoin's price and the euphoria among investors: the U.S. government made welcoming comments about the future of virtual currencies and the Chinese bitcoin market was on a spectacular rise. But the record high was followed by a sharp decline. Chinese government restricted the use of the cryptocurrency and Mt. Gox, at the time the world's leading bitcoin exchange, had to file for bankruptcy. These price developments resemble the common pattern of a bubble as it was discussed in chapter 2. The findings of the used models confirm the hypothesis of a speculative bubble during this time period. Both the SADF test (2.088 > 2.005, see table 1) and the GSADF test (5.176 > 2.211, see table 1) provide significant evidence of explosive behaviour in the bitcoin data at the 1% level suggesting the presence of a speculative bubble.

The second data set includes the recent peak of bitcoin's price in 2017. So far, this year has been the most successful one for the cryptocurrency. At the beginning of 2017, a single bitcoin was again worth more than 1,000 U.S. dollars as it was the case before the collapse in 2014. Not even half a year later, bitcoin's price tripled leading to its record high of 3,000 U.S. dollars. The growth is mainly driven by investors who anticipate that further countries and international companies will accept the digital currency as a legal payment method. This phenomenal increase raises the question if the bitcoin market is experiencing another speculative bubble. At the time of writing, the price movements resemble the boom and euphoric phase of a typical bubble cycle.

Homm and Breitung (2012) point out that the SADF test is most powerful if the sample contains the rise and ends with the price series' maximum. Including observations of the decline might distort the research results. The authors propose to determine the bubble phases from visual inspection of the time series. The range of the sample should be restricted to this time span in order to get best possible results. Therefore, the time period from March to June 2017, which ends with the peak on the 11^{th} of June, was chosen to test for explosive behaviour.

The SADF test does not exceed the critical value at the 5% significance level (1.310 < 1.419, see table 2). However, at the 10-% level the null hypothesis is rejected in favour of the right-tailed alternative hypothesis (1.310 > 1.085, see table 2) which would imply explosive behaviour. The GSADF test yields a more significant result. The model gives empirical evidence for explosive behaviour in the Bitcoin-USD exchange rate at the 5% significance level (3.789 > 2.764, see table 2) which indicates a further speculative bubble in the bitcoin market.

However, the results of the second data set must be interpreted with caution. As explained above, the sample should include the rise and the peak of the data in order to correctly detect whether a speculative bubble occurred. Nevertheless the process of visually deciding where the boom phase begins runs the risk of being subjective. Other researcher might choose another range of the data and, therefore, obtain different findings. At the time of writing, bitcoin reached its peak in mid-June, which was then followed by a sharp decline. However, being confronted with a volatile asset like bitcoin, it is difficult to forecast future developments. There is the possibility that the exchange rate of the cryptocurrency recovers which would mean that the boom phase and especially the euphoria are not finished yet. In that case, further research should be done to investigate the presence of a current speculative bubble in the bitcoin market.

7 Conclusion

Due to bitcoin's recent skyrocketing increase the digital currency is more topical than ever. Almost every day the media cover stories about ground-breaking developments in the bitcoin market. Nakamoto (2008) aimed to create a secure virtual currency which relies on a peer-to-peer network. The revolutionary component of bitcoin is its decentralized structure. No trusted party is needed, including central authorities and financial institutions. Cutting out the middleman is possible because of bitcoin's core invention known as the blockchain.

The purpose of this thesis was to determine whether the bitcoin market experienced a speculative bubble or not. Since its implementation, bitcoin's exchange rate is widely fluctuating versus fiat currencies such as the U.S. dollar or the euro. Certain time periods follow a boom and bust pattern which indicate the presence of speculative bubbles. The investigated time span contains the rapid rise and the sharp decline in the years 2013 and 2014. Returning to the research question posed at the beginning of this thesis, it is now possible to give an answer. The results for the data set, using the SADF test and the GSADF test, show empirical evidence for the existence of a speculative bubble at the 1-% significance level.

In recent years, an increasing number of researchers has investigated the field of cryptocurrencies with its front-runner bitcoin, e.g. Barber et al. (2012) who give an in-depth analysis of bitcoin, Ron and Shamir (2013) who analyse the behaviour of bitcoin users and Dwyer (2015) who explains the economics of bitcoin. This thesis gives important insights on the presence of speculative bubbles in the bitcoin market. In particular, the results obtained from the second data set that includes bitcoin's skyrocketing rise in 2017 are a strong contribution to bitcoin's current development. Further research which uses a similar approach is conceivable and would help to gain a deeper understanding of bitcoin's price movement and its connection to speculative bubbles.

List of Figures

List of Tables

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