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Bitcoin as a financial asset: Impact of Bitcoin on a well-diversified European portfolio

Mémoire recherche réalisé par
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1. Introduction

"This Is Not a Passing Fad: CFA Exam Adds Crypto, Blockchain Topics" is the headline of the article published by Bloomberg on the 17th of July 2018 (Patterson & Tan, 2018). The journalists argue that the announcement made by the CFA institute might be the sign that cryptocurrencies have arrived on Wall Street. Other major institutes such as the ECB and the IASB investigate cryptocurrencies to better understand how they function and how they should be classified (Houben & Snyers, 2018; IASB, 2018). Cryptocurrencies have also massively appeared in the media, showing the interest of the broad public. All these elements underline the fact that cryptocurrencies are a topic that receives massive attention from institutions and is broadly present in our society and our economy.

Of all the cryptocurrencies, Bitcoin is the most commonly known and mediatised. Bitcoin is currently the largest cryptocurrency with a market cap of €109,9 Billion (Coinmarketcap, 2018). For this reason, the focus will be kept, throughout this paper, on Bitcoin. However, it is important to note that by Bitcoin we refer to Bitcoin Core[1].

Bitcoin made its appearance in 2008 in a paper written by Satoshi Nakamoto, an unknown individual or group of individuals. The main purpose of Bitcoin was to create a pure peer-to-peer [2]version of electronic cash that would not need any intervention of a financial institution. Bitcoin aims to replace trust in a third party by cryptography. Bitcoin's underlying technology is the blockchain (Nakamoto, 2009).

The very first time Bitcoin was traded and thus valued was in 2010 when 10,000 Bitcoin were exchanged for 2 pizzas from the restaurant Papa John's. From there on Bitcoin started to be valued and to have a price. Some even argue that Bitcoin could be used as a currency. However, only Japan has adopted Bitcoin as legal tender and many other national and international institutions do not see Bitcoin as a currency (EBA, 2014 ; ECB, 2015; Gaidosch,

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[1] There exist other types of Bitcoin i.e. Bitcoin Gold, Bitcoin Cash and Bitcoin Private that we will not discuss in this thesis.
[2] Peer-to-peer refers to a network of peers who share resources amongst each other without the need for a central authority or trusted third party.

2018). The debate in academic literature tends to describe Bitcoin under its current form as a financial asset rather than as a currency (Baeck and Elbeck, 2015; Cheah and Fry, 2015; Glaser, Zimmermann, Haferkorn, Weber & Siering, 2014). Literature shows that Bitcoin has properties that are very interesting for different areas of finance as it has low correlations with other assets and has high returns due to its high volatility. Bitcoin has therefore been analysed as a safe haven in times of crisis, as a potential hedge for other assets as well as a tool for portfolio diversification (Brière, Oosterlink, Szafarz, 2013; Katjazi & Moro, 2017). The latter especially caught our attention. Research has been performed on the impact of Bitcoin on a well-diversified portfolio from different geographical point of views i.e. world investor, US investor, Chinese investor. We therefore chose to extent and complement existing literature, as the European market has not yet been investigated. Our research question formulates as following: “What is the impact of Bitcoin on a well-diversified portfolio from the point of view of a European investor?”.

Section 2 gives an in-depth theoretical explanation of Bitcoin and its related concepts: How it functions, its uses and its nature i.e. a currency or a financial asset. Section 3 gives a theoretical overview of portfolio diversification and a mathematical formalisation of the used concepts. Section 4 analyses the impact of Bitcoin on a well-diversified European portfolio. We would recommend to the reader that is familiar with the concepts of Bitcoin and portfolio diversification to directly leap to section 4. The reader who is not familiar with these concepts can find all necessary information in sections 2 and 3 to better understand the analysis as well as the results outlined in section 4.

2. Bitcoin

2.1 A general overview

2.1.1 Brief history of digital cash and Bitcoin

Most of today's world consumer trades happen in paper cash, but more and more consumers make purchases using online electronic money transfers (Capgemini & BNP Paribas, 2017, p.5). During an online transfer, money is transferred from a payer to a payee (by using a credit or a debit card). Cryptography is used in combination with technology by money transfer service providers e.g. mastercard and paypal, to establish a secure transfer of money. Cryptographers have tried to build an electronic cash system based on the security features of paper cash[1]. One example of an attempt to create an electronic cash system is Digicash, designed by David Chaum (1983). However, many, if not all, of these electronic cash systems never managed to replicate the security features of cash paper (Drainville, 2012). Bitcoin (BTC) is the first digital currency that could fill the gaps that the previously described Digicash was suffering from.

Although there is no confirmation[2], it is often mentioned that bitcoin came into existence as a reaction to the diminished trust in financial institutions and the financial crisis in 2008. In fact, the genesis or first block, contains a reference to an article of "The times" from the 3rd of January 2009 which cites as a headline "Chancellor Alistair Darling on brink of second bailout for banks" (Marr, 2017; The times, 2009, p.1). This shows that the developers referred to the crisis and shows their willingness to no longer trust the financial world.

Bitcoin saw its original whitepaper released in 2008 by an unknown person or group of persons under the pseudonym Satoshi Nakamoto. Bitcoin is a digital cryptocurrency that works on a peer-to-peer digital payment system that does not have a central authority and does not rely on a trusted third party. Furthermore, it eliminates the need for trust, the mediation costs charged by the third parties and it avoids double spending. It relies on a

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[1] Recognizability, Portability, Transferability, Divisibility, Unforgeability, Untraceability, Anonymity, Security.

[2] As mentioned earlier, it is still unknown who created Bitcoin.

network of nodes that cooperate together to secure transactions through cryptography in a public distributed ledger known as the Blockchain (Brito, Castillo, 2013)

On 3 January 2009, the genesis block of Bitcoin (the first block also called block number 0) was mined i.e. created, bringing the Bitcoin network into existence (Block Explorer, 2009). In the following years, Bitcoin gradually gained in popularity. In 2011, WikiLeaks started to accept Bitcoin for donations. Bitcoin also started to be accepted as a method of payment by several American-based companies OkCupid, Foodler and Overstock.com in 2013, Dell and Newegg in 2014 etc. Next to legal businesses using Bitcoin, the latter was also extensively used on black markets such as the infamous SilkRoad, who only accepted Bitcoin as means of payment (Christin, 2012). As of 2015 a debate around the 1 MB block size of the Bitcoin Blockchain emerged, dividing the Bitcoin supporters into two groups. One group favours the increase in the block size, arguing that keeping the 1MB limit will greatly slow down the transaction speed of the Bitcoin and increase transaction fees, while the other group argues that the 1 MB limit should be maintained and other solutions found to solve the speed and fees issues. On August 1st 2017, the initial Bitcoin Blockchain split/forked into two derivative coins, the Bitcoin Core (BTC) with its 1 MB block size and Bitcoin Cash (BCH) with an 8 MB block size.[1](Fahmy, 2018). In this paper, Bitcoin will refer to **Bitcoin Core.**

2.1.2 Dominance of Bitcoin in the cryptocurrency sphere

Table 1 shows a top 5 of cryptocurrencies according to their market cap in the crypto-currency sphere. The most famous virtual currency is the Bitcoin which has the largest market cap of approximately €109,9 Billion. Bitcoin represents currently 43% of the total market cap of cryptocurrencies in July 2018. This is double of the market Cap of Ethereum, which is second in ranking. The current daily trade volume of Bitcoin is €5,7 Billion and is thus the most traded cryptocurrency. As a result, Bitcoin is the most prominent cryptocurrency according to recent figures.

[1] We will not elaborate this topic since it is beyond the scope of this paper.

Top 5 cryptocurrencies by market capitalization					
#	Name	Price	Circulating supply	Market Cap	Volume (24h)
1	Bitcoin (BTC)	€6,409.78	17,155,737 BTC	€109,964,466,119	€5,700,655,486
2	Ethereum (ETH)	€426.55	100,767,362 ETH	€42,982,426,492	€2,148,599,878
3	Ripple (XRP)	€0.44	39,262,444,717 XRP	€17,331,486,133	€332,030,113
4	Bitcoin Cash (BCH)	€747.53	17,244,000 BCH	€12,890,408,744	€682,960,800
5	EOS	€7.68	896,149,492 EOS	€6,878,468,576	€872,563,460

Table 1: Shows the top 5 cryptocurrencies ranked according to their market cap[1] on the 18th of July 2018.

2.1.3 The functioning of Bitcoin

2.1.3.1 Blockchain

Bitcoin owes its success in part to its underlying technology, the Blockchain. The Blockchain is a distributed database over many nodes[2] that contains the transaction history in chronological order. This technology overcomes the double spending problem by keeping a public history of all spent Bitcoins (past transactions) on the Blockchain which makes it possible for the nodes on the network to verify that a Bitcoin is not spent a second time.

This technology is - as the name implies- an ongoing chain of blocks that each contain, inter alia, a block header and a list of transactions. The block header contains information about the preceding block in the chain as well as a valid nonce. A valid nonce is a random number that miners have to find that demonstrates the proof of work[3] (Nakamoto, 2008).

To complete the proof of work a hash function is used (in the case of Bitcoin, SHA-256). An input in a hash function is converted by that hash function into an output/digest of random letters and numbers of a fixed length[4]. However, altering the input changes the output completely. An example is given in Figure 1. When the input used is “Bitcoin”, a certain

[1] Source: Coinmarketcap URL: https://coinmarketcap.com/all/views/all/

[2] Nodes: Refers to participants in the network which are mainly computers. There function is to support the network by maintaining a copy of the blockchain.

[3] “A proof of work is a piece of data which is difficult to produce but easy for others to verify and which satisfies certain requirements”. (Proof of work, 2016)

[4] The SHA256 function (Bitcoin's proof-of-work function) has a serie of 256 bits i.e. numbers and letters, as output no matter the input. However, changing only slightly the input will completely alter the output.

string is given as an output. However, changing “Bitcoin” into “bitcoin” alters the output completely.

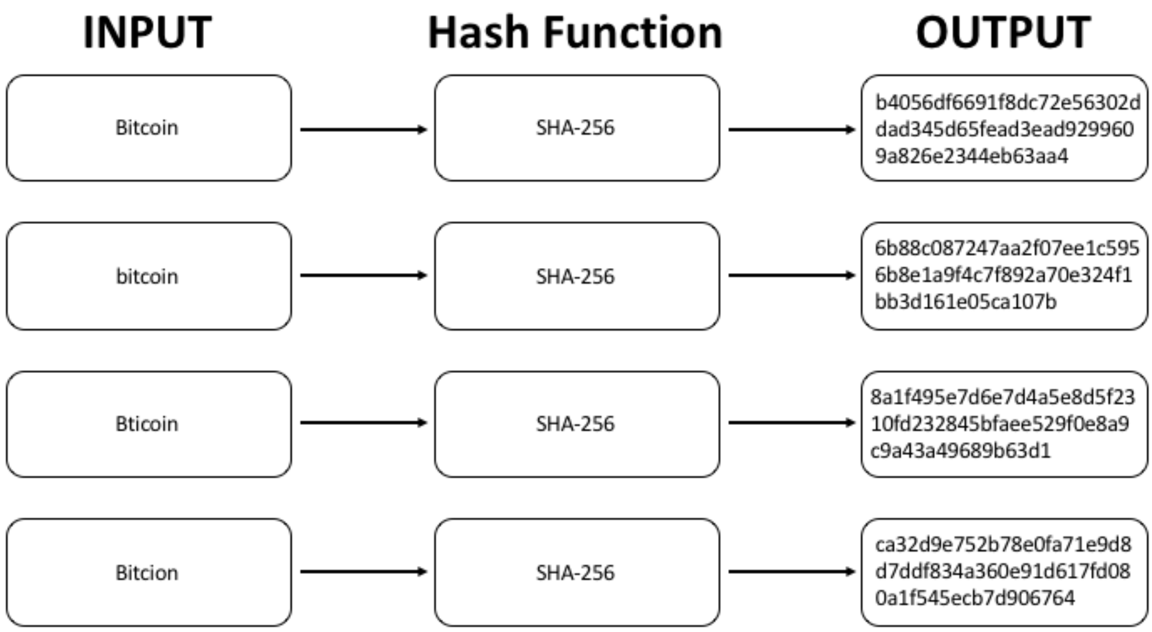

Figure 1: This figure describes how the SHA-256 hash function works. This hash function is, amongst others, used for Bitcoin cryptography. Not every cryptocurrency uses this hash function.

The proof-of-work is the fact of finding a valid nonce. A nonce is a number that is such that, when a block is hashed by the miner i.e. the nonce and other information is entered into the hash function, the hash begins with a certain number of zeros. In the ideal case, the right nonce can only be discovered by trying many possible nonce values. This can be considered as a sort of mathematical or cryptographic puzzle that miners try to solve. The higher the number of tries, the higher the probability of finding the corresponding hash that respects the number of leading zeros i.e. the actual difficulty. The probability of finding a hash and thus the time to create a block can be adjusted by increasing or decreasing the number of leading zeros. A block is mined approximately every 10 minutes and the algorithm adapts the amount of work so that the pace of block creation is maintained stable around ten minutes (Becker et Al., 2013; Böhme et all. 2015).

The miners are continuously trying to solve the cryptographic puzzles i.e. adding blocks to the chain, and once the solution obtained, broadcasting the solutions as well as the obtained tail of the chain. This way miners are agreeing on the correct record of transactions and thus actually verifying the transactions. The Blockchain will incorporate the record of transactions that obtains the majority of similar solutions. It is thus possible that a node produces a sequence of blocks but changes it's the sequence of blocks later because the majority of miners has reached a different solution (Böhme et al., 2015).

In order to ensure the security of the Blockchain a block is only added to the chain once it provides a proof-of-work (see above). This step, commonly known as mining, increases the security of the chain because changing a block would require redoing the work of that block as well as all the following blocks that are added to the chain and is impossible if one does not own more than 50% of the computing power (Nakamoto, 2008).

2.1.3.2 Mining: security and minting of Bitcoin

Nodes of the system that participate in solving the cryptographic hash i.e. the proof-of-work of the blocks, are called *miners* (Kroll, Davey, Felten, 2013; Nakamoto, 2008). Mining can be considered as a contest in which all participants try to solve the cryptographic puzzle as fast as possible (Dwyer, 2015). The first participant to solve the puzzle is rewarded by newly issued Bitcoins (Franco, 2014). Initially this was 50 Bitcoins per block, but the amount is halved every 210,000 blocks (which takes approximately four years) and in July 2018 miners receive 12,5 Bitcoin per block mined (Kroll et al., 2013). The Bitcoin protocol thus states that the total supply of Bitcoin is finite and will ultimately reach 21,000,000 Bitcoins in 2140 (Nakamoto, 2008; Kroll et al., 2013). The reward of the miner wil fall to zero once all the bitcoins are in circulation. Miners will be further incentivised by optional fees per transaction so that they include the transaction in the block. In other words, Bitcoin mining will shift from a reward-based model to a fee-based model (Dwyer, 2015; Kroll et al., 2013). According to Möser and Böhme (2014) since the number of Bitcoins minted per block decreases, the transaction fee per transaction will consequently increase. In a later stage where no new Bitcoins are issued, an equilibrium model is proposed by Houy (2014a). Nowadays mining requires specialised hardware and miners organize themselves in mining pools. Having more computing power increases the probability of mining the next block and consequently receive the Bitcoin reward. The Bitcoin reward will be shared amongst all participants of the pool (Böhme et al., 2015).

2.1.3.3 Transactions

Transactions using Bitcoin are all recorded in the Blockchain. When a Bitcoin is transferred, one actually transfers ownership over a Bitcoin. A Bitcoin is a chain of digital signatures that is protected cryptographically. To transfer one coin, the previous owner must sign the hash of both the previous transaction and the next owner's public key with his own private key (cf. Figure 2). By doing this, the previous transaction is entangled with the next one. Any participant can now verify the digital signatures, by using the public key, to establish the chain of ownership. However, to spend the Bitcoin i.e. making the next transaction, one needs the knowledge of the according private key. (Becker et al., 2013; Nakamoto, 2008).

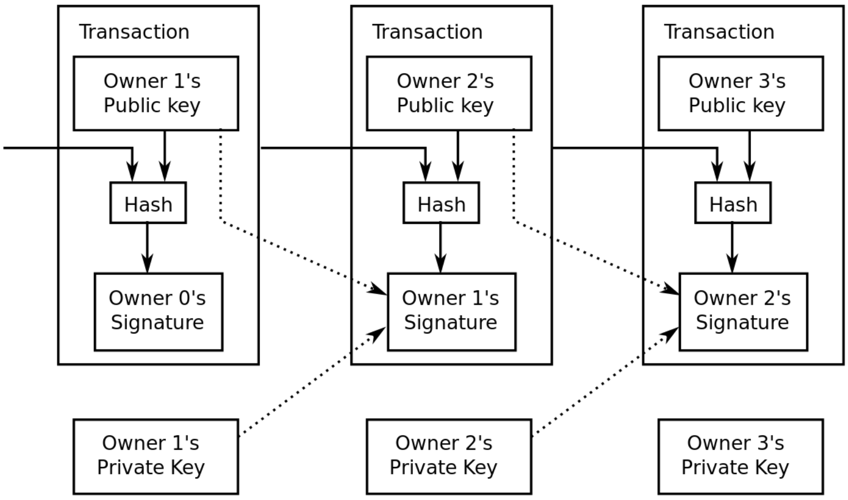

Figure 2: Explains Bitcoin transactions (Nakamoto, 2008, p2).

Establishing transactions this way secures that no other participants in the network can spend a Bitcoin they do not own. The other main problem of digital currencies i.e. double spending will be explained in section 2.1.4.2 and is solved by using the Blockchain. The interested reader can refer to Fantazzini, Nigmatullin, Sukhanovskaya & Ivliev (2016) or Böhme et al. (2015) for an illustrative example of a transaction in the Blockchain.

To perform transactions, a user must own a Bitcoin wallet. A wallet is the place where the Bitcoins can be accessed. In more technical terms, a wallet contains the private key and its related public key, which are both needed to receive or send Bitcoins or more precisely to receive or send the ownership of the Bitcoin(s). There is thus no real exchange of Bitcoin but just a change in balance of Bitcoins owned on the wallet and the transaction or change of ownership is recorded on the Blockchain. The private key is used to control the Bitcoins of a certain wallet. In other words, the knowledge of the private key related to an address equals possession of the "stored" Bitcoins and the possibility to make transactions (Fantazzini et al., 2016)[1].

2.1.4 The main features of Bitcoin

2.1.4.1 Pseudonymity

When Bitcoins are spent the transactions are recorded in a public ledger, better known as the Blockchain (see section 2.1.3.1 "Blockchain"). "The public can see that someone is sending an amount to someone else, but without information linking the transaction to anyone" (Nakamoto, 2008, p.6). This is similar to having a pseudonym online, other users can see what the user under the pseudonym is doing but you cannot relate the pseudonym to someone's real identity. In other words, a user can only remain anonymous as long as the user's public key (explained in section 2.1.3.2 "Transactions") cannot be linked to the user's personally identifiable information i.e. his own identity. However, Goldfeder, S., Kalodner, H., Reisman, D., & Narayanan, A. (2017) found that it is possible and not that difficult to link a user's personally identifiable information to a Bitcoin address by using information collected by cookies and Web trackers during an online purchase. Furthermore Androulaki, E., Karame, G. O., Roeschlin, M., Scherer, T., & Capkun, S. (2013) use a simulator to imitate the use of Bitcoin in a university and were able to uncover 40% of the users' identities. All in all, Bitcoin should not be considered as a cryptocurrency that provides anonymity but rather pseudonymity to a certain extent.

2.1.4.2 Double spending avoidance

As already discussed, the cash paper system has different security features that Bitcoin seems to possess. One feature is that a cash note cannot be spent twice, once you hand it out you do not have it anymore. Furthermore, the value of a note is, amongst others, guaranteed by the fact that it is hard to counterfeit. Whereas double spending is thus hard to achieve with physical notes, double spending could not be easier with a digital currency (Dwyer, 2015). For a digital currency to exist it must not be possible to spend the same amount multiple times (Wayner, 1997).

[1] For more detailed explanation, the reader is invited to consult Fantazzini et al. (2016), Böhme et al. (2015)

The problem of double spending is similar to counterfeiting, using the idea of a legal tender. If the double spending issue is not solved, the value of the digital currency, which is just a set of bits[1], is as much as the marginal cost to produce any particular set of bits i.e. zero, because bits are costless to produce (Becker, Breuker, Heide, Holler, Rauer & Böhme, 2013). One solution is to have a central authority that keeps a record of every transaction performed so that it is possible to assess whether the money has already been spent and who the rightful owner of the money is (similar to the role played by a bank that holds a deposit). However, in the case of Bitcoin, the deposit would not be held by the bank, the Bitcoin ecosystem would only certify who the owner of the money is (Becker et al., 2013; Dwyer, 2015). Bitcoin overcame the double-spending issue by establishing a network of nodes that receives distributed databases (i.e. the Blockchain, see section 2.1.3.1) that contain all transaction history in temporal order and certifies that transactions are authorised i.e. that the Bitcoins are spent once by the rightful owner.

2.1.4.3 Decentralised

One of the main drivers of Bitcoin is that it does not need a centralised authority or third party to accomplish transactions as it relies on the Blockchain and hence on the peer-to-peer verification of transactions based on computing power rather than trust (Nakamoto, 2008). According to Böhme et al. (2015), decentralisation comes with a series of advantages.

First, it avoids that one person can seize power of the whole system because the system makes sure that it is nearly impossible to have a concentration of power in the hand of one single individual i.e to seize power one should have more than 50% computing power (if an attacker did so, he could redo the work of the past and therefore outperform the honest chain) (Becker et Al., 2013). Second, it also avoids having one single point of failure, the rest of the computer network remains able to keep functioning. Third, it allows for lower transaction fees than traditional financial institutions (Segendorf, 2014). Lastly, since Bitcoins are virtual and have low transaction fees, they are not constrained by national borders and can easily be used for fast cross-border payments (Yermack & Raskin, 2016). Payments can be done anywhere at any time. Conceptually, following the Bitcoin protocol, Bitcoin should be completely decentralised (Nakamoto, 2008). However Böhme et Al. (2015, p.220) also argue that

[1] Binary digit that is the smallest unit of data in the computer. It can either be 0 or 1.

"significant economic forces push towards de facto centralisation and concentration among a small number of intermediaries at various levels of the Bitcoin ecosystem". Examples of this include Bitcoin exchanges, mining pools, etc. that show that Bitcoin is in fact not completely decentralised.

2.1.4.4 Transparent

The fact that all transactions are publicly available and traceable in the blockchain (see section 2.5.1) is also described as transparency. The main advantage is that the ownership of the bitcoin can be traced back by anyone to make sure who is the rightful owner. This feature of Bitcoin goes hand in hand with decentralisation as it helps solving the double spending issue. This can also be considered as a downside because everyone has access to all the important information such as the number of bitcoin one user owns and his transaction history (Dwyer, 2015; Becker et al, 2013).

2.1.4.5 Irreversible

One particularity of Bitcoin is that once a Bitcoin transaction is locked in the Blockchain it is irreversible. This is because the Bitcoin protocol does not allow a user to alter or reverse an unwanted or accidental transaction, in contrast to other traditional payment methods. Irreversibility of transactions is a consequence of solving the double spending problem. As there is no third party involved it must be that no participant can change any past transaction otherwise anyone could change his record of Bitcoin transactions and spend them more than once (Böhme et al, 2015).

2.1.5 Uses of Bitcoin

In addition to legal businesses using Bitcoin, it was also extensively used on black markets (Christin, 2012). In its early stage, Bitcoin was extensively used for illegal purposes as it offered two major advantages: a certain degree of anonymity and the lack of rules about what services and goods could be bought or sold (Böhme, Christin, Edelman & Moore, 2015; Brians, 2014). Consequently, Bitcoin was used for money laundering purposes as it leaves no physical evidence that can be observed by authorities (Brians, 2014; Moser, Böhme & Breuker, 2013). Bitcoin was used as the only payment method on the Silk Road which is an online marketplace where illegal goods were sold such as drugs, weapons etc. (Böhme et al, 2015; Christin, 2013). According to the lawsuit (US v. Ulbricht, 2014, Government Exhibit

940) against the Silk Road creator, more than $214 million trades have been conducted in Bitcoin. However, it is unclear whether the closing of the Silk Road has reduced illegal activities as new smaller and similar online marketplaces have emerged (Böhme et al, 2015). Other activities and industries, such as gambling and casinos, began to embrace Bitcoin. Finally, Bitcoin was also used to escape international capital controls. For example, the Chinese Central Bank banned Bitcoin trading because, amongst others, capital evasion through Bitcoin was feared (Van Alstyne, 2014).

Bitcoin gradually gained in popularity and came to be accepted as a method of payment by several big companies and organisations. This is because Bitcoin payment processing is cheaper for stores than most other payment processing methods. The use of Bitcoin as a payment method is slowed down by the scaling problems around the size of blocks in the Blockchain. This forms a barrier to further expansion of Bitcoin as payment method, because every transaction needs to be recorded in the Blockchain. If Bitcoin would be used as a day-to-day payment method, millions of transactions would need to be stored in blocks, that only have a limited size and are mined on a fixed interval i.e. every 10 minutes, which would not be sufficient to handle all transactions (Houy, 2014).

Finally, Bitcoin can be used for investment purposes. In that case Bitcoin would more be seen as a financial investment vehicle that is bought with speculative purposes i.e. buying with the belief that the price would increase in the future. This use of Bitcoin is supported by a considerable body of literature (Baeck and Elbeck, 2015; Cheah and Fry, 2015; Glaser, Zimmermann, Haferkorn, Weber & Siering, 2014). This will be explained in detail in the section Bitcoin as a financial asset.

It is interesting to see that not only Bitcoin found different uses but that the Blockchain will find even more uses (Blockchain is very often described as an innovative and potentially disruptive technology rather than the Bitcoin itself which is only an application of the concept). Examples of Blockchain applications can be found back in supply chain management, identity management and online reputation, insurance, healthcare, finance, voting systems, etc. (Mattila, 2016; Trautman, 2016).

2.1.6 Reasons for Bitcoin's value

Across the literature, many authors explained why Bitcoins have value. The main reason that Bitcoins have value is simply because there is a demand for Bitcoins (Ciaian, Rajcaniova & Kancs, 2015a; Kroll et al., 2013). Authors have noted (Arnason, 2015; Dwyer, 2015) that the demand for Bitcoin comes from many ways to use Bitcoin. A first example is that Bitcoin, due to its decentralisation, can be used by people who do not want the control of their money in the hands of the governments and banks[1]. A second example is that, due to Bitcoin being digital and used on a peer-to-peer network, it can be used to make relatively cheap and fast digital payments from anywhere and at any time compared to traditional payment methods. Indeed, today, when someone wants to make a payment to someone else, several banks and sometimes clearing houses intervene to make the transfer successful. However, Bitcoin makes it possible to bypass these intermediaries and their associated costs (Segendorf, 2014; Dwyer, 2015). A third example is that Bitcoin attracts certain types of investors due to its volatility and possible high returns. A last example is that Bitcoin is often used as a medium of exchange due to its pseudonymity features[2].

The second reason that enables the Bitcoin to have value is that people have trust in the system. This is mainly for three reasons. Firstly, Bitcoin's software is open source. This means that everybody can see and verify that Bitcoin's source code is sufficiently robust and tamper proof (Buchholz, Delaney, Warren, & Parker, 2012). Secondly, the 'no double spending' rule, enforced by the Blockchain and its ecosystem, ensures that the same Bitcoin cannot be spent twice. People can therefore trust that the Bitcoins cannot be counterfeited (Dwyer, 2015). Thirdly, trust is encouraged by the scarcity of the Bitcoin. The total amount of Bitcoins that will be issued i.e. 21,000,000, is publicly known, and will be attained in 2140. This means that the total amount of Bitcoins in circulation is currently increasing but at a decreasing rate (Ciaian et al., 2015a). This results in scarcity of the Bitcoin and effectively provides value to it. Users place their trust in the technology and the mathematics on which

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[1] A characteristic of cash money or traditional money.

[2] We should note that this was mainly the case when Bitcoin was still considered a fully anonymous, non-traceable cryptocurrency, however other cryptocurrencies with better anonymity features such a Zcash, Monero, Dash to name a few, are increasing in popularity and are already finding their ways on the black markets.

basis the Bitcoin has been created (Polasik, Piotrowska, Wisniewski, Kotkowski & Lightfoot, 2015).

The third reason that provides Bitcoin with value is that a general consensus exists between Bitcoin's users about the functioning of Bitcoin and its ecosystem. Due to decentralisation of the cryptocurrency, consensus has to exist between the users to make sure the cryptocurrency functions and operates correctly. There are three types of consensus that ultimately give Bitcoin value. The first type is simply that every user agrees that Bitcoin has value and that payments can be made in Bitcoin. The second type is that every user agrees on the rules that determine which transactions are valid and which are not. The last type is that users have to agree which transactions have occurred on the Blockchain and which have not. This ensures that all users agree on the history of the transactions (Kroll et al., 2013).

2.1.7 Determinants of Bitcoin's price

With Bitcoin increasing in popularity, academic literature appeared on the topic of price formation of the Bitcoin. Previous research indicates that several factors influence the price formation of Bitcoin.

Buchholz, Delaney, Warren & Parker (2012) find that supply and demand play an important role in the forming of the price of Bitcoin. The scarcity of the Bitcoin is defined by the supply of Bitcoin i.e. the number of Bitcoins in circulation. They also find that demand is mainly driven by transactions where Bitcoin plays the role of a medium of exchange.

However, Kristoufek (2013), states that Bitcoin price formation cannot be explained by the interaction between supply and demand in a satisfactory way. This is because the supply is either fixed or evolves according to an algorithm, which is the case for Bitcoin. As there is no underlying economy there cannot be macroeconomic expectations that steer the demand. Kristoufek (2013) states that the demand and thus the price, as supply is fixed, is solely driven by speculative investors that have faith in growth of the Bitcoin, which is approximated by the number of Wikipedia and Google queries concerning Bitcoin.

Van Wijk (2013) investigates by using an Error Correction Model (ECM) whether different world economic indicators have an impact on the price of the Bitcoin. The main factors analysed are stock exchange indices, exchange rates and oil price measures for Europe, the U.S. and Japan. The Dow-Jones indexes, the euro-dollar exchange rate and the WTI oil price are pointed out as main influencers of the Bitcoin price.

Ciaian, Rajcaniova and Kancs (2014) analyse different factors and their interactions, based on the separate findings in Buchholz et al. (2012), Kristoufek (2013) and Van Wijk (2013), in a Vector Autoregressive (VAR) model. Ciaian et al. (2014) find that the price formation of Bitcoin fit the standard fundamentals of currency price formation and especially the demand-side drivers i.e. size of the Bitcoin economy and velocity of Bitcoin circulation, have an important impact on Bitcoin price formation, the supply being fixed. Furthermore, Ciaian et al. (2014) establish a link between speculative interest and price formation, confirming Kristoufek (2013). Finally, no link is found between price formation and macro-economic indicators, disconfirming the findings established in Van Wijk (2013).

Kristoufek (2015) analyses the different factors[1] that have the potential to influence the price of the Bitcoin by using a continuous wavelet analysis. The main findings are that fundamental factors i.e. usage in trade, money supply and price level, are influencing the price formation confirming Ciaian et al. (2014). Furthermore, he suggests that the interest in the currency by speculative investors also influences the price, confirming the findings in Kristoufek (2013) and Ciaian et al. (2014) and has amplifying effects on the change in price.

Similar to Kristoufek (2015) and Ciaian et al. (2015a, 2015b, 2016), Polasik et al. (2015) establish a link between the price of the Bitcoin and the number of Google queries as well as the number of publications in English written media. However, the link with speculative behaviour is not investigated.

Caian et al. (2015a), (2015b), Caian and Rajcaniova (2016) and Bouoiyour and Selmi (2015) are in line with the findings of Caian et al. (2014) and Kristoufek (2015) confirming that

[1] Economic drivers, transaction drivers, technical drivers, the interest in Bitcoin.

fundamental factors i.e. usage in trade, money supply and price level are influencing price formation. Furthermore, Bouoiyour and Selmi (2015) find that speculation is dominating other drivers when considering the importance of these drivers in Bitcoin price formation.

In a nutshell, the existing literature on Bitcoin price formation explains that the main price fluctuations come from the demand side, since the supply of Bitcoin is controlled by an algorithm and is thus limited. Literature suggest that the demand for Bitcoin and thus Bitcoin price is not influenced by the main macroeconomic indicators of the world economy. It rather suggests a link between the fundamentals of quantity theory of money; namely the usage in trade, money supply and price levels. Furthermore, a strong link is established by several authors between the price of Bitcoin and the speculative interest in the currency by investors. Also, an evident link is established between the number of media publications or Google and Wikipedia queries and the demand for Bitcoin influencing its price.

2.2 Bitcoin as a currency

2.2.1 Properties and characteristics of a currency

According to the traditional theory from an economic perspective, a currency must fulfil three functions: store of value, unit of account and medium of exchange (ECB, 2012; IMF, 2018; Mankiw, 2007). Currencies known as 'traditional money' or 'fiat currencies' have these functions. The ECB (2012, p.9) defines a currency as "*any legal tender designated and issued by a central authority*" and that is accepted as a medium of exchange in the issuing country because people trust this central authority. In comparison, the ECB (2012, p.13) defines a virtual currency as "*a type of unregulated, digital money, which is issued and usually controlled by its developers, and used and accepted amongst the members of a specific virtual community"*.

The focus of the sections 2.2.1.1, sections 2.2.1.2 and sections 2.2.1.3 will be to analyse whether Bitcoin can act as a currency i.e. as store of value, as a medium of exchange and as a unit of account.

2.2.1.1 Store of value

The ECB (2015, p.23) describes this function of money as money that *"can be stored and retrieved in the future"*. The user of money can thus store money and use it at a future point in time. He will expect to receive the same economic value when he spends the money than at the time he received it. This is also described as the stability of money.

Whereas in the past the function of store of value could be achieved by putting money in a safe or under a mattress this can only difficulty be done with Bitcoins[1] (Yermack, 2013). Instead they are mainly stored in digital wallets. However, security of wallets and of exchanges is a major issue as proved by some major hacks in the past e.g. Mt Gox, Coincheck hack (New York Times, 2014; cnn, 2018), etc. Yermack (2013) further states that although some third-party wallet insurers exist, this forces the customer i.e. Bitcoin user, to bear all the cost of assessing the financial and other risks related to the wallet as well as the costs to assess the risks related to the insurance company.

[1] The access to the Bitcoin can be materialized by printing or storing relevant information offline that give access to the Bitcoin. This sheet of paper or USB stick would thus grant access to the Bitcoin and thus has the value of the Bitcoin. One could thus imagine hiding this piece of paper or USB stick under a mattress or in a safe.

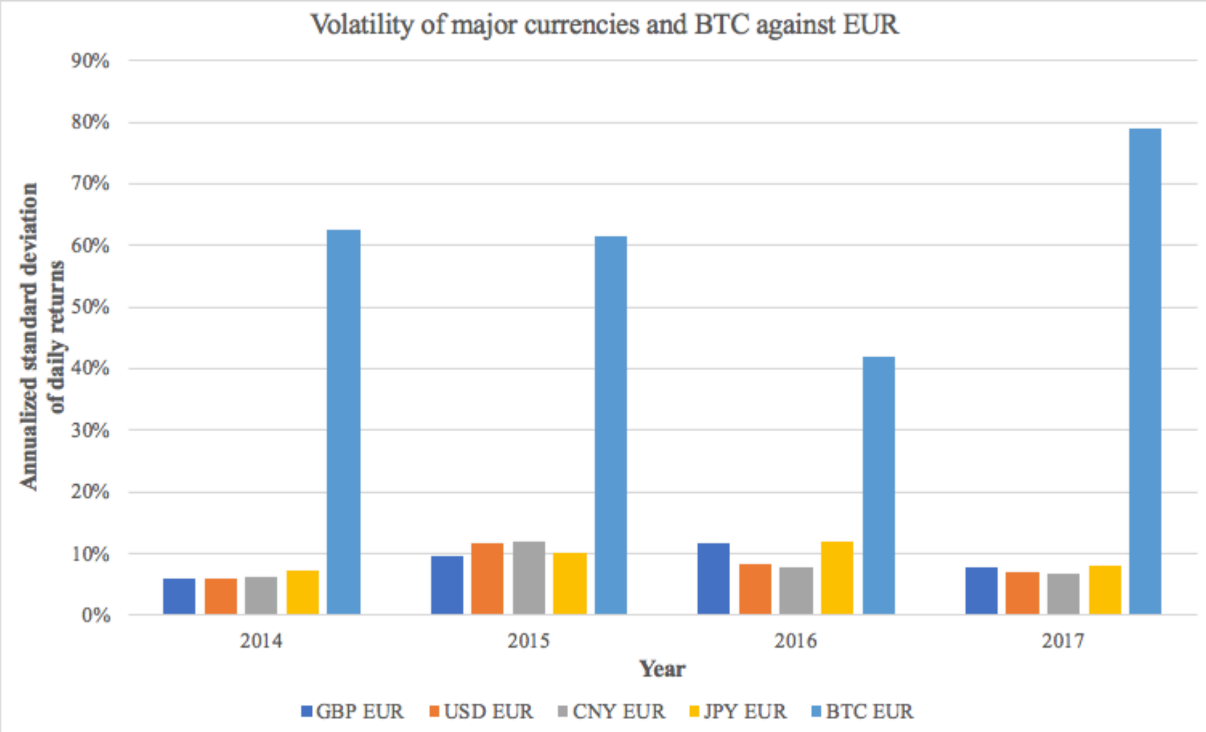

Figure 3: This figure represents the yearly evolution of the volatility of major currencies and BTC compared to the EUR (GBP/EUR, USD/EUR, CNY/EUR, JPY/EUR and BTC/EUR). Volatility is expressed as the annualised standard deviation of daily returns. Data was retrieved from Bloomberg and from CoinGecko[1]. Data covers the period from 2014 to 2017. Computed by the authors.

One of the main issues for the Bitcoin to act as a store of value is its volatility, meaning that the future value of a Bitcoin is very uncertain. Figure 3 shows the volatility of BTC and other major currencies compared to the Euro. Our analysis shows that BTC's volatility was constantly higher than other major currencies from 2014 to 2017. This is in line with previous research (Caian, Rajcaniova and Kancs, 2015a; ECB, 2018; Kùbat, 2015; Yermack ,2013). Due to this volatility, if one stores a Bitcoin today, one cannot be sure of its value at retrieval.

2.2.1.2 Medium of exchange

ECB (2012) describes money as a medium of exchange that allows to avoid the drawbacks of a barter system which mainly is that you need to have a participant that has simultaneously the same wants.

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[1] Source: CoinGecko URL: https://www.coingecko.com/fr/graphiques_cours/bitcoin/eur

More and more stores accept Bitcoin as an alternative to fiat currency for payment. Most of the stores accepting Bitcoin are operating online or for online services e.g. Microsoft for Xbox software or hardware. Some other companies, amongst others, such as takeaway.com, Overstock.com and Shopify also allow Bitcoin as a payment. Low transaction costs seem to be beneficial for the Bitcoin as a medium of exchange, as they are between 0% and 1% for Bitcoin[1] whereas they are between 2% and 5% for standard online payment systems (EBA, 2014; Folkinshteyn, Lennon & Reily, 2015; Plassaras, 2013).

Despite the growing number of companies that accept Bitcoin as payment and the lower transaction costs, academic literature suggests that Bitcoins are mainly held as financial assets for speculative purposes and are not used as a medium of exchange. Baur, Hong, Lee (2017) analyse the different user types of Bitcoin according to their wallet. They conclude that Bitcoin is used as a speculative investment and do not find support for the use of Bitcoin as an alternative to a fiat currency for a medium of exchange. Similarly, Glaser et Al. (2014) investigate what the intentions are of users that exchange their fiat currency for cryptocurrencies. Their finding indicate that specifically uninformed users will own cryptocurrencies as a speculative investment and do not seem to be part of an alternative transaction system confirming Yermack (2013) which states that at least 80% of Bitcoin were traded for speculative purposes. Yermack (2013) further identifies the problem of procuring new Bitcoins as a barrier to Bitcoin becoming a medium of exchange as they must be procured from online exchanges and dealers and then manage to store them safely.

2.2.1.3 Unit of account for comparison of products and services

The ECB describes money as a unit of account once it “acts as a standard numerical unit for the measurement of value and costs of goods, services, assets and liabilities” (ECB, 2015, p.23). In their analysis, the ECB does not consider Bitcoin as a unit of account because it is

[1] A sender can choose the fee he is willing to pay when sending bitcoins. The speed at which the transaction will be confirmed depends on the fee amount paid by the sender. Usually, Miners will want to maximise the fee amount they collect from the transactions they include in their blocks- since blocks have a size limit; therefore, in times with lots of transactions (traffic) and a congested bitcoin network (end of 2017), higher fees are recommended to increase the confirmation speed of the transaction. (Houy, 2014)

not yet largely accepted by the public and because of the unstable purchasing power of the Bitcoin due to the high volatility of its exchange rate to other currencies.

Several authors corroborate the ECB's view that Bitcoin's volatility does not make it a suitable unit of account (Ammous, 2016; Wolla, 2018; Yermack, 2013). According to these authors the volatility of Bitcoin's price makes it difficult and costly for retailers to correctly price their goods and services and is confusing for the clients. Since most goods and services are offered at a price in a traditional currency, using Bitcoin would require the vendor to correctly convert the price from the traditional currency to Bitcoin each time the price fluctuates too much.

Moreover, Wolla (2018) and Yermack (2013) note that while traditional currencies use two decimal points in the price of a good or service, Bitcoin uses four or five decimal points for most goods[1] and can go as far as eight decimal points[2] which could confuse consumers due to the many leading zeros and thus makes it a less practical unit of account.

Yermack notes that Bitcoin "trades for different prices on different exchanges without the possibility of arbitrage" (Yermack, 2013, p.2) which violates the law of one price and adds a layer of complexity for vendors who have to price their goods and services but cannot find the right market price for a Bitcoin.

According to Ammous (2016), stability in Bitcoin's price and its purchasing power is not likely to happen since it does not have a central authority - like a central bank - that could regulate its price. The author notes that "the only point at which a cryptocurrency could become stable in value is when it is the only form of money used globally, and nobody is exchanging it with other currencies" (Ammous, 2016, p. 25).

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[1] If we imagine the price of Bitcoin at 1 Bitcoin for €10.000, a beer at €2 would be noted as 0.0002 Bitcoin.

[2] The smallest fraction of a Bitcoin is called a Satoshi and is worth 100 millionth of a Bitcoin or 0.00000001 Bitcoin

2.2.2 Bitcoin as a currency: Point of view from the ECB

According to the analysis of the ECB “Bitcoin cannot be regarded as full forms of money at the moment” (2015, p24) since it does not fulfil the economic definition of money. Still, the ECB does not exclude the possible emergence of other cryptocurrencies that will correct Bitcoin’s and other crypto-currencies’ flaws and correspond to the three functions of the ECB’s definition of money.

In addition, the ECB explains that cryptocurrencies do not fulfil the definition of money or currency from a legal perspective. The definition is as follows: “From a legal perspective, money is anything that is used **widely** to exchange value in transactions. The term currency is used for ‘minted’ forms of money; nowadays usually taking the form of coins and banknotes” (ECB, 2015, p.24). The ECB further states that “a (particular) currency refers to the specific form of money that is in **general** use within a country” (ECB, 2015, p.24) and continue by stating that crypto-currencies (e.g. Bitcoin) are not widely used and therefore cannot be considered as money. Moreover, since crypto-currencies are not minted, they cannot be considered as currencies either.

The ECB further specifies that crypto-currencies are not considered legal tender in the eurozone. "For the acceptance of money for payments, only euro banknotes and coins are legal tender in the countries of the euro area and therefore, by law, must be accepted as payment for a debt within those countries” (ECB, 2015, p.24). Following these definitions, one might be wondering if scriptural money and electronic money are considered legal tender? They are not. However, since these forms are widely accepted and in general use by the public inside the eurozone, they do respect the previous definition of a currency. Therefore, the euro as a currency can take these different forms. In contrast, Bitcoin is something different from known currencies (the ECB does not consider crypto-currencies as a scriptural, electronic, digital or virtual form of a particular currency) and may not be used as legal tender. Still, they can be used as contractual money between different parties that all accept to pay and be paid in a crypto-currency.

In 2015, the ECB considered the phenomenon of crypto-currencies as relatively new and declared that, due to its low usage, it was too early to change or create new legislations for crypto-currencies. In February 2018, Daniele Nouy, Chair of the supervisory board of the ECB, told CNBC, in an interview regarding legislation of cryptocurrencies, the following: “We scrutinise the issue in a regulatory perspective, we are ready to do something if it was needed, but so far it's not exactly very high on our to-do list” (CNBC, 2018). This indicates that the ECB’s stance on cryptocurrencies has not evolved much since their report in 2015.

2.3 Bitcoin as a financial asset

Currencies can be used in different forms: as a currency, as a financial instrument to invest in or even as a speculative asset (Burnside, Eichenbaum, Kleshchelski & Rebelo, 2006; Schulmeister, 2013). For the clarity of our discussion we will use the definition of speculation given by Kaldor (1939, p.1):

Speculation ... may be defined as the purchase (or sale) of goods with a view to resale (repurchase) at a later date, where the motive behind such action is the expectation of a change in the relevant prices relatively to the ruling price and not a gain accruing through their use, or any kind of transformation effected in them, or their transfer between markets.

Section 2.2 showed that a consistent body of literature as well as national institutions do not support the fact that Bitcoin is a currency. There is still no consensus about what type of asset Bitcoin is (Cheah & Fry, 2015). Several countries have already imposed regulation on Bitcoin but there is also no consensus across countries about what asset Bitcoin could be. In some countries its use is illegal e.g. Bangladesh, or has been banned e.g. Iceland and Kyrgyzstan, whereas in some countries it is considered legal tender e.g. Japan. Most of the countries are somewhat in the middle of these two extremes of the spectrum with varying opinions on what asset class it pertains to e.g. a good, a currency, etc. and how it should be taxed. In the US different states have different regulation towards Bitcoin and in China banks are not allowed to trade or hold Bitcoin and other cryptocurrencies (Thomson Reuters, 2017).

According to Glaser et al. (2014), fiat currencies are exchanged for Bitcoin with speculative intentions. Baek and Elbeck (2015) confirm by their analysis that the Bitcoin returns’ volatility is internally driven and that the market is thus highly speculative. Cheah and Fry (2015), Beer and Weber (2015) and Baur et al. (2017) also suggest that Bitcoin is used for speculative purposes and even find evidence of the fact it shows speculative bubble behaviour. Bitcoin is thus not so much a currency used to buy other financial instruments but rather a financial instrument itself for which fiat currency is needed to acquire.

Based on our analysis of the existing academic literature, we consider Bitcoin as a speculative financial asset and its use is comparable to other speculative financial assets such as commodities, stocks etc. According to literature, Bitcoin also entails huge risks related to its volatility (Bukovina & Marticek, 2016). Interestingly, Bitcoin returns do not correlate (Bouri, Molnár, Azzi, Roubaud & Hagfors, 2017) with other major financial assets and therefore shows the potential to be used to increase the risk return of a diversified portfolio. Some authors (Brière, Oosterlink & Szfaraz, 2013; Dyrhberg, 2016) also state that Bitcoin presents hedging capabilities similar to gold and could be used to hedge against market specific risk.

3. Theoretical overview of portfolio diversification

3.1 Diversification and Modern Portfolio Theory

Diversification dates from the ancient times and has been alluded to in several ancient texts. For instance, diversification is present in the bible as an advice: "But divide your investments among many places, for you do not know what risks might lie ahead." (Ecclesiastes 11:2, New Living Translation) as well as in the Talmud[1] where "A person should always divide his money into three: one third in land, one third in commerce, and one third at hand." (Bava Metzia 42a, Babylonian Talmud). Today's understanding of what diversification means, originates from Markowitz's thesis about the Modern Portfolio Theory (MPT). In his thesis, Markowitz (1952) (mathematically) formalised the concept of diversification by explaining how to construct a portfolio of assets in such a way that the expected returns are maximised for a given level of risk. Markowitz explains that the expected risk and expected return of assets should not be assessed individually, but that rather, the assets' individual contribution to the overall return and risk of a portfolio should be assessed. This method should, on average, provide the portfolio with higher returns and less risks than any individual

[1] The Talmud is the central text of Rabbinic Judaism and the primary source of Jewish religious law and theology.

investment that has been selected in the portfolio. In essence, Markowitz states that portfolio diversification is keeping or increasing a portfolio's expected return while simultaneously reducing the portfolio's risk by holding a mix of not perfectly positively correlated assets.

We can illustrate the idea of portfolio diversification with a simple example: Suppose one has two investments, X and Y. Investment X increases by 100% the first year but drops by 50% the second year. Investment Y decreases by 50% the first year but increases by 100% the second year. Individually both investments X and Y did not evolve at the end of these two years. However, if we construct a portfolio based on 50% of investment X and 50% of investment Y, and the portfolio is rebalanced in between the first and the second year, we notice that the portfolio would yield a return of 25% in both the first year and the second year, without any volatility in the yearly returns since they remain 25% over both periods. In essence, diversification amounts to not putting all your eggs in one basket. This portfolio is ideal due to the perfect negative correlation and the similar risk-return profiles[1] between both investments. But if a portfolio is made up of investments with different risk-return profiles then risk-diversification has to be applied. This means that a right balance has to be found between the risky and safe investments. Typically, to diversify investment risk, less will be invested in the risky investment and more in the safe assets. Admittedly, the proportion of risky and safe investments in a portfolio depends on the risk profile of the investor (Qian, 2011).

The purpose of MPT is to eliminate idiosyncratic risk i.e. risk that is inherent to a particular investment (firm specific), uncorrelated to market risk and can be diversified away in a portfolio (Nasdaq, 2018; Bartram, S. M., Brown, G., & Stulz, R. M., 2009). Markowitz (1952) assumes that investors will try to maximise their returns but are also risk averse. This means that an investor will prefer a portfolio with less risk at a given return over a portfolio with similar return and more risk. An investor will thus only engage in more risk if he expects a higher reward.

[1] Relationship between the returns obtained from an investment and the amount of risk taken

3.2 Mathematical Formalisation on Modern Portfolio Theory

MPT states that a portfolio return is a weighted average of non-perfectly correlated assets, where the weights are fixed by the investor and the returns are random variables. The return on the portfolio will be expressed by R where R_i is the return on the i[th] asset and $0 < i < n$ (in our analysis $n = 9$ when Bitcoin is included in the analysis and $n = 8$ when Bitcoin is excluded from the analysis). X_i are the weights arbitrarily chosen by the investor. It is important to note that in case no short-selling is admitted, the value of the weights cannot be negative i.e. $X_i > 0$ and it should always be the case that since the X_i are percentages, $\sum_{i=1}^{n} X_i = 1$.

$$R = \Sigma R_i X_i$$

From here we can deduct the expected return E which is the expected value of a weighted sum and is also denoted by μ,

$$\mu = E(R) = \sum_{i=1}^{N} X_i E(R_i)$$

$$E = \sum_{i=1}^{N} X_i \mu_i$$

The next step is to establish the variance of a weighted sum i.e. our portfolio. To do so we need to establish the covariance of the portfolio. As the number of assets we use is rather high i.e. 9, the use of algebra would be cumbersome and we prefer shifting to matrix notation. First, the return and expected return of the portfolio i.e. μ_p will be rewritten as the matrix product of two vectors:

$X = \begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix}$ and $R = \begin{bmatrix} R_1 \\ \vdots \\ R_n \end{bmatrix}$, from which we get the return of the portfolio $R_p = X'R$, where R_p denotes the Return of the portfolio.

In a similar fashion we obtain the expected return of the portfolio:

$X = \begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix}$ and $\mu = \begin{bmatrix} \mu_1 \\ \vdots \\ \mu_n \end{bmatrix}$, from which we get $\mu_p = X'\mu$

The variance of the portfolio [1]is described as $\sigma_p^2 = var(X'R) = X'\Sigma X$, where Σ is the variance covariance matrix.

$$\sigma_p^2 = var(X'R) = X'\Sigma X \text{ and } \Sigma = \begin{bmatrix} \sigma_1^2 & \cdots & \sigma_{1n} \\ \vdots & \ddots & \vdots \\ \sigma_{1n} & \cdots & \sigma_n^2 \end{bmatrix}$$

This matrix is symmetric such that $\Sigma = \Sigma'$. The diagonal contains the variances between assets and off-diagonal values represent the covariances.

MPT gives us thus all the optimal portfolios given levels of risk i.e. variance (σ_p^2), or returns i.e. expected returns (μ_p). The set of all these risk returns points is called the efficient frontier and encompasses all the optimal portfolios i.e. for which the expected return is maximised given a certain level of risk or for which the risk is maximised given an expected return. Nevertheless, the risk return of these portfolios is not necessary the same although they are optimal at their own given level of risk or return.

To measure the risk-return ratio the Sharpe ratio will be used, introduced by William F. Sharpe in 1964. The Sharpe ratio is the excess return i.e. the expected return (μ_p) of the portfolio from which is subtracted the risk-free rate (r_f), divided by the standard deviation (σ_p). In other words, the sharpe ratio is the excess returns, i.e. desirable for an investor, divided by volatility i.e. undesirable for an investor under the assumption of Markowitz that the investor is risk averse. The higher this ratio the better the risk-return of the portfolio.

$$Sharpe\ ratio = \frac{\mu_p - r_f}{\sigma_p}$$

[1] Please note that the variance is the square of the standard deviation, $variance = \sigma^2$

3.3 Portfolio diversification strategies

In the literature on portfolio diversification, we notice that there are many different portfolio diversification strategies are presented. There is not one specific method particularly recognised as the best method to diversify. As Fragkiskos mentions in his paper: "The quest for diversification is never ending, its definition is not unique and diversification measures are continuously evolving" (Fragkiskos, 2014, p.8). In his paper the author gathers the most common diversification strategies and shows how they compare with real data[1]. We will discuss the diversification strategies that we considered when building our own diversified portfolio.

A first portfolio diversification strategy is called the market portfolio. This portfolio is constructed by every available asset traded in the world financial market where each asset is weighted based on its capitalisation in the world financial market. The expected return from this portfolio is thus equal to the expected return of the world financial market. Since this portfolio includes all assets in the world financial market it means that the portfolio is considered entirely diversified and the risk non-diversifiable. (Fragkiskos, 2014; Lintner, 1965; Mossin, 1966). In 1977, Richard Roll, an American economist known for his works on asset pricing and portfolio theory, claims that it is not possible to observe a truly diversified market portfolio because in practice it would require the portfolio to include all existing assets within that portfolio which is practically not possible. Roll considers the market portfolio only as a theoretical concept. (Roll, 1977)

Multiple authors (de Vassal, 2001; Evans and Archer, 1968; Sankaran and Patil, 1999) have described another diversification strategy that consists in constructing a portfolio with a large number of securities to achieve diversification. Evans and Archer (1968) first analysed what would happen to the variation of a portfolio's return if the total number of securities in that portfolio would increase. Their study showed that a linear relationship exists between the variance of the constructed portfolios and the inverse of the portfolio size. Another study, by Sankaran and Patil (1999), showed similar results. They found that portfolios with an increasing number of securities achieve higher Sharpe ratios but that the marginal

[1] For more information refer to Fragkiskos (2014)

diversification benefits, by increasing the number of securities, increases at a decreasing rate. Their assumptions are based on constant pairwise correlations and no short-selling.

The total risk in a portfolio not only decreases when combining different financial assets and increasing the number of securities in a portfolio but the dependency or correlation between different securities also plays a role. International portfolio diversification selects securities from several countries in order to reduce the portfolio's total risk. Driessen and Laeven (2007) - extending the analyses of Huberman and Kandel, 1987, Bekaert and Urias, 1996, De Roon et al., 2001, Li et al., 2003 on international diversification benefits- found that there are clear diversification benefits for domestic investors who invest in securities across several countries and that these benefits are greater in countries with a higher country risk. This is partly due to the well-documented[1] home-bias, which states that investors often prefer to invest in domestic stocks rather than international ones.

While there exist many more portfolio diversification strategies we decided to mainly rely on the above described strategies to construct a well-diversified portfolio on which we will test our hypotheses.

4. Impact of Bitcoin on a well-diversified portfolio

We have analysed Bitcoin as a currency and as a financial asset based on existing literature. The main result is that Bitcoin tends to be considered as a financial asset by literature and certain national and international institutions. Following this idea, we investigated further what uses Bitcoin could have as a financial asset. Adding different asset classes to a portfolio has already been studied in the past e.g. Belousova & Dorfleitner (2012) demonstrated the positive impact on a portfolio by adding different types of commodities to the portfolio. One particular area of research on Bitcoin caught our attention which is the use of Bitcoin as a tool for diversification of a portfolio.

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[1] For more information refer to: Baxter and Jermann, 1997; Coval and Moskowitz, 1999 French and Poterba, 1991; Lewis, 1996; Li, 2004.

We identified research that investigates whether adding Bitcoin to a well-diversified portfolio is beneficial. Wu & Pandey (2014), Carpenter (2016), Eisl et al. (2015) and Guesmi et al. (2018) analyse the effects from the point of view of a US investor. Brière, Szafarz and Oosterlink (2013) analyse the effects from the point of view of a world investor. Kajtazi & Moro (2017) investigate the effects of adding Bitcoin to a Chinese portfolio. Other research has been performed by Chuen, Lee, Guo & Wang (2017) to investigate the positive benefits of adding a cryptocurrency index i.e. CCi30, to a diversified portfolio from the perspective of an US investor. However, to the best of our knowledge, no previous research has been conducted on the diversification benefits of adding Bitcoin to a portfolio from the point of view of a European investor. This gap was also mentioned by Kajtazi & Moro (2017). The focus of our research will thus only be on the European market.

Our descriptive statistics will be discussed in greater depth later. Our major findings show that the Bitcoin has features that are interesting to increase the risk-return of a well-diversified portfolio as it has low correlations with other assets, which would reduce the overall portfolio risk the risk (Markowitz, 1952), and it has extremely high volatility compared to other assets which could increase the overall portfolio returns.

Building on this we construct the following hypothesis:
Hypothesis: Adding Bitcoin to a well-diversified European portfolio is beneficial for diversification i.e. increases the Sharpe ratio, and increases return at a given level of risk or decreases risk at a given level of return.

4.1 Methodology

4.1.1 Portfolio construction and data

To construct our portfolio, we based ourselves on the one hand on the different portfolio diversification strategies and on the other hand on previous research. Amongst the strategies, we mainly used three strategies: market portfolio strategy, many securities strategy and international diversification strategy. Market portfolio strategy (Fragiskos, 2014; Lintner, 1965; Markowitz, 1952; Mossin, 1966) is implemented in our portfolio by trying to include nearly every traditional and alternative security that exists for an investor that focusses solely on Europe, to achieve maximal diversification. We also used the strategy of many securities (de Vassal, 2001; Evans & Archer, 1968; Sankaran & Patil, 1999). In order to make sure that our portfolio encompasses most of the possible investment opportunities, indexes are used to make sure that the number of securities is sufficient to reach significant diversification e.g. for stocks, the Europe Stock 600 index is used to make sure that most of the possible investments in the most prominent European stocks are covered. The last strategy we used is international diversification. This refers to the inclusion of stocks of different countries which automatically happens as our portfolio covers all of Europe, which is composed of many countries (Archer, 1968; Markowitz, 1952; Roll, 1977). Furthermore, we also based ourselves on comparable research by Brière, Szafarz and Oosterlink (2013) and Kajtazi & Moro (2017).

In conclusion, we created a well-diversified portfolio that focusses solely on the European market, since we adopt the point of view of a European investor that is only active in the European market. The portfolio contains both traditional assets (i.e. European stocks, European sovereign bonds, European corporate bonds, hard currencies) and alternative investments (i.e. commodities, real estate). The portfolio design can be found in table 2.

Asset Class	Index/Asset	Source	Link
Real Estate	Dow Jones Europe Select Real Estate Total Return Net Index	S&P Dow Jones Indices	https://kr.spindices.com/indices/equity/dow-jones-europe-select-real estate-securities-index-usd
Sovereign bonds	S&P Eurozone Sovereign Bond Index	S&P Dow Jones Indices	https://us.spindices.com/indices/fixed -income/sp-eurozone-sovereign-bond-index
Sovereign inflation linked bonds	S&P Eurozone Inflation-Linked Bond Index	S&P Dow Jones Indices	https://us.spindices.com/indices/fixed-income/sp-eurozone-sovereign-inflation-linked-bond-index
Corporate bonds	S&P Eurozone Investment Grade Corporate Bond Index	S&P Dow Jones Indices	https://us.spindices.com/indices/fixed-income/sp-eurozone-investment-grade-corporate-bond-index
Crude oil	Crude Oil (WTI) in Eur	Bloomberg Terminal	N/A
Gold	Gold Spot Price Eur-Oz	Bloomberg Terminal	N/A
Euro Currency Index	Bloomberg Euro Index	Bloomberg Terminal	N/A
Bitcoin	Bitcoin/EUR	CoinGecko	https://www.coingecko.com/fr/graphiques_cours/bitcoin/eur
EU stock	Europe Stock 600	iShare(Blackrock)	https://www.ishares.com/lu/individual/en/products/251931/ishares-stoxx-europe-600-ucits-etf-de-fund

Table 2: Well diversified portfolio for the European Market based on market indices which encompasses most investment possibilities in traditional asset classes and alternative asset classes.

Our analysis focusses on the Bitcoin. However, data on the Bitcoin price in Euro could only be found from the middle of 2013. After performing descriptive statistics on the different asset classes, Skewness and Kurtosis levels were observed that were not realistic and we therefore concluded that using incomplete data from 2013 would distort the model and not be representative of the economic reality. For similar reasons we only use data up until 2017 and leave 2018 out of the scope of our analysis. Therefore, our analyses cover data that ranges over 4 years from 2014 to 2017. The data used to perform the statistical analysis are daily returns of the different indexes and asset classes. The returns used are the logarithmic returns as we consider that returns are continuous and not discrete, because this is a better representation of the economic reality. The risk-free rate is the 10-year rate of the German Bund, as this can be considered the largest and most reliable European economy according to Fitch and Standard & Poor's who both rate Germany AAA in 2017.

4.1.2 Statistical model

In the first step of our analysis, we use descriptive statistics to assess Bitcoin's potential for diversification. We compute yearly the mean, median, standard deviation (σ) i.e. a measure of volatility, the variance, Kurtosis and Skewness as well as the same metrics over the complete period. Furthermore, the annualised returns of the different asset classes will be compared. Finally, we will analyse the correlation of Bitcoin with other asset classes over the four-year period (2014-2017).

In the second step, we investigate the effect of adding Bitcoin to a well-diversified portfolio. Bitcoin returns cannot be described by a normal distribution due to its extreme Kurtosis and Skewness levels (see descriptive statistics). The Markowitz mean-variance optimisation assumes that the distribution of the returns of the different assets is normal. Therefore, it would be more appropriate to use C-VaR or Mean-VaR as these methods account better for non-normal asset returns. However, to avoid the imposing complexity of these models we will use the mean-variance model in a similar fashion as in Brière, Szafarz and Oosterlink (2013) and Carpenter (2016), who obtained similar results to Eisl et al. (2015) and Moro Kajtazi (2017) who used the mean-VaR/C-VaR method.

Markowitz' (1952) MPT and especially the mean variance optimisation will be used for our analysis. We will compare, through the use of MPT, the impact of adding Bitcoin to an equally weighted portfolio, to a portfolio with long-selling only and to a portfolio allowing short-selling. The reader can find a detailed explanation of MPT concept in section 5.1 and a mathematical formalisation in section 5.2.

Based on the MPT and the Sharpe ratio we want to investigate whether adding Bitcoin to a well-diversified European portfolio is beneficial. We will investigate this by comparing the Sharpe ratio of a portfolio with Bitcoin and a portfolio without Bitcoin and assess whether adding Bitcoin has an impact on the Sharpe ratio. To obtain the set of portfolios that optimise the expected return given a certain level of risk or minimise the risk, we will use a solver provided by Microsoft Excel to maximise or minimise an objective function under constraints. The variables that the solver will modify to maximise or minimise the output are the weights of the portfolio. To find the different weights in the portfolio we set as objective to minimise variance under a constraint of target expected return that is arbitrary set i.e. μ_a.

4.1.2.1 Equally weighted portfolio

To compute the optimal portfolios for an equally weighted portfolio, means that all the weights of the different assets must be similar and that the sum of the weights must be equal to 1. We maximise the Sharpe ratio under the constraint that all weights must be equal. To compare a portfolio with Bitcoin to a portfolio without Bitcoin, we add a constraint that states that the weight of Bitcoin must equal zero e.g. $X_8 = 0$ where the index of bitcoin is 8 and we remove X_8 (the weight of Bitcoin) from the equal weight constraint. As all weights are similar only one portfolio can be computed.

Objective function: Max $\frac{\mu_p - r_f}{\sigma}$

Constraints:

$X_1 = X_2 = X_3 = X_4 = X_5 = X_6 = X_7 = X_8 = X_9$ (Remove X_8 only if we want to exclude Bitcoin)

$\sum X_i = 1$

$\mu_p = \mu_a$

$X_8 = 0$ (only if we want to exclude bitcoin)

4.1.2.2 Long portfolio

When computing the different optimal portfolio possibilities for a long portfolio, the value of the weights must be higher or equal to zero and the sum of all weights must be equal to 1, thus no weight can exceed 1. In the case we want to exclude Bitcoin we add a constraint that states that the weight of Bitcoin must equal zero. In [1] the optimal portfolios are found by minimising variance and by setting the expected return arbitrarily.

[1]

Objective function: Min σ_p^2

Constraints:

$X_i > 0$

$\sum X_i = 1$

$\mu_p = \mu_a$

$X_8 = 0$ (only if we want to exclude bitcoin)

To find the portfolio that optimises the risk-return i.e. [2], we maximise the Sharpe ratio without setting any constraints for variance and return. The other constraints are still applicable.

[2]

Objective function: Max $\frac{\mu_p - r_f}{\sigma}$

Constraints:

$X_i > 0$

$\sum X_i = 1$

To find the minimum variance portfolio i.e. [3], we minimise the variance without setting any target for the expected returns

[3]

Objective function: Min σ_p^2

Constraints:

$X_i > 0$

$\sum X_i = 1$

4.1.2.3 Portfolio allowing short selling

Short selling means to sell a stock that the investor borrowed and is not owning yet because the investor assumes that the price will fall in the future therefore making a positive margin (Nasdaq, 2018). Recently the CME group allowed to short Bitcoin through Bitcoin futures (CME Group, 2018). We would therefore also demonstrate whether it would be interesting to add Bitcoin into a portfolio which allows short selling. The optimal portfolios forming the efficient frontier will be computed using the excel solver. The Sharpe ratio is kept as the metric for risk return investigation. The main difference is that the weights of the portfolio are allowed to be negative, but the total sum of the portfolio still needs to be 1. To find the portfolios on the efficiency frontier, a target expected return is fixed and variance is minimised, similar to [1] but without the positive weights constraint. To obtain the minimum variance portfolio and the maximised risk-return portfolios, the same approach as in [2] and [3] is recommended but without the positive weights constraint in each case.

4.2 Results and Findings

4.2.1 Descriptive Statistics

Figure 4 shows the cumulative returns of the different assets comprised in the portfolio over the period 2014-2017. Bitcoin performs remarkably better than other asset classes. The volatility of Bitcoin, which is described for each year in table 3, can be measured by the standard deviation and is 4,07% on a daily basis. Bitcoin's volatility is thus larger than any other asset class with the exception of Oil in 2016. Table 4 outlines the average daily returns as well as the annualised returns of the different asset classes over the period 2014-2017. Bitcoin outperforms any other asset class with an annualised return of 79,12%. The extremely high figures also show that investments in Bitcoin are associated with a huge amount of risk.

Frehen et al. (2013) describe financial innovations as hard to price and are likely to show bubble-like features. As Bitcoin is still considered as an innovation over the period 2014 – 2017, we suggest that the extreme returns observed might be due to its novelty and would not be observable in the future. One should thus be careful when using the past return to try to establish future returns (the choice of using historical data to assess expected returns is in itself debatable, but there are few alternatives) (Elton, 1999).

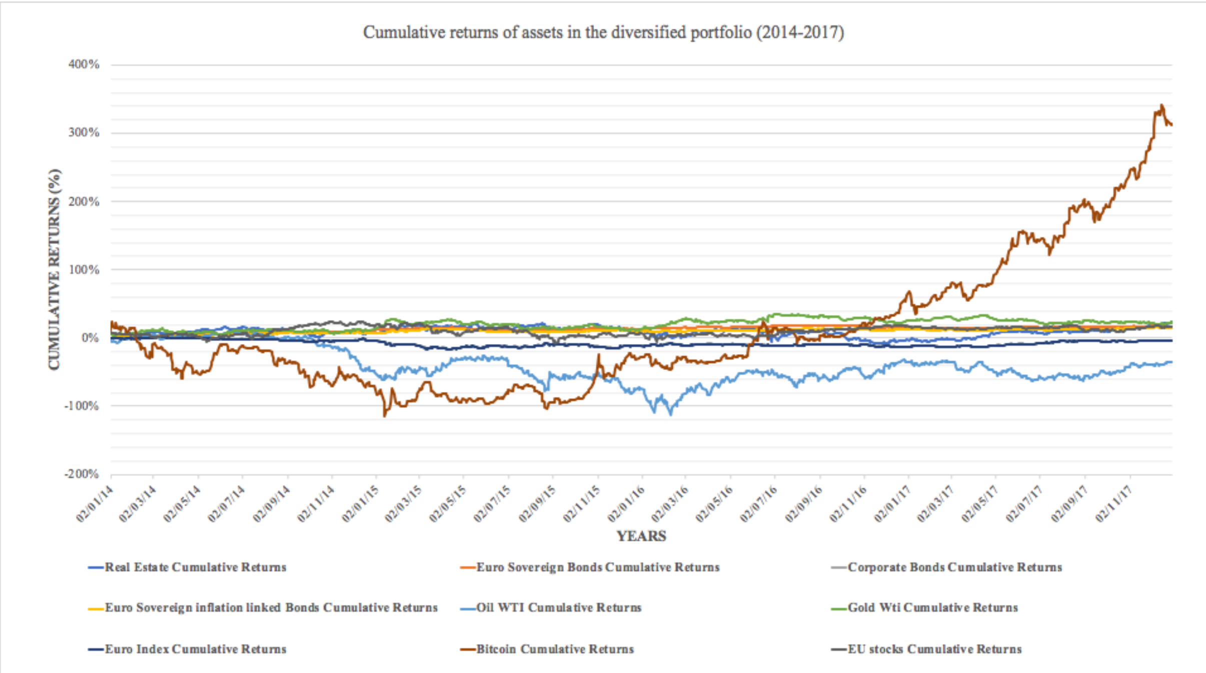

Figure 4: Cumulative returns of the diversified portfolio comprised of traditional assets (i.e. European Stocks, European sovereign bonds, European corporate bonds, Euro currency) and alternative investments (i.e. commodities, real estate) contained in the portfolio over the period 2014-2017.

Volatility									
	Real Estate	Sovereign Bonds	Sovereign Inflation-Linked Bonds	Corporate Bonds	Crude Oil (WTI)	Gold (WTI)	EUR Currency Index	Bitcoin	EU Stocks
2014	0,82%	0,16%	0,21%	0,08%	1,59%	0,90%	0,32%	3,96%	0,93%
2015	1,14%	0,28%	0,29%	0,14%	3,00%	0,94%	0,63%	3,89%	1,27%
2016	1,73%	0,23%	0,23%	0,12%	3,03%	0,97%	0,38%	2,66%	1,30%
2017	0,85%	0,19%	0,19%	0,11%	1,63%	0,65%	0,35%	5,22%	0,60%
Total (2014-2017)	**1,19%**	**0,22%**	**0,23%**	**0,12%**	**2,41%**	**0,87%**	**0,43%**	**4,07%**	**1,06%**

Table 3: Yearly volatility based on the daily returns of the diversified portfolio comprised of traditional assets (i.e. European Stocks, European sovereign bonds, European corporate bonds, Euro currency) and alternative investments (i.e. commodities, real estate) contained in the portfolio over the period 2014-2017.

Average daily and annualized returns (2014-2017)									
	Real Estate	Sovereign Bonds	Sovereign Inflation-Linked Bonds	Corporate Bonds	Crude Oil (WTI)	Gold (WTI)	EUR Currency Index	Bitcoin	EU Stocks
Average daily returns	0,02%	0,02%	0,01%	0,01%	-0,04%	0,02%	0,00%	0,32%	0,02%
Annualized Returns	5,86%	4,11%	3,58%	3,20%	-9,08%	5,65%	-0,84%	79,12%	3,79%

Table 4: Average daily returns and Annualised returns of the diversified portfolio comprised of traditional assets (i.e. European Stocks, European sovereign bonds, European corporate bonds, Euro currency) and alternative investments (i.e. commodities, real estate) contained in the portfolio over the period 2014-2017.

Table 5 contains the descriptive statistics of the different asset classes over the period 2014-2017. The high level of risk inherent to Bitcoin is represented by the high level of Kurtosis of 4.71, which is a measure used to describe the distribution, more especially it assesses extreme values in the tail of the distribution. Yearly Kurtosis levels can be found in table 6. Bitcoin shows a leptokurtic behaviour (i.e. a Kurtosis level higher then 3[1]) every year except for 2017. Leptokurtic behaviour is more commonly denoted as "fat tails" which indicates that extreme outcomes are more likely to happen (Verhoeven & McAleer, 2004). Brière, Szafarz and Oosterlink (2013), Kajtazi & Moro (2017) also found leptokurtic behaviour of the Bitcoin but the values found in our study are lower than the values from those previous studies. Skewness is a measure of comparison of the tails of the distribution and is represented in table 7. The Skewness of the Bitcoin over the period 2014-2017 is of 0.422. and thus positive. Positive Skewness indicates a long right tail or in other words a lower probability of huge losses and higher probability for few extreme gains. Although Skewness levels are positive, they are lower than the levels found by previous research.

[1] This is a rule of thumb that is used by investors. However, the choice putting the boundary at 3 to observe leptokurtic behaviour is debatable.

Descriptive Statistics 2014-2017									
	Real Estate	Sovereign Bonds	Sovereign Inflation-Linked Bonds	Corporate Bonds	Crude Oil (WTI)	Gold (WTI)	EUR Currency Index	Bitcoin	EU Stocks
Mean	2,34E-04	1,65E-04	1,43E-04	1,28E-04	-3,63E-04	2,26E-04	-3,36E-05	3,16E-03	1,52E-04
Standard error	3,80E-04	6,98E-05	7,41E-05	3,76E-05	7,73E-04	2,78E-04	1,39E-04	1,27E-03	3,39E-04
Median	4,58E-04	2,27E-04	1,68E-04	1,46E-04	-2,53E-04	3,16E-04	3,45E-05	2,10E-03	7,72E-04
Mode	#N/A	0	0	0	#N/A	#N/A	0	#N/A	0
Standard deviation	1,20E-02	2,19E-03	2,33E-03	1,18E-03	2,43E-02	8,75E-03	4,37E-03	3,98E-02	1,06E-02
Variance	1,43E-04	4,82E-06	5,43E-06	1,40E-06	5,90E-04	7,66E-05	1,91E-05	1,58E-03	1,13E-04
Kurtosis	25,74	2,51	2,63	2,67	2,72	3,86	3,34	4,56	4,71
Skewness	-2,15	-0,41	-0,09	-0,53	0,25	0,47	-0,11	0,40	-0,73
Range	0,20	0,02	0,03	0,01	0,23	0,10	0,05	0,40	0,12
Minimum	-0,15	-0,01	-0,01	-0,01	-0,10	-0,03	-0,03	-0,19	-0,08
Maximum	0,05	0,01	0,01	0,005	0,12	0,06	0,02	0,20	0,04
Sum	0,23	0,16	0,14	0,13	-0,36	0,22	-0,03	3,13	0,15
Number of data points	988	988	988	988	988	988	988	988	988

Table 5: Descriptive statistics (Mean, median, standard deviation, Variance, Kurtosis, Skewness) based on the daily returns of the traditional assets (i.e. European Stocks, European sovereign bonds, European inflation linked bonds, European corporate bonds, Euro currency index) and alternative investments (i.e. commodities such as Gold and Oil, real estate) contained in the portfolio over the period 2014-2017.

Kurtosis									
	Real Estate	Sovereign Bonds	Sovereign Inflation-Linked Bonds	Corporate Bonds	Crude Oil (WTI)	Gold (WTI)	EUR Currency Index	Bitcoin	EU Stocks
2014	28,92%	186,71%	109,83%	87,71%	718,09%	182,42%	394,78%	316,92%	123,99%
2015	76,19%	206,68%	297,02%	297,80%	104,01%	187,92%	157,83%	749,10%	83,86%
2016	2146,62%	142,40%	165,41%	79,60%	136,83%	662,62%	110,78%	1068,05%	625,78%
2017	348,85%	104,58%	89,90%	103,34%	88,79%	28,75%	105,42%	174,72%	70,33%
Total (2014-2017)	**2573,76%**	**251,04%**	**262,58%**	**267,14%**	**272,47%**	**385,74%**	**334,33%**	**456,40%**	**471,47%**

Table 6: Yearly Kurtosis based on the daily returns of the traditional assets (i.e. European Stocks, European sovereign bonds, European inflation linked bonds, European corporate bonds, Euro currency index) and alternative investments (i.e. commodities such as Gold and Oil, real estate) contained in the portfolio over the period 2014-2017.

Skewness									
	Real Estate	Sovereign Bonds	Sovereign Inflation-Linked Bonds	Corporate Bonds	Crude Oil (WTI)	Gold (WTI)	EUR Currency Index	Bitcoin	EU Stocks
2014	-23,58%	-36,14%	-24,50%	-39,26%	-137,12%	20,35%	-74,69%	45,06%	-24,83%
2015	-30,13%	-58,89%	-36,66%	-90,14%	31,52%	22,23%	-5,74%	-21,55%	-37,87%
2016	-266,69%	23,24%	66,07%	39,94%	42,26%	95,20%	3,71%	122,64%	-114,45%
2017	63,93%	-47,62%	-20,87%	-52,75%	-67,29%	4,72%	45,62%	35,45%	4,63%
Total (2014-2017)	**-214,63%**	**-40,63%**	**-9,25%**	**-53,17%**	**24,85%**	**46,66%**	**-10,71%**	**40,22%**	**-72,52%**

Table 7: Yearly Skewness based on the daily returns of the traditional assets (i.e. European Stocks, European sovereign bonds, European inflation linked bonds, European corporate bonds, Euro currency index) and alternative investments (i.e. commodities such as Gold and Oil, real estate) contained in the portfolio over the period 2014-2017.

Table 8 describes the coefficient of correlation between the different assets in our well-diversified portfolio. At a p-value of 1%, Bitcoin is correlated with Sovereign Bonds (8,34%), Sovereign inflation linked Bonds (11,12%), corporate bonds (9,24%) and Euro Currency Index (-12,94%). However, these correlations remain below 13% which is still arguably low.

This contradicts previous findings by Brière, Szafarz and Oosterlink (2013) who only found correlations of Bitcoin with inflation linked bonds and Gold. Our study shows only a 5,67% correlation with gold at a p-value of 10%. We can thus only partly confirm previous findings by the ECB (2012) and Harper (2013) who describe Bitcoin as an inflation hedge due to its limited supply as we also found correlations with other assets.

The correlations obtained in our study should be considered with caution as they are obtained only over a short time-span in which no major economic or financial crisis has happened. However, correlation tend to highly increase in periods of crisis (Brière et al., 2012; Goetzmann et al., 2005). Because of the time span used to perform the analysis we cannot demonstrate whether correlations of Bitcoin with other assets increases during an economic or financial crisis.

Correlation Matrix (2014-2017)									
	Real Estate	Sovereign Bonds	Sovereign Inflation-Linked Bonds	Corporate Bonds	Crude Oil (WTI)	Gold (WTI)	EUR Currency Index	Bitcoin	EU Stocks
Real Estate	100%								
Sovereign Bonds	13,01%***	100%							
Sovereign Inflation-Linked Bonds	24,09%***	81,05%***	100%						
Corporate Bonds	6,68%**	77,87%***	58,41%***	100%					
Crude Oil (WTI)	10,37%***	-6,29%**	10,83%***	-8,44%***	100%				
Gold (WTI)	-17,35%***	18,45%***	12,93%***	20,56%***	9,57%***	100%			
EUR Currency Index	7,54%**	-18,75%***	-22,30%***	-20,63%***	-25,76%***	-30,62%***	100%		
Bitcoin	-5,93%*	8,34%***	11,12%***	9,24%***	0,64%	5,67%*	-12,49%***	100%	
EU Stocks	59,14%***	7,18%**	24,51%***	-0,62%*	31,70%***	-7,63%***	-36,74%***	3,72%*	100,00%

*Table 8: Coefficient of Correlation between the different assets comprised in the portfolio i.e. the traditional assets (i.e. European Stocks, European sovereign bonds, European inflation linked bonds, European corporate bonds, Euro currency index) and alternative investments (i.e. commodities such as Gold and Oil, real estate) contained in the portfolio over the period 2014-2017. ***/**/* for coefficient estimates to be significantly different from zero at p-values of 1% / 5% / 10%.*

4.3 Mean-Variance Analysis

4.3.1 Equally weighted portfolio

The aim of our research is to investigate whether adding Bitcoin to a well-diversified portfolio increases the risk-return of this portfolio. In a first stage, an equally weighted portfolio with Bitcoin is compared to an equally weighted portfolio that does not comprise any Bitcoin[1]. A

[1] The weights of the assets in the equally weighted portfolio are 12,5%, whereas the weights of the assets in the equally weighted portfolio including Bitcoin are 11,11%.

summary of the results can be found in table 9. Table 10 shows the variance-covariance matrix. The standard deviation i.e. the metric for volatility, is 7,05% for the portfolio without Bitcoin. Adding Bitcoin (weight of Bitcoin in the portfolio is 11,11%, as 100% divided by 9 assets equals to 11,11% weight for every asset) to the portfolio increases volatility to 9,4374%. The annualised return of the equally weighted portfolio, which is represented by the annualised expected return as those metrics are actually the same, increases the return from 2,03% to 10,59%. The performance of the portfolio dramatically improves as the Sharpe ratio increases from 23,73% to 108,50%. Adding Bitcoin appears thus to be very beneficial for portfolio optimisation. However, the result is arguable since a reasonably risk-averse investor would not hold 11% of his portfolio in Bitcoin as its volatility is too high.

Equally weighted Portfolio with BTC

Variance	St Dev	Exp Return	Sharpe ratio
0,8906%	9,4374%	10,5998%	108,5027%

Equally weighted Portfolio without BTC

Variance	St Dev	Exp Return	Sharpe ratio
0,4977%	7,0548%	2,0343%	23,7326%

Table 9 describes the variance , standard deviation, annualised expected return of an equally weighted portfolio including Bitcoin and an equally weighted portfolio excluding Bitcoin based on the daily returns of the traditional assets (i.e. European Stocks, European sovereign bonds, European inflation linked bonds, European corporate bonds, Euro currency index) and alternative investments (i.e. commodities such as Gold and Oil, real estate) contained in the portfolio over the period 2014-2017.

Variance Covariance Matrix (2014-2017)									
	Real Estate	Sovereign Bonds	Sovereign Inflation-Linked Bonds	Corporate Bonds	Crude Oil (WTI)	Gold (WTI)	EUR Currency Index	Bitcoin	EU Stocks
Real Estate	1,43E-04	3,41E-06	6,71E-06	9,44E-07	3,01E-05	-1,82E-05	3,93E-06	-2,82E-05	7,52E-05
Sovereign Bonds	3,41E-06	4,82E-06	4,14E-06	2,02E-06	-3,35E-06	3,54E-06	-1,80E-06	7,29E-06	1,68E-06
Sovereign Inflation-Linked Bonds	6,71E-06	4,14E-06	5,43E-06	1,61E-06	6,13E-06	2,64E-06	-2,27E-06	1,03E-05	6,08E-06
Corporate Bonds	9,44E-07	2,02E-06	1,61E-06	1,40E-06	-2,43E-06	2,13E-06	-1,07E-06	4,35E-06	-7,87E-08
Crude Oil (WTI)	3,01E-05	-3,35E-06	6,13E-06	-2,43E-06	5,90E-04	2,03E-05	-2,73E-05	6,14E-06	8,20E-05
Gold (WTI)	-1,82E-05	3,54E-06	2,64E-06	2,13E-06	2,03E-05	7,66E-05	-1,17E-05	1,97E-05	-7,11E-06
EUR Currency Index	3,93E-06	-1,80E-06	-2,27E-06	-1,07E-06	-2,73E-05	-1,17E-05	1,91E-05	-2,17E-05	-1,71E-05
Bitcoin	-2,82E-05	7,29E-06	1,03E-05	4,35E-06	6,14E-06	1,97E-05	-2,17E-05	1,58E-03	1,58E-05
EU Stocks	7,52E-05	1,68E-06	6,08E-06	-7,87E-08	8,20E-05	-7,11E-06	-1,71E-05	1,58E-05	1,13E-04

Table 10 describes the variance covariance matrix based on the daily returns of the traditional assets (i.e. European Stocks, European sovereign bonds, European inflation linked bonds, European corporate bonds, Euro currency index) and alternative investments (i.e. commodities such as Gold and Oil, real estate) contained in the portfolio over the period 2014-2017.

4.3.2 Long portfolio

The second step of the analysis is to research in greater depth the effect of Bitcoin into a well-diversified portfolio by using the Portfolio optimisation. The analysis will be divided into two parts. The first part will analyse only long portfolios and the second part will allow short selling in the portfolio.

Figure 5 show the mean-variance efficient frontier for long portfolios with and without Bitcoin. The frontier that includes Bitcoin is much steeper than the frontier not including Bitcoin. Furthermore, the minimal-variance portfolio does not hold any Bitcoin. This result is in line with the expectations as we assume risk averse investors and the volatility of the Bitcoin is relatively high. In other words, Bitcoin's volatility is too high to be incorporated in the minimum risk portfolio. However, if we consider that an investor has a higher tolerance for risk, we see that adding Bitcoin increases expected returns dramatically at a given level of risk. The results in table 11 show that a Bitcoin including portfolio increases in return from

15,44% to 24,65% by allowing variance, i.e. risk, to increase from 1% to 3%. On the contrary, the expected annualised returns of the portfolio not including Bitcoin only increases slightly from 5,70% to 5,84%.

	1% Variance	
	With BTC	Without BTC
Exp Return	15,44%	5,70%
Sharpe Ratio	150,84%	53,36%
Weight BTC	14,72%	0,00%
Observations	988	988

	3% Variance	
	With BTC	Without BTC
Exp Return	24,65%	5,84%
Sharpe Ratio	140,24%	31,65%
Weight BTC	26,74%	0,00%
Observations	988	988

Table 11 describes the return of a portfolio including Bitcoin against a portfolio excluding Bitcoin at a variance level of 1% and 3% over the period 2014-2017. The portfolio only allows for long positions.

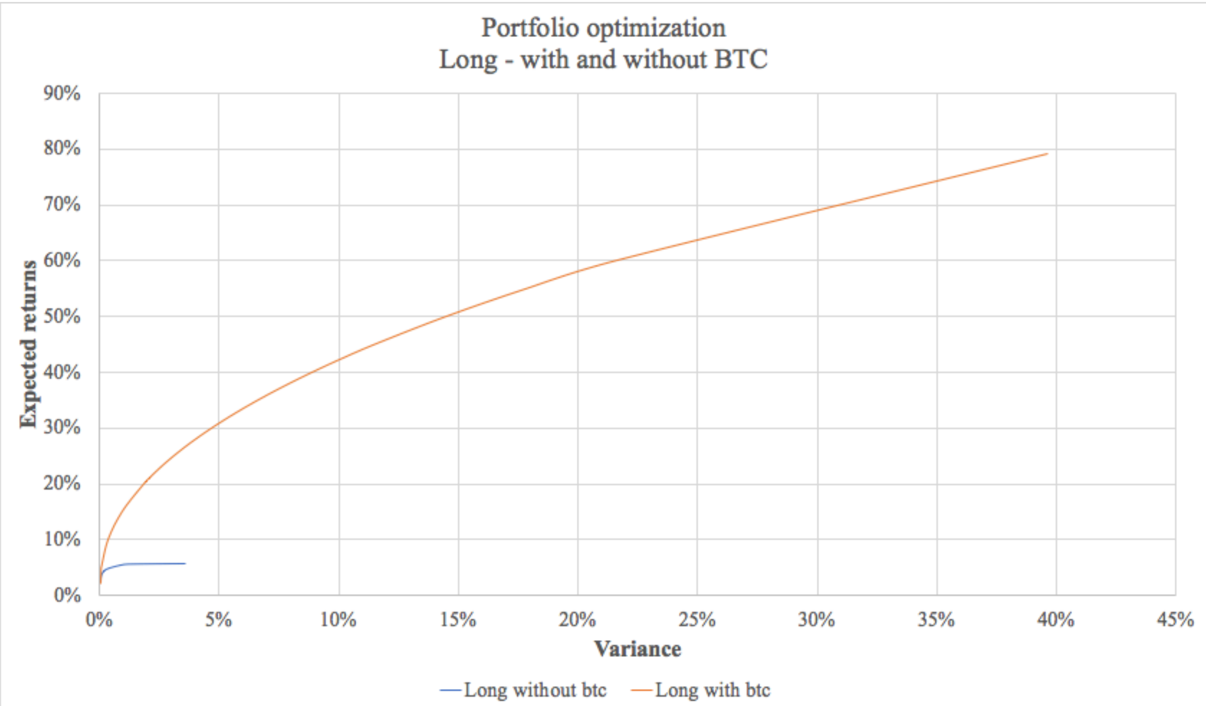

Figure 5: Depicts the efficient mean-variance frontier of the long portfolios including Bitcoin (orange frontier) as well as the efficient mean-variance frontier of the long portfolios excluding Bitcoin (blue frontier).

Including Bitcoin thus increases the annualised expected return at a certain given level of risk. Next, we optimise both portfolios to see what the maximal Sharpe ratios are and establish the optimal amount of Bitcoin in the well-diversified portfolio. The Sharpe ratio of the optimised portfolio including Bitcoin is 193,39%, whereas the optimised portfolio excluding Bitcoin only reaches a Sharpe ratio of 156,24%. The weight of Bitcoin that needs to be included to reach the maximised Sharpe ratio is 2,05%. These results show the huge diversification potential of Bitcoin as only a small fraction of Bitcoin dramatically affects the overall performance of the portfolio.

4.3.3 Portfolio allowing short-selling

When conducting the same analysis on a portfolio that allows for short selling, similar results are obtained. Figure 6 shows the mean-variance efficient frontier for portfolio that allow short selling with and without Bitcoin. The slope of the efficient frontier is much steeper for the portfolio including Bitcoin than the portfolio excluding Bitcoin. Similarly, to the long portfolio, the volatility of Bitcoin is too high to be incorporated in the minimum risk portfolio. This is in line with the expectation of a relatively risk-averse investor and the high volatility of Bitcoin. Furthermore, adding Bitcoin if the risk tolerance of the investor increases, adding Bitcoin improves performance of the portfolio.

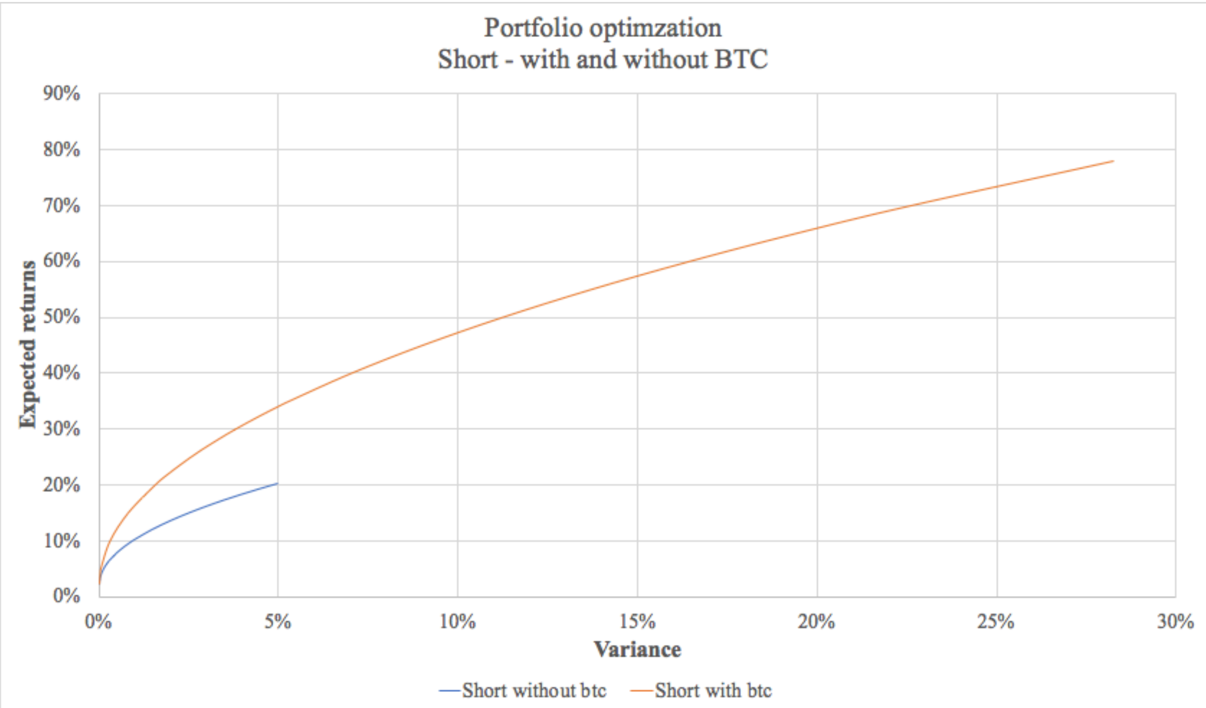

Figure 6: Depicts the efficient mean-variance frontier of the portfolios allowing for short selling including Bitcoin (orange frontier) as well as the efficient mean-variance frontier of the long portfolios excluding Bitcoin (blue frontier).

Given a certain level of risk adding Bitcoin into a portfolio increases the return as observable in table 12. By increasing the variance from 1% to 3% the annualised expected return of the

Bitcoin containing portfolio increases from 16,39% to 26,88%. However, increasing the variance from 1% to 3% in a Bitcoin free portfolio also increases the annualised expected return from 10,29% to 16,21%, in contrast with the findings for the long portfolio where increasing variance to 3% only had a very small effect. The increase of return in the Bitcoin free portfolio compared to the long portfolio is due to short-selling, as it is a riskier way to invest[1].

	1% Variance	
	With BTC	Without BTC
Exp Return	16,39%	10,29%
Sharpe Ratio	160,28%	99,32%
Weight BTC	13,13%	0,00%
Observations	988	988

	3% Variance	
	With BTC	Without BTC
Exp Return	26,88%	16,21%
Sharpe Ratio	153,14%	91,52%
Weight BTC	22,95%	0,00%
Observations	988	988

Table 12 describes the return of a portfolio including Bitcoin against a portfolio excluding Bitcoin at a variance level of 1% and 3% over the period 2014-2017. The portfolio allows for short positions.

Next, we optimise the Sharpe ratio of both portfolios. We obtain a Sharpe ratio of 195,29% for the portfolio including Bitcoin and Sharpe ratio of 158,90% for the portfolio excluding Bitcoin. The weight of Bitcoin in the optimised portfolio is 1,98%, so by only adding a small fraction of Bitcoin the Sharpe ratio increases dramatically. The results are thus comparable to the long-selling portfolios and confirms that Bitcoin has a huge potential for diversification in a portfolio that allows for short selling. However, no proof was found that short selling Bitcoin itself can contribute to diversification. This is in line with expectations that the price of Bitcoin has increased over the analysed time frame and is therefore not a good potential candidate for short selling.

4.4 Concluding remarks of the analysis

Some conclusions can be drawn from the obtained results. First, Bitcoin has fascinating Skewness and Kurtosis levels that are generally in line with previous research. Second,

[1] Losses in long portfolios are limited whereas losses in short-selling portfolio are potentially unlimited.

Bitcoin displays low correlations with traditional and alternative assets. Finally, we can confirm that in both our long-selling and short-selling portfolios, which focus solely on the European market, including a small fraction of Bitcoin increases dramatically the Sharpe ratio. This confirms previous research by Brière, Szafarz and Oosterlink (2013) who investigated the effect of adding Bitcoin to a well-diversified world portfolio, Kajtazi & Moro (2017) who investigated the effect of adding Bitcoin to a well-diversified Chinese portfolio and, Eisl et al. (2015) and Carpenter (2016) who investigated the impact of Bitcoin on a U.S. focused portfolio.

4.5 Limitations and further research

The research performed throughout this paper is subject to some limitations. First, data of Bitcoin in Euro could not be found earlier as mid-2013. This limits the scope of our analysis to a time-span of four years and excludes the beginning years of Bitcoin. Second, our analysis is solely focussed on Bitcoin. As described earlier it is still the major cryptocurrency but it is no longer representative of all cryptocurrencies. It would therefore be interesting to analyse the impact of a cryptocurrency index e.g. CRIX or CCi30, on a well-diversified portfolio, as to the best of our knowledge only Chuen et al. (2017) perform similar research. Third, not every index covers exactly the same countries of Europe but represents still the major European economies. Therefore, a computation with different indexes could lead to slightly different results but the general results should remain the same. Fourth, there is only little research on other cryptocurrencies and how they behave as financial assets. Further research is thus needed to analyse whether adding another cryptocurrency would have similar effects.

5. Overall conclusion and answer to the research question

Building on the existing body of literature on portfolio diversification by adding Bitcoin, we have investigated the impact of Bitcoin on a European well-diversified portfolio. Our descriptive statistics show that Bitcoin demonstrates low correlations with other assets, which supports the idea of bitcoin as a hedge or even safe haven. The studied time span does however not contain any economic crisis. Previous literature has shown that correlations tend to increase during crises (Goetzmann et al., 2005, Brière et al., 2012). Furthermore, we can also not foresee how Bitcoin will be perceived during a crisis. Therefore, we cannot confirm that Bitcoin can be used as a safe haven.

The results of our Mean-Variance analysis show that for an equally weighted portfolio, as well as for a long and a short portfolio, the Sharpe ratio dramatically increases when Bitcoin is included. Our main finding is that adding 2,05% of Bitcoin in a long portfolio and 1,98% of Bitcoin in a short portfolio maximises its risk-return. In both the long and the short portfolio, the most risk-averse investor would not include bitcoin in its portfolio as it is too volatile. However, we find no evidence that short selling Bitcoin is beneficial.

Adding Bitcoin to a European well-diversified portfolio has diversification benefits as it increases the risk-return of the portfolio. To the best of our knowledge, we are the first to research the impact of bitcoin on a well-diversified portfolio with as geographic focus the European market. Other papers have conducted similar research but with other geographic focusses, such as China or the U.S. Our findings are relevant for investors who can use Bitcoin for diversification purposes. Our results also contribute to the academic research on Bitcoin which at this date is still the most prominent cryptocurrency and for which the academic literature is still limited. Finally, our research might help regulators to define Bitcoin as an asset class because we show that it is not only used for speculative purposes but can also be held for diversification purposes in a portfolio. The main take-away of this paper is that Bitcoin can have a huge impact on well-diversified portfolios and should consequently be seriously considered by financial analysts as well as by financial and regulatory institutions.

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