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Cryptocurrencies as an Alternative Asset Class

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Abstract

Bitcoin was the first digital currency to rely on a decentralized peer-to-peer network instead of a trusted third party. This was achieved through Bitcoin's revolutionary underlying technology based on cryptographic proof: the blockchain. After Bitcoin's emergence, many other so called cryptocurrencies entered the market and we have seen enormous price increases that promised large returns for early users. The return characteristics of cryptocurrencies have been studied by various scholars and some have even declared cryptocurrencies to be an asset class instead of a digital currency. Due to the fast changes in the cryptocurrency market and the increased importance of other cryptocurrencies than Bitcoin, we believe that research focusing on the financial performance of cryptocurrencies should be renewed on a regular basis. Therefore, with this work we aim to shed light on the return characteristics of cryptocurrencies in relation to traditional asset classes and on the potential of cryptocurrencies to improve portfolio diversification. In addition, we investigate the cryptocurrency market, describe selected cryptocurrencies in more detail and provide an overview of potential technological risks arising with the use of cryptocurrencies. Our results indicate that cryptocurrencies provide large return potentials with high levels of volatility but compared to traditional asset classes provide a higher level of return per level of risk. We also find that selected cryptocurrencies can improve diversification in a cryptocurrency portfolio, as well as in a portfolio of international equity and private equity investments.

Keywords: Alternative Asset Classes, Cryptocurrency, Portfolio Diversification, Risk-Reward Profile und Cryptocurrency Risks

1. Introduction

People have multiple options to transfer money online. The most established method is to use online banking while there are also online money transfer providers such as PayPal, that enable sending money from one online account to another. However, all options have one flaw in common: they rely on trust of a third party. This was challenged in 2008 with the introduction of Bitcoin, the first decentralized virtual currency. Bitcoin was developed to enable transferring money without the need to rely on a trusted third party through *blockchain technology*. It enables Bitcoin to rely on cryptographic proof instead of a third party, leading to the birth of cryptocurrencies. Many believe that the introduction of Bitcoin will have a similar impact on payments as emails had on communication: to disrupt an entire industry.

After Bitcoin's introduction it took over two years until Namecoin, the second cryptocurrency, was introduced in 2011. Namecoin's purpose was not to introduce another digital currency but to enable domain name registration without the need of a trusted third party. After Namecoin was introduced, many other cryptocurrencies emerged with the aim to either provide innovative decentralized features or to serve as other digital currencies based on blockchain technology. The underlying technology is considered to be more innovative than Bitcoin itself, as the blockchain allows to avoid the need for a trusted third party for many other means than just transferring money online. This is reflected by the growth of the cryptocurrency market, whose combined market value increased from around $11 billion in early 2014 to around $100 billion in June 2017: an increase of over 800% (CoinMarketCap, 2017).

Cryptocurrencies emerged as a form of payment but because of its stark increase in prices many people have started to purchase cryptocurrencies with the goal of financially benefiting from the positive market development.

This development did not go unnoticed by scholars and over the years the amount of research on cryptocurrencies steadily increased. The majority of work focused on Bitcoin as it is the most prominent cryptocurrency in the market. However, due to recent developments in the cryptocurrency market, scholars have begun to investigate other cryptocurrencies as well.

Research on cryptocurrencies spans different fields such

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as security (Barber et al., 2012; Eyal and Sirer, 2014; Bonneau et al., 2015), regulation of cryptocurrencies (Hughes and Middlebrook, 2014; Marian, 2015), competition in the cryptocurrency market (Iwamura et al., 2014; White, 2015), but also on individual's intended use when purchasing cryptocurrencies (Glaser et al., 2014).

Although there are many fields to investigate in the cryptocurrency universe, this work focuses on the financial performance of cryptocurrencies. More precise, the aim of this thesis is to shed light on the financial performance of cryptocurrencies in relation to traditional asset classes and on the potential of cryptocurrencies to improve portfolio diversification. Besides, we provide information regarding the cryptocurrency market, describe selected cryptocurrencies in more detail and provide an overview of potential technological risks arising with the use of cryptocurrencies. However, we do not present an in-depth description of the market for cryptocurrencies or on cryptocurrencies' underlying technologies but, whenever the case, we will point the interested reader to several other sources that provide more detailed information.

This work focuses specifically on five cryptocurrencies which were primarily selected based on their market capitalization. The cryptocurrencies in scope are Bitcoin, Ripple, Ethereum, NEM and Litecoin, which combined amount to over 80% of the total cryptocurrency market capitalization as of June 9th, 2017 (CoinMarketCap, 2017). We investigate their financial performance over the time period from mid of August 2015 until mid of June 2017 and compare it with the performance of six asset classes. The asset classes under investigation are equity, fixed income, commodities, real estate, hedge funds and private equity.

Scholars have addressed the financial performance of cryptocurrencies and its use to improve portfolio diversification in a number of publications.

Work by Baur et al. (2015) concentrates on whether Bitcoin is used as a currency or as an investment and investigates the correlation of Bitcoin with other asset classes. They find that Bitcoin is mainly used as a speculative investment and that its returns are uncorrelated with those of traditional asset classes.

Eisl et al. (2015) and Brière et al. (2015) focus on the diversification effect when including Bitcoin in an already well-diversified portfolio. They follow different approaches but come to a similar conclusion: investors should include Bitcoin in an optimal portfolio as it improves the risk-return ratio.

Elendner et al. (2016) widen the scope of prior research and include ten different cryptocurrencies in their work. They investigate cryptocurrencies as alternative investment assets and investigate correlations between different cryptocurrencies and between other asset classes. They find low correlations between cryptocurrencies and, in line with prior research, that adding cryptocurrencies to a portfolio consisting of traditional assets enhances the risk-return ratio.

Work by Chuen et al. (2017) reinforces prior research. They also find low correlations between cryptocurrencies and traditional assets, and argue that it is beneficial to include cryptocurrencies in a portfolio consisting mainly of traditional assets.

When starting this work there was only limited amount of research on the return characteristics of cryptocurrencies compared to other asset classes. Most scholars focused on Bitcoin in particular and did not include other cryptocurrencies in their research. We believe that investigating multiple cryptocurrencies is more relevant for people interested in their financial behavior, especially because of the increased importance of other cryptocurrencies besides Bitcoin. In addition, the market for cryptocurrencies is very dynamic, with daily price fluctuations of over 10% being commonly observed. Cryptocurrencies also only emerged recently and the amount of data is therefore quite limited. Increases in available data allow for more observations and this enables to reinforce or to reject prior findings. We therefore believe that work on cryptocurrencies should be renewed on a regular basis in order to support practitioners and interested individuals when making investment decisions.

1.1. Structure.

This work is organized as follows. In Chapter 2 we provide a cryptocurrency glossary, explain the blockchain technology and introduce standard financial terminology to help an unfamiliar reader better understand the following chapters. We continue with general information on cryptocurrencies and specific information on the cryptocurrencies we investigate in Chapter 3. In Chapter 4 we introduce common asset classes and provide insights on what these asset classes are used for. We explain our approach for collecting data and provide the reader with the methods we use for analyzing the data in Chapter 5. In Chapter 6 our findings regarding the risk-reward profile of cryptocurrencies and asset classes, including correlation analyses and potential limitations of our work are presented. We highlight selected technological risks of cryptocurrencies including their potential implications in Chapter 7 and finish with our conclusion in Chapter 8.

1.2. Contributions.

In this work we make the following contributions:

- The market for cryptocurrencies is very dynamic and has experienced large growth (Section 3.2)
- Bitcoin was the first cryptocurrency but lost market shares to other cryptocurrencies (Section 3.2)
- Cryptocurrencies emerged as an alternative payment system but their underlying technology can serve various purposes (Section 3.4)
- Asset classes can be used for market allocation decisions, performance measurement and investment product development (Section 4.2)
- Investments in cryptocurrencies provide large return potentials with high levels of volatility (Section 6.1)

- Cryptocurrency investments provide a higher level of return per level of risk compared to traditional assets (Section 6.1)
- Combining different cryptocurrencies in a portfolio provides beneficial diversification effects (Section 6.2)
- Combining investments in Ethereum with international equity or private equity investments provides beneficial diversification effects (Section 6.2)
- Costs for operating on Ethereum's blockchain can be hedged through international equity or private equity investments (Section 6.2)
- Technological risks of cryptocurrencies pose threats for both businesses and individuals concerning usability, potential fraud and anonymity (Chapter 7)

1.3. Used resources.

We used Coinmarketcap[1], an online website providing transparency on cryptocurrency metrics, to collect data for cryptocurrencies. We accessed data for asset classes through Bloomberg Terminals provided by Goethe University. For analyzing data we used Stata 15 provided by Goethe University and a private version of Microsoft Excel 2013.

2. Preliminaries

In this chapter we introduce a cryptocurrency glossary, explain how the blockchain technology works and define several financial notions which we believe will help an unfamiliar reader better understand the following chapters.

2.1. Cryptocurrency glossary

2.1.1. Peer-to-peer.

Peer-to-peer refers to decentralized interactions between network participants through a single mediation point (BlockchainTechnologies.com, 2016).

2.1.2. Altcoin.

The term altcoin refers to a decentralized digital currency. Cryptocurrencies differ from altcoins in a way that they are built creating a new purpose, while altcoins can be seen as clones of existing cryptocurrencies, only changing minor parameters such as currency supply or the way in which they are issued (Hileman and Rauchs, 2017).

2.1.3. Token.

Term for a coin that is used on a blockchain.

[1] The site can be reached at www.coinmarketcap.com.

2.1.4. Initial Coin Offering (ICO).

Process through which start-ups sell cryptocurrency tokens to the public with the aim of collecting funds to finance their project. An ICO can be compared to an Initial Public Offering through which a company that is getting listed on a stock exchange sells company shares in the form of stocks. Presale or crowdsale are different terms used to describe an ICO (BlockchainTechnologies.com, 2016).

2.1.5. Smart contracts.

Contracts with terms recorded in a computer language rather than in a legal language. Smart contracts synchronize their current state and can execute automatically through a computing system such as a blockchain (BlockchainTechnologies.com, 2016; Hildenbrandt et al., 2017).

2.1.6. DApps.

Decentralized applications built on top of blockchain technology.

2.1.7. Genesis block.

The genesis block is the first block of a blockchain (Decker and Wattenhofer, 2013).

2.1.8. Mining.

Process of verifying transactions by providing computational power, thereby adding new blocks to the blockchain (NEM.io Foundation Ltd, 2017).

2.1.9. Mining pool.

A mining pool refers to groups of miners that share mining rewards in relation to their contribution in terms of computational power (Tuwiner, 2017).

2.1.10. Node.

A node refers to an active computer/device that is connected to a certain network. In the case of cryptocurrencies, nodes are usually responsible for verifying transactions.

2.1.11. Consensus mechanism.

The process used by the network to collectively agree on the contents recorded on the blockchain (BlockchainTechnologies.com, 2016).

2.1.12. Block time.

Time required for a block to be added to the blockchain, which varies among different blockchains.

2.1.13. Cryptography.

In this work it refers to the encoding and decoding of information with the help of computers (Merriam-Webster, Incorporated, 2017).

2.1.14. Hashing.

Hashing refers to the transformation of original information into a shorter, fixed-length value or key representing the original data.

2.1.15. Cryptographic hash function.

A hash function is responsible for hashing original information by transforming the information and producing a hash value (Dwyer, 2015).

2.1.16. Mining difficulty.

The difficulty of finding a certain hash required to verify blocks in a blockchain network. The difficulty is adjusted to keep the block time at a predefined level (BlockchainTechnologies.com, 2016).

2.1.17. Merkle tree.

A merkle tree refers to a special way of structuring data to summarize and verify the integrity of large data sets efficiently. The word "tree" refers to its upside-down structure in the form of branches with a "root" at the top and "leaves" at the bottom (Antonopoulos, 2017). A Figure in the Appendix displays a typical Merkle tree.

2.1.18. Hard fork.

Major, permanent divergence from a previous version of a blockchain that requires all nodes to update to the latest protocol software. This creates a fork in the blockchain, as one path follows the upgraded blockchain, while one path follows the old way (Li, 2017).

2.1.19. Soft fork.

Change to the blockchain protocol introducing new rules, that invalidates some previously valid blocks but preserves the remaining valid blocks as valid. The majority of nodes in the network need to update to the latest protocol software in order to enforce the new rules (Li, 2017).

2.1.20. Double spending.

Double spending refers to spending the same account balance on two different transactions.

2.1.21. Multisignature transactions.

Blockchain adoption that increases protection against theft (BlockchainTechnologies.com, 2016).

2.1.22. Application Specific Integrated Circuit (ASIC).

ASICs are computer chips that are designed to perform one specific function. They are used by miners to process hashing algorithms and are especially used for processing the complex SHA-256 algorithm used by Bitcoin (BlockchainTechnologies.com, 2016).

2.1.23. Internet Protocol (IP) Address.

An IP address is a code of numbers that identifies a particular computer/device connected to the internet (PC.net, 2017).

2.1.24. Application Programming Interface (API).

An API is a set of functions and protocols for building software applications that enable communicating between different software components and accessing data of an operating system, application or other service (Schueffel, 2017).

2.2. Blockchain

A blockchain refers to a distributed, continuously growing, public database of permanent records, called blocks, which are linked to each other and secured using cryptography. It can be seen as a public ledger of all executed transactions, which is shared among its participants (Narayanan et al., 2016). Nakamoto proposed the blockchain technology in order to rely on cryptographic proof instead of a trusted third party for individuals willing to execute online financial transactions.

The blockchain technology was introduced through Satoshi Nakamoto's white paper on Bitcoin but its technology is used for a variety of cases in both the financial as well as non-financial world (Crosby et al., 2016). Due to its different applications, with Bitcoin as the most prominent one and its intrinsic link to Bitcoin, we explain the functioning of the Bitcoin blockchain in the following (ElBahrawy et al., 2017).

A general description of the process of how Bitcoins are transferred helps understand how the blockchain works. When a person wants to send an amount of Bitcoins to another person, the transaction is represented in the network as a block. The block is then broadcasted to every node in the network and the majority of nodes need to verify the transaction. As soon as the transaction is verified, the block is added to the blockchain and the amount of Bitcoins is moved to the account of the receiver. Thereby, new blocks are continuously added to the blockchain, which keeps growing with the amount of blocks verified.

In a more technical way, the blockchain technology orders hashed and encoded transactions in a Merkle tree in groups of data called blocks. These blocks are linked in a linear, chronological chain of transactions with each block containing a hash of the previous block as seen in Figure 1. Before a block is added to the blockchain, the majority of nodes within the network verify the validity of the transaction through a consensus mechanism. By linking each block with its preceding block, the blockchain can ensure the validity of all added blocks back to the genesis block.

A block consists of two parts: a header and transaction details. When transactions are executed they are broadcasted to all nodes in the network, which individually collect the transactions in a block. In order to add the block to the blockchain one node needs to solve a mathematical "puzzle", a process called mining. This puzzle refers to finding a value that when hashed with the SHA-256 algorithm[2], the hash

[2] More details on SHA-256 can be found at https://csrc.nist.gov/csrc/media/publications/fips/180/2/archive/2002-08-01/documents/fips180-2.pdf.

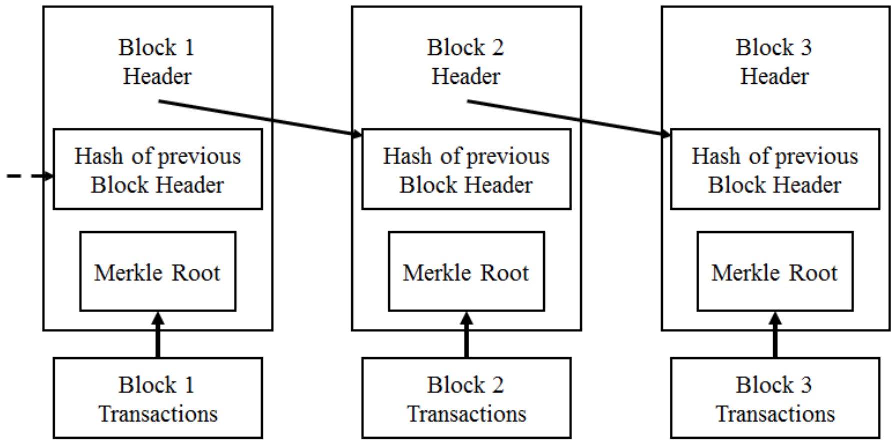

Figure 1: Simplified Bitcoin blockchain; Adapted from Bitcoin Project (Bitcoin Project, 2017a).

value shows a certain structure that starts with zeros. Solving the puzzle refers to the proof-of-work, the consensus mechanism on which Bitcoin's blockchain relies. After finding the proof-of-work, the block is broadcasted to all nodes in the network which accept the block if all transactions within the block are valid and funds are not already spent. This can be ensured through linking all the blocks on the blockchain with their previous block. Copies of the transactions within each block are hashed and the hashes consequently paired until only a single hash remains. This hash refers to the Merkle root of a Merkle tree and is stored in the block header of each block. Nodes express their acceptance of the current block by working on creating the next block using the hash of the accepted block as the previous hash. Thereby, a chain of blocks is created that rely on the information of the previous blocks and thus ensure validity of the transactions within the network (Nakamoto, 2009; Bitcoin Project, 2017a).

2.3. Financial terminology

2.3.1. Fiat money.

Fiat money refers to a currency without intrinsic value that a government or law declared to be legal tender (Mankiw, 2014).

2.3.2. Market capitalization.

Total value of a corporation's outstanding shares. It is calculated as the sum of the market price per share and the number of shares outstanding.

2.3.3. Trading volume.

Total amount of value that was traded during a predefined period.

2.3.4. Portfolio.

A portfolio refers to the totality of assets held by an investor.

2.3.5. Market index.

An index consists of different components of an asset class with the aim to represent certain sections of the market or the market as a whole. One of the most known market indices is the S&P 500 which consists of stocks of the 500 largest publicly listed U.S.-based companies aiming to provide a picture of the total U.S. stock market (Bodie et al., 2010).

2.3.6. Mutual fund.

A mutual fund is a pool of funds provided by investors and managed by a fund manager with the purpose of realizing positive returns by investing the capital (Bodie et al., 2010).

2.3.7. Index fund.

A mutual fund with the same positions and proportions as represented in a market index (Bodie et al., 2010).

2.3.8. Exchange traded fund (ETF).

An Exchange traded fund is a form of a mutual fund that can be traded on an exchange (Bodie et al., 2010).

2.3.9. Real Estate Investment Trusts (REITs).

REITs refer to publicly traded companies with pooled investments in real estate properties and/or real estate debt (Maginn et al., 2007).

2.3.10. Volatility.

Volatility provides a measure of how much the returns of an asset are likely to fluctuate. It is measured as the standard deviation of the returns of an asset (Mankiw, 2014).

2.3.11. Correlation.

The correlation coefficient is a measure that quantifies the linear relationship between two variables. The correlation coefficient can be any number between 1 and −1. If the coefficient is equal to 1 the variables move up and down in perfect unison. If the variables are uncorrelated, the correlation coefficient equals 0 and the variables do not move irrespective of the state of the other variable. A negative correlation coefficient refers to one variable moving up while the other variable moves down (Weiss, 2011; Markowitz, 1968).

2.3.12. Hedge assets.

Hedge assets have a negative correlation with other assets in a portfolio and can be used to reduce the total level of risk in a portfolio (Bodie et al., 2010).

2.3.13. Futures contract.

The holder of a futures contract is obliged to purchase or sell an asset for a predefined price at a future point in time (Bodie et al., 2010).

2.3.14. Contracts for Difference (CFD).

A CFD is a contract that provides the holder with the option to receive the difference between an arranged future price and the current price of an underlying asset.

2.3.15. Bridge currency.

A bridge currency refers to a central currency that can be used as a bridge for cross-border payments. Instead of exchanging one fiat currency against another fiat currency, bridge currencies serve as the central medium of exchange (Pisa and Juden, 2017).

3. Cryptocurrencies

In this chapter we start with an overview of the historical development of cryptocurrencies in Section 3.1 and we continue with providing information on the market for cryptocurrencies in Section 3.2. We then explain major use cases of cryptocurrencies in Section 3.3 and finish this chapter with Section 3.4, where we provide detailed information regarding the cryptocurrencies we investigate in this work.

3.1. Historical development

The general idea of digital currencies was first explored through a research paper in 1982 by (Chaum, 1982). In further work, Chaum's aim was to develop a form of payment that allowed users to privately execute payments online (Chaum, 1985). Based on the ideas from his research, Chaum founded DigiCash in 1990, a company specializing in electronic payments (Kißling, 2003). However, as the market did not seem to be mature enough for this new development, Chaum's invention did not attract enough users and consequently failed.

In 1996, e-Gold was introduced, a centralized digital currency that was backed by gold, offering anonymous accounts for its users. In order to create a digital account balance denoted in the platform's digital currency *e-Gold*, users had to either send the company physical gold or wire money to the company. The platform allowed its users to instantly transfer value from one individual's digital account to another individual's digital account. However, due to legal and privacy issues, e-Gold suspended transfers after its management pleaded guilty to money laundering and for operating an unlicensed money transfer business (Condon, 2008; Miller, 2014).

The next major step towards digital currencies came with the introduction of PayPal in 1998. PayPal is a payment processor acting as an online intermediary for transferring money from one bank account to another bank account. However, instead of offering its own currency, PayPal uses fiat currencies as a medium of exchange (Skinner, 2007).

Although forms of digital currencies came into existence in the early 90's, all previous approaches had one major flaw in common: they relied on trust of a third party. This was challenged in 2008 through the release of Satoshi Nakamoto's paper *Bitcoin: A Peer-to-Peer Electronic Cash System*. Other than existing versions of digital currencies, Nakamoto introduced the concept of Bitcoin, a pure peer-to-peer version of electronic cash based on cryptographic proof instead of trust of third parties. With the release of Bitcoin, Nakamoto introduced the blockchain technology, which allows Bitcoin to serve as a decentralized platform that can be used to send and receive the platform's virtual currency *Bitcoin*[3] without relying on a trusted third party, thereby leading to the birth of cryptocurrencies (Nakamoto, 2009).

Bitcoin was officially launched in early January 2009 but it took over two years until Namecoin, the second decentralized digital currency, entered the market in April 2011. Instead of building its own blockchain, Namecoin is considered to be an altcoin that is based on Bitcoin's code, and arose as the first Bitcoin fork (Hileman and Rauchs, 2017). Namecoin's primary goal of development was to create an alternative cryptographic network enabling decentralized domain name registration instead of serving as a digital currency (Buterin, 2014). After the emergence of Namecoin, numerous other cryptocurrencies and altcoins were introduced and cryptocurrencies enabled more innovative new features, some of which are explained in more detail in Section 3.4, based on their underlying technology. Hence, launching new cryptocurrencies was mainly driven by innovative technological features and not in order to create other cryptocurrencies to compete with fiat currencies as was the case with the introduction of Bitcoin (Nakamoto, 2009). The market for cryptocurrencies kept growing over the years and as of June 9th, 2017, Coinmarketcap provided data for a total of 745 cryptocurrencies and altcoins amounting to a combined market capitalization of approximately $100 billion.

3.1.1. Note.

In the following, we will use the term cryptocurrencies interchangeably for both altcoins and cryptocurrencies.

3.2. Market for cryptocurrencies

In this section we provide information regarding the overall cryptocurrency market. We start by introducing the historical development of coins in the market, continue with the

[3] Bitcoin's internal currency is called Bitcoin.

development of the overall market capitalization and finish this section with information on daily trading volumes in the cryptocurrency market.

When thinking about cryptocurrencies the first thing that usually comes to people's minds is Bitcoin. However, as described in Section 3.1, there are far more cryptocurrencies in the market. We extracted the number of cryptocurrencies that are listed on Coinmarketcap from May 2013 until June 2017 in order to provide insights about the development of the number of coins in the market. To do so, we used www.archive.org, a service that enables to view historical snapshots of websites, to extract data presented in Figure 2. It is important to note that throughout time some cryptocurrencies go extinct while others are added. Thus, only active cryptocurrencies fulfilling certain minimum requirements (e.g. minimum trading volume) are taken into account.

Figure 3 provides insights about the development of the total market capitalization including the share of Bitcoin over the period from May 2013 until June 2017 based on data from Coinmarketcap. With Bitcoin as the most prominent cryptocurrency, we decided to provide a comparison of the development of Bitcoin with the remaining market.

Figure 4 shows daily trading volume including the share of Bitcoin over the period from August 2015 until June 2017 based on data from Coinmarketcap. We neglected data before August 2015 as there was little movement and to improve the visualization of recent developments.

By comparing the development presented in Figures 2 to 4 we can clearly see a stark increase in the amount of coins, the amount of money invested in coins and the value of trades executed per day. This is especially true for the development of the market capitalization and trading volume in 2017. It is interesting to see how the relative share of Bitcoin in terms of both market capitalization and trading volume decreased over time. Until 2017 Bitcoin's relative market capitalization constantly exceeded 74% - within less than six months it had reduced to 46%. When comparing the overall trading volume with that of Bitcoin, we see a relative trading volume averaging at around 74% until 2017, which decreased to an average relative trading volume around 60% in 2017 with a relative trading volume of around 47% by the beginning of June 2017. This implies that Bitcoin lost substantial shares to other cryptocurrencies.

3.3. Use of cryptocurrencies

Cryptocurrencies emerged with the purpose to be used as a digital currency but can serve a variety of purposes (Nakamoto, 2009). Most prominent use cases of cryptocurrencies are as a form of payment, as an internal pricing mechanism on the blockchain, for investment purposes but also for start-ups to receive funding (ElBahrawy et al., 2017).

3.3.1. Note.

It is important not to get confused between using a certain cryptocurrency and using a cryptocurrency's underlying technology. As our work focuses on specific cryptocurrencies, including the financial behavior of the respective coins, our focus is to provide insights about the usage of the cryptocurrencies' coins and not the usage of their technology.

Form of payment: Cryptocurrencies emerged with the purpose to pay for goods online and by now there are numerous merchants accepting different cryptocurrencies, with Bitcoin being the most widely accepted one (Hileman and Rauchs, 2017). According to a survey by Luca et al. (2015), the majority of people questioned used cryptocurrencies for online shopping, followed by online gaming or gambling and for paying credit card bills. However, cryptocurrencies are also used for illegal activities such as money laundering, tax evasion and illicit trade (Conti et al., 2017). One of the most well-known examples is the case of Silk Road, a hidden online marketplace where goods such as illegal drugs, fake identification documents but also hit men or computer hackers could be paid for in cryptocurrencies. Silk Road generated revenues of over $1.2 billion with almost one million customers before it was shut down in 2013 (Leinwand Leger, 2014).

Pricing mechanism on the blockchain: Usually it is required to pay a fee when sending transactions through a blockchain. This is mainly due to the characteristic of cryptocurrencies relying on miners to validate transactions. These miners have to provide computational power and thus use electricity for validating transactions. In order to provide a monetary incentive, miners receive the token of the cryptocurrency for their effort. Thereby, the cryptocurrency is used to keep the network running but also to mitigate spam on the network (NEM.io Foundation Ltd, 2015a; Wood, 2014).

Investment purposes: Similar to investing in stocks, many individuals and professional investors use cryptocurrencies as an alternative asset class (Baur et al., 2015). In this case, cryptocurrencies are bought with the aim to financially benefit from price increases. The price development is a cryptocurrency's only income component and thereby it differentiates from other assets such as stocks that pay dividends or bonds that pay coupons.

Investors of cryptocurrencies can pursue different approaches. The most common approach is to directly purchase a cryptocurrency from an online exchange. Exchanges provide the service to purchase and sell cryptocurrencies for fiat currencies but also to trade cryptocurrencies against other cryptocurrencies (Hileman and Rauchs, 2017). Thereby, an investor has the opportunity to directly invest in a cryptocurrency without the need of a broker as it is usually the case for investments in e.g. stocks.

Additionally, there is the option to invest through alternative approaches such as ETFs or investment trusts. Thereby, executing investments becomes easier and investors can benefit from fund manager's knowledge e.g. through the purchase of diversified cryptocurrency portfolios (Gao, 2017).

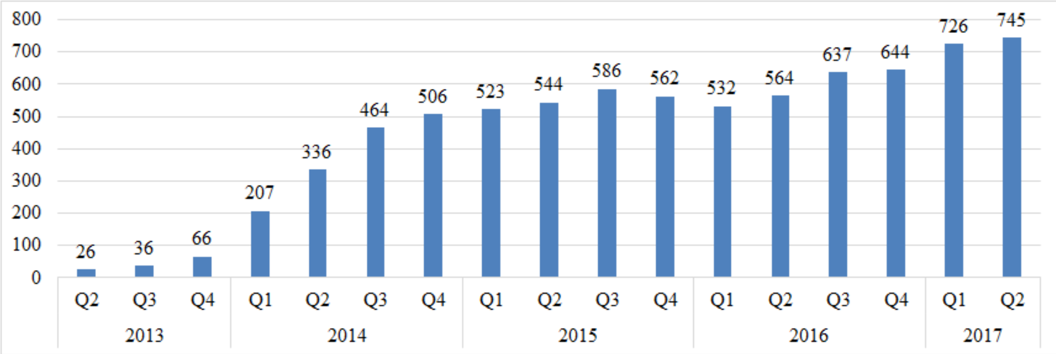

Figure 2: Development of listed cryptocurrencies.

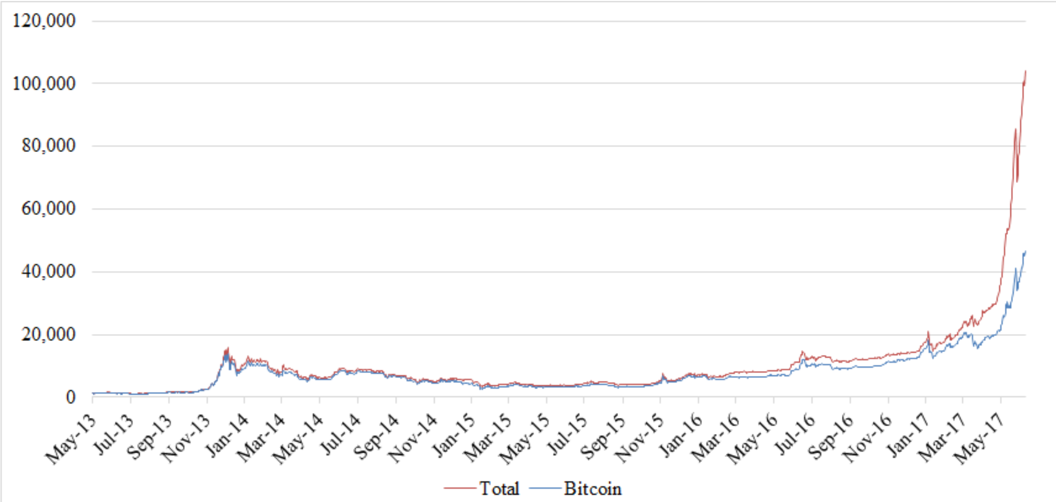

Figure 3: Development of the total market capitalization (Numbers in USD millions)

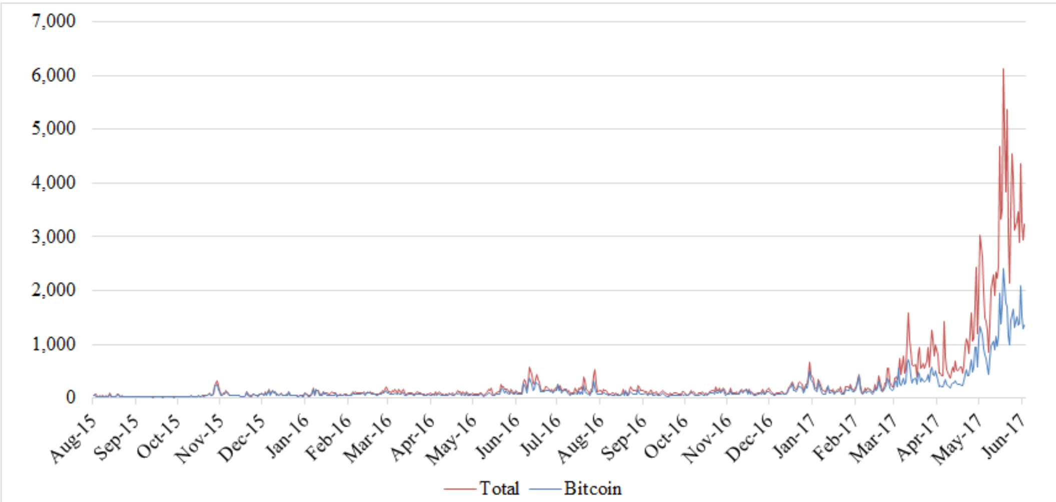

Figure 4: Development of the total daily trading volume (Numbers in USD millions)

Funding purposes. Start-ups have discovered the opportunity to collect funds by issuing their own cryptocurrency. This process refers to an *Initial Coin Offering* (ICO) and can be compared to an *Initial Public Offering* (IPO) of a company. In an IPO a company sells its shares when it is being listed on a stock exchange for the first time (Hern, 2017). The underlying cryptocurrency is thus used similar to stocks, thereby reinforcing its use as an alternative asset class.

3.4. Definition of considered cryptocurrencies

In the following we provide a general introduction of the cryptocurrencies we investigate in our financial analysis.

3.4.1. Bitcoin

The concept of Bitcoin was introduced by the pseudonymous Satoshi Nakamoto in 2008 and launched on January 3rd, 2009 as the first decentralized virtual currency (Meiklejohn et al., 2013). Although there are many rumors and speculations about the person or group behind the pseudonym, the true identity of the inventor of Bitcoin is still unknown (Chuen, 2017).

Bitcoin is an open source project (i.e. its source code is publicly available), providing anybody with the opportunity to contribute to the development process (Bradbury, 2013). As a blockchain validation mechanism, Bitcoin relies on the Hashcash proof-of-work function[4] using the SHA-256 algorithm with an average block time of approximately 10 minutes. The coin running on the Bitcoin protocol is listed under the code *BTC* and is mineable, with a maximum supply of 21,000,000 coins (Nakamoto, 2009; Chen et al., 2016). Similar to fiat currencies, a single Bitcoin can be divided into smaller units. The smallest unit denoted in Bitcoin is one *Satoshi*, with one hundred million Satoshi equaling one Bitcoin (Margaret, 2016).

Bitcoin underwent several upgrades since its introduction. One major upgrade of Bitcoin was *Segregated Witness (SegWit)*, which was first deployed on Litecoin in May 2017 and consequently on Bitcoin in August 2017 (Holmes, 2017). The upgrade allows for faster transactions, as it solves a blockchain size limitation, and for the development of innovations based on Bitcoin's blockchain. One of those innovations is the *Lightning Network* which allows for instant payments before they are written on the blockchain (Poon and Dryja, 2015). Initially, SegWit was supposed to be launched on Bitcoin first but due to resistance by the Bitcoin community it was first deployed on Litecoin (van Wirdum, 2017).

Since its launch in 2008, Bitcoin has remained the most prominent cryptocurrency and by 2015, Bitcoin was accepted by over 100,000 merchants globally (ElBahrawy et al., 2017). In April 2017 Bitcoin also became an official method of payment in Japan, and the technology merchants require to accept Bitcoin is currently being rolled out at around 260,000 Japanese stores (Williams, 2017; Helms, 2017).

Bitcoin's source code also served as the foundation of other cryptocurrencies such as Litecoin and Namecoin. These cryptocurrencies modified Bitcoin's source code to allow for technological changes such as decreased block time and innovations such as decentralized domain name registration (Ueland, 2013).

Based on data from Coinmarketcap, as of June 9th, 2017, Bitcoin had a price of $2823.81 per coin, with a 24 hour trading volume of $1,348,950,000, a circulating supply of around 16,390,000 coins and the highest market capitalization with approximately $45,987,100,000.

3.4.2. Ethereum

In late 2013 the concept of Ethereum was first described in a white paper by Vitalik Buterin, which became more formalized in early 2014 in a paper by Gavin Wood and launched in July 2015 (Buterin, 2014). Through a presale in 2014, Ethereum was able to raise approximately $18 million worth of Bitcoin and used these funds to establish the Ethereum Foundation, a Swiss nonprofit organization responsible for developing the Ethereum software (Extance, 2015).

Ethereum is based on a blockchain similar to Bitcoin's, but instead of serving as a form of digital payment it was developed with the purpose to provide *smart contracts* and to enable developers to build and deploy decentralized applications on top of its technology. Applications executing on Ethereum's blockchain are written in its internal programming language *Solidity*[5] (Hildenbrandt et al., 2017).

As validation mechanism, Ethereum relies on the Ethash[6] hashing algorithm for its proof-of-work function with an average block time of apprixametly 0.2 minutes (Dannen, 2017; Beck et al., 2016). Similar to Bitcoin, Ethereum provides a token on its plattform called *Ether* which is listed under the code *ETH*. The token is transferable between accounts and is used to pay for *Gas*, a special unit within the Ethereum network that measures how much computational power a certain action on the network requires. Thereby, gas is used as a transaction fee to prevent spam and to compensate participant nodes for mining (Wood, 2014; Chen et al., 2016). A single unit of Ether can be divided into smaller units. The smallest unit denoted in Ether is one *Wei* and one trillion Wei equal one Ether (Ethereum Community, 2016). Different to other cryptocurrencies, Ethereum pursues an inflationary approach as its total supply is unlimited (Bouoiyour and Selmi, 2017). This allows for a wider distribution of Ether and prevents that a few early miners own the majority of coins, which is usually the case for early adopters of a cryptocurrency.

Although Ethereum was publicly established because of introducing smart contracts, it attracted media attention during a scandal in 2016, when *The DAO*, a decentralized organization developed on the platform to fund Ethereum-based projects, became subject to an attack by hackers, resulting in the loss of approximately $50million worth of Ether. The event lead to a debate about hard forking the Ethereum blockchain to recover the funds, which resulted in the split of the network into two distinct cryptocurrencies: Ethereum listed under the code ETH and Ethereum Classic, listed under the code ETC (Hildenbrandt et al., 2017; Bradbury, 2016; Chen et al., 2016).

[4] More details on proof-of-work can be found in Nakamoto's white paper (Nakamoto, 2009).

[5] More details on Solidity can be found at `solidity.readthedocs.io/en/develop/`.

[6] More details on Ethash can be found at `https://github.com/ethereum/wiki/wiki/Ethash`.

Based on data from Coinmarketcap, as of June 9th, 2017, Ethereum had a price of $281.74 per coin, with a 24 hour trading volume of $557,986,000, a circulating supply of around 85,770,000 coins and the second highest market capitalization with approximately $24,165,000,000.

3.4.3. Ripple

Ripple is an open source, distributed peer-to-peer payment system, based on the idea of Jed McCaleb and Chris Larsen and was launched in 2012 by the Ripple Labs (Chuen et al., 2017; Reutzel, 2012).

Ripple uses the *Ripple Consensus Protocol*[7], an open source, decentralized consensus protocol, which allows participants instant, secure and nearly free global financial transactions without the need of a central correspondent (Hameed and Farooq, 2016; Chen et al., 2016; Armknecht et al., 2015). Additionally, Ripple serves as a currency exchange for both cryptocurrencies and fiat currencies, and its protocol is designed to route every transaction to the best price available in the network with transactions in four seconds or less (Hayden, 2017). The coins running on the Ripple protocol are called Ripples, listed under the code *XRP*, and are transferable between accounts (Chen et al., 2016; Hameed and Farooq, 2016). The smallest unit denoted in Ripples is one *Drop* with one million Drops equaling one Ripple (Hodl the Moon, 2017). If network participants want to exchange a fiat currency pair that is not available, XRP can be used as a bridge currency between the fiat currencies. It is furthermore used to mitigate spam, as transaction fees are paid in XRP and users have to keep a minimum balance of the coin in their account in order to participate in the network.

Ripple has a restricted total supply of 100 billion coins of which 20 billion were retained by Ripple's founders, 25 billion are held by Ripple Labs and the remainder of 55 billion are steadily distributed to promote network growth (Chen et al., 2016; Hameed and Farooq, 2016).

Within the Ripple network, participants can take three different roles: (1) participants that make or receive payments; (2) market makers that enable trade between participants and (3) validators, executing the Ripple Consensus Protocol to validate transactions within the network. Although Ripple's protocol is said to be decentralized, other than it is the case for e.g. Bitcoin, its validator nodes are individually selected, hence currently not making it completely decentralized (Hameed and Farooq, 2016; Armknecht et al., 2015; Thomas, 2017).

A major application of Ripple's payment network can be found in Japan. In 2016, a consortium of 15 banks was formed with the plan to use Ripple's technology to process payments. Within few months after founding the consortium, the number of banks grew to 47 and by July 2017, a total of 61 banks were participating. These banks together represent over 80% of total assets in Japan and plan to unite all of their customers through a common mobile application for payments by the end of 2017 (Elison, 2016; Yoshikawa, 2017).

Based on data from Coinmarketcap, as of June 9th, 2017, Ripple had a price of $0.286 per coin, with a 24 hour trading volume of $102,482,000, a circulating supply of around 38,864,200,000 coins and the third highest market capitalization with approximately $11,115,900,000.

3.4.4. NEM

The concept of the cryptocurrency and blockchain platform New Economy Movement (NEM) was introduced in early 2014 through a blog post on the forum Bitcointalk by the user Utopianfuture before it was launched, after extensive testing, on March 31st in 2015 (Utopianfuture, 2014; Beikverdi, 2015).

NEM's code was entirely set up from scratch and programmed solely using Java. Similar to Ethereum, NEM does not only provide a coin on its network but serves as a platform that allows individuals to develop applications and scripts that execute on its blockchain. NEM's blockchain features its own innovative consensus mechanism, called *proof-of-importance*[8], which requires less computational power and is hence more environmentally sustainable compared to traditional consensus mechanisms. Besides its innovative consensus mechanism, NEM offers multisignature transactions, a secure and encrypted peer-to-peer messaging system and a modified EigenTrust++ reputation system[9] (NEM.io Foundation Ltd, 2015a). NEM's technological approach further differs from other cryptocurrencies as it was the first to offer a private blockchain and a public blockchain. The private blockchain differs as it consists of a network of trusted nodes, providing faster transactions (NEM.io Foundation Ltd, 2014; Chuen et al., 2017). Besides, its blockchain offers an API interface that can be used with any programming language. NEM uses its internally-developed proof-of-importance function with an average block time of approximately one minute. The coin running on the NEM protocol is listed under the code *XEM*, which is transferable between accounts, with a total supply of 8,999,999,999 coins (Chen et al., 2016). The smallest unit denoted in XEM is one *microXEM*, with one million microXEM equaling one XEM (NEM.io Foundation Ltd, 2015b). The coin is used as a fee for transactions on the public blockchain, which is dependent on the complexity of the transaction, and passed to *harvesters*. Harvesters are responsible for verifying transactions on NEM's blockchain (NEM.io Foundation Ltd, 2017).

As no mining is required for the proof-of-importance mechanism, new coins cannot be created and therefore, the

[7] More details on the consensus protocol can be found at `https://ripple.com/build/ledger-format/`.

[8] More details on proof-of-importance can be found in NEM's technical reference (NEM.io Foundation Ltd, 2015a).

[9] An algorithm that enhances security. More information can be found at `https://steemit.com/nem/@jwiz168/nem-s-node-reputation-and-network-security-using-eigentrust`.

initial distribution of XEM was done through a crowdsale on the forum Bitcointalk (Utopianfuture, 2014).

One of the most prominent applications of NEM's blockchain technology is the private blockchain *Mijin*. This blockchain can be used for a variety of solutions such as asset management, as a payment system or as a contract system. Through its approach, Mijin aims to reduce the costs of financial infrastructure to 10% of its current costs by 2018 (Tech Bureau Corporation, 2017).

Based on data from Coinmarketcap, as of June 9th, 2017, NEM had a price of $0.202 per coin, with a 24 hour trading volume of $11,840,000, a circulating supply of around 8,999,999,999 coins and the fourth highest market capitalization with approximately $1,970,650,000.

3.4.5. Litecoin

Litecoin was launched by former Google employee Charlie Lee as an open source fork of Bitcoin on October 13th in 2011. Lee decided to launch Litecoin as a copy of Bitcoin with minor changes so that future improvements of Bitcoin could be easily implemented. Litecoin was developed with the purpose to complement Bitcoin instead of challenging it and is sometimes referred to as "the silver to Bitcoin's gold" (Ogundeji, 2017).

Similar to Bitcoin, Litecoin is an open source project and its blockchain relies on the proof-of-work mechanism. However, Litecoin has a lower average block time of 2.5 minutes and it is the first cryptocurrency that uses the Scrypt[10] hashing algorithm instead of SHA-256. Lee decided to use the Scrypt algorithm as it changes the computation to be memory intensive instead of processor intensive. The main reason for this was Bitcoin's market power, which made it difficult to attract miners to switch from mining Bitcoin to mining another coin that requires the same computation, as it was the case for Namecoin. Another reason for using Scrypt was to make mining possible with computer processors instead of graphics processors, and the different computation would make the costs for setting up ASICs extremely high compared to setting them up for Bitcoin. Thereby, Lee's goal was to keep mining from being centralized and allow anyone to mine Litecoin (Iddo, 2014). However, due to the increase in mining difficulty, by now the only profitable way of mining Litecoin is through the use of ASICs (Xie, 2017). The coin running on the Litecoin protocol is called Litecoin, listed under the code *LTC*, which is transferable between accounts and has a maximum supply limited to 84,000,000 coins (Lee, 2017; Chen et al., 2016). The smallest unit denoted in Litecoin is one *Litoshi*, with one hundred million Litoshi equaling one Litecoin (Dean, 2015).

Similar to Bitcoin's token, LTC can be used as a form of payment but its acceptance is far from that of Bitcoin.

Based on data from Coinmarketcap, as of June 9th, 2017, Litecoin had a price of $29.68 per coin, with a 24 hour trading volume of $176,841,000, a circulating supply of around 52,350,000 coins and the sixth highest market capitalization with approximately $1,553,630,000.

4. Asset classes

We start this chapter by giving a general introduction to major asset classes in Section 4.1 and we continue with providing use cases of the discussed asset classes in Section 4.2.

4.1. Introduction to asset classes

There is no general definition of an asset class and the specification of asset classes highly differs in the financial world. In this work we use the definition given by Greer (1997), who defines an asset class as "... a set of assets that bear some fundamental economic similarities to each other, and that have characteristics that make them distinct from other assets that are not part of that class". We use this definition as it is currently used by the CFA Institute in their study program for becoming a Chartered Financial Analyst, a well established programm for setting a standard for excellence for investment professionals (CFA Institute, 2017). Due to a missing clear classification of asset classes, there exist numerous forms of individual classes. However, commonly used asset classes are equity, fixed income, commodities, real estate, hedge funds and private equity, and we will briefly introduce these asset classes in the following (Maginn et al., 2007; Kräussl, 2014).

4.1.1. Equity.

Equity refers to stocks that represent an investor's share of ownership in a company. Companies that go public release shares of their corporation, in the form of stocks, which individual investors can purchase. Financial returns from investing in stocks come from increases or decreases in stock prices and from dividends, which are based on a company's current and future financial performance (Wells Fargo Asset Management, 2017; UniSuper Management Pty Ltd, 2017).

4.1.2. Fixed Income.

Fixed income refers to debt instruments that represent a certain value owed by governments, government agencies, or corporations to investors. The issuer of the debt instrument usually receives a certain amount of money from the investor and pays back the initial amount including an additial payment, in the form of one or multiple coupons, at a predefined future point in time (Wells Fargo Asset Management, 2017).

4.1.3. Commodities.

Commonly referred to as commodities are metals (e.g. gold), agricultural products (e.g. livestock), and energy (e.g. oil). Investment exposure to commodities can be achieved through different investment approaches. Selected approaches are direct purchase of a commodity, purchase of stocks of a company with revenues largely determined by commodity trade, such as oil refineries, or through the purchase of financial products that are tied to commodity prices, such as commodity futures contracts (Maginn et al., 2007; Wilcox and Fabozzi, 2013).

[10]More details on Scrypt can be found at `http://www.bsdcan.org/2009/schedule/attachments/87_scrypt.pdf`.

4.1.4. Real Estate.

Investments in the real estate asset class can be directly and indirectly. Typical direct investment approaches are investments in residences, commercial real estate, and agricultural land. On the other hand, indirect investments cover approaches such as investing in a real estate fund or by investing in REITs (Maginn et al., 2007).

4.1.5. Hedge Funds.

Hedge funds are investment funds that pool capital and are actively managed by a hedge fund manager. These funds apply a variety of portfolio strategies with the aim to generate positive returns irrespective of current market developments (Wilcox and Fabozzi, 2013).

4.1.6. Private Equity.

Private equity refers to companies which raise capital to purchase ownership in non-publicly-traded companies. Private equity companies usually invest with a short-term focus, are typically highly involved in the company and have a well defined exit strategy (Maginn et al., 2007).

Asset classes can be categorized into endless sub-classes based on different characteristics such as industry, geography or size. In order to specify an asset class appropriately, the following characteristics should be met: Assets within the same asset class should be relatively homogeneous and they should not be considered to be part of two different asset classes at the same time. Different asset classes should also not be highly correlated and the asset classes should be large enough to matter so that the combined asset classes make up a majority of world investable wealth. Finally, assets within the asset class should have a certain level of liquidity so that, if part of an investor's portfolio, they do not seriously threaten the portfolio's liquidity (Maginn et al., 2007).

4.2. Use of asset classes

Individuals and investors can use asset classes for a variety of purposes. Common uses of asset classes are for asset allocation decisions, performance measurement and for investment product development (Maginn et al., 2007; Bodie et al., 2010; Australian Securities and Investments Commission, 2012; Svetina and Wahal, 2008).

For market asset allocation decisions, investors can adopt active- or passive management decisions.

For active management, an investor takes into account the performance of an asset class as a whole but invests in selected components of the asset class. Thereby, the components of the asset class invested in can either be single components such as a single stock of a company or aggregate components within an asset class, such as an index following a certain industry. Furthermore, investors can use this approach to invest in single components across different asset classes. This enables the investor to receive a general picture about the asset classes under consideration but offers the possibility to exclude certain components of the asset class. However, investigating different components of an asset class and executing multiple orders involves high cost due to the time required for gathering information and for fees paid per transaction.

In the case of passive management, an investor purchases an index fund or exchange traded fund representing the asset class as a whole. This approach enables the investor to receive a general picture about the asset class under consideration and offers the possibility to invest in the asset class as a whole, leaving the investor with more diversification than if components were excluded (Fraser-Sampson, 2011; Greer, 1997; Maginn et al., 2007).

Asset classes are oftentimes also used as benchmarks to evaluate an investor's performance. In this case, investors compare the performance of their investment with the performance of a relevant asset class to gain insights about one's individual performance compared to the overall market's performance. Benchmarks can either comprise the whole asset class or sub-classes of the asset class, dependent on the comparability with the investor's portfolio composition (Maginn et al., 2007).

Another use of asset classes is in the development of investment products. In this case, investment professionals tie the performance of an asset class to a financial product. Common cases are CFDs based on the performance of an index or exchange traded funds that comprise the same components as an index in order to reproduce returns of a specific asset class (Australian Securities and Investments Commission, 2012; Svetina and Wahal, 2008).

5. Methodology

In this chapter we start by illustrating how and what data was collected in Section 5.1 and continue with presenting the approach we follow in our financial analysis in Section 5.2.

5.1. Data collection

In order to shed light on the characteristics and financial performance of cryptocurrencies, we collect data from August 10th, 2015 until June 9th, 2017 of five cryptocurrencies and six asset classes. We chose different cryptocurrencies primarily based on their market capitalization and secondarily based on their emergence. The time period was chosen based on the starting date of conducting this work and on the ability to access qualified data.

The cryptocurrencies in scope are Bitcoin, Ethereum, Ripple, NEM, and Litecoin and as asset classes we select fixed income, commodities, real estate, hedge funds and private equity.

As this work is aimed to represent the view of a U.S. investor and to control for changes in exchange rates, all exported data are denoted in U.S. dollars and all calculations are performed using U.S. dollar values.

In order to start this research, daily closing prices, trading volumes and market capitalizations for cryptocurrencies and daily closing prices for asset classes are required. Data for cryptocurrencies were extracted from Coinmarketcap and data for asset classes, in the form of indices, were accessed through Bloomberg terminals, or directly exported from the website of the entity responsible for the index.

Cryptocurrencies

According to Coinmarketcap, as of June 9th, 2017 the six largest cryptocurrencies by market capitalization are Bitcoin (BTC), Ethereum (ETH), Ripple (XRP), NEM (XEM), Ethereum Classic (ETC) and Litecoin (LTC), respectively. Together, these six cryptocurrencies amount to 84.92% of the total cryptocurrency market capitalization (CoinMarketCap, 2017). As described in Section 3.4.2, Ethereum Classic emerged as a continuation of the original Ethereum blockchain after splitting the network in two in 2016, and therefore we exclude it from our analysis. As a result, the remaining five cryptocurrencies in scope amount to 83.35% of the total cryptocurrency market capitalization (CoinMarketCap, 2017).

Due to the relevance of Coinmarketcap as a source of information, in the following we describe the basics of Coinmarketcap's approach to gather and provide information.

Coinmarketcap does not act as an exchange for cryptocurrencies, but solely collects and merges data from different exchanges and provides those metrics on their website. Besides a vast variety of information on cryptocurrencies, the most relevant metrics provided on Coinmarketcap are average price, market capitalization and circulating supply for a variety of cryptocurrencies.

As of August 8th, 2017, Coinmarketcap accesses information from a total of 4,927 markets on which cryptocurrencies are traded. However, only markets are considered which incorporate trading fees. Reason for this is that without trading fees, it is possible to trade the same currency back and forth with multiple accounts, manipulating a cryptocurrency's trading volume, and thereby distorting the mechanism used for price determination.

For prices, Coinmarketcap uses the average price weighted by trading volume reported at each of the markets in scope. This method is known as the *Volume Weighted Average Price*, which can be expressed mathematically as seen in Equation 1.

$$VWAP_i = \frac{\sum_{i=1} P_i \times Q_i}{\sum_{i=1} Q_i} \tag{1}$$

where

$VWAP_i$ = Volume Weighted Average Price of cryptocurrency i,
P_i = Price at exchange i,
Q_i = Quantity traded at exchange i.

The market capitalization for each cryptocurrency is calculated by the sum of the cryptocurrency's price and its supply as seen in Equation 2. The approach uses the circulating supply to calculate market capitalizations, which is similar to the approach of calculating the market capitalization of companies listed on a stock exchange.

$$MC_i = P_i \times CS_i \tag{2}$$

where

MC_i = Market Capitalization of cryptocurrency i,
P_i = Price of cryptocurrency i,
CS_i = Circulating Supply of cryptocurrency i.

For approximating the number of coins that are in public hand or circulating in the market, Coinmarketcap uses the circulating supply instead of the total supply. The difference between total supply and circulating supply is that total supply takes into account coins which cannot be sold to the public as they are e.g. locked or reserved (CoinMarketCap, 2017). The circulating supply for each cryptocurrency is obtained from the exchange listing the cryptocurrency.

Asset classes

We aim to provide a comparison of the financial performance and characteristics of cryptocurrencies and traditional asset classes. To do so, we use the asset classes equity, fixed income, commodities, real estate, hedge funds and private equity as described in Section 4.1. As asset classes consist of numerous single assets, we select indices, either combined with other indices or independently, based on their ability to approximately represent the asset class as a whole. Table 1 shows the indices we use for composing each asset class and we briefly describe each index in the following.

5.1.1. MSCI US Broad Market Index.

The index aims to capture the performance of U.S. equity by tracking approximately 99% of the total U.S. equity (MSCI Inc., 2017a).

5.1.2. MSCI EAFE Index.

The index aims to capture the performance of large and mid cap equity across developed markets countries around the world, excluding the U.S. and Canada (MSCI Inc., 2017b).

5.1.3. MSCI Emerging Markets Index.

The index aims to capture the performance of large and mid cap equity across 24 emerging markets countries (MSCI Inc., 2017c).

5.1.4. Barclays Capital US Aggregate Bond Index.

The index aims to capture most U.S. traded bonds and some foreign bonds traded in the United States (Thune, 2016).

Table 1: Asset class compositions

Index Name	Asset Class
MSCI US Broad Market Index	Equity
MSCI EAFE Index	Equity
MSCI Emerging Markets Index	Equity
Barclays Capital U.S. Aggregate Bond Index	Fixed Income
Barclays Capital Global Aggregate ex U.S. Bond Index	Fixed Income
Barclays Capital High Yield Bond Index	Fixed Income
Bloomberg Commodity Index	Commodity
S&P Global REIT	Real Estate
HFRX Global Hedge Fund Index	Hedge Funds
LPX50 Index	Private Equity

5.1.5. Barclays Capital Global Aggregate ex U.S. Bond Index.

The index aims to capture the performance of the global bond market, excluding U.S. securities (T. Rowe Price Investment Services Inc., 2017).

5.1.6. Barclays Capital High Yield Bond Index.

The index aims to capture the performance of the global high yield bond market (Bloomberg L.P., 2017a).

5.1.7. Bloomberg Commodity Index.

The index, formerly known as the Dow Jones-AIG Commodity Index, is composed of futures contracts and physical commodities and aims to capture the development of global commodity prices (Bloomberg L.P., 2017b).

5.1.8. S&P Global REIT.

The index aims to capture the performance of global real estate investment by tracking the performance of global, publicly traded equity of real estate investment trusts (S&P Dow Jones Indices LLC, 2017).

5.1.9. HFRX Global Hedge Fund Index.

The index aims to capture the performance of the global hedge fund universe (Hedge Fund Research, Inc., 2017).

5.1.10. LPX50 Index.

The index aims to capture the performance of the global private equity industry by covering the 50 largest listed private equity companies (LPX AG, 2017).

For all indices, we extracted relevant data using Bloomberg terminals except for the HFRX Global Hedge Fund Index, for which data was directly extracted from the website of HFR[11], the company responsible for building the index.

[11] Data extracted from www.hedgefundresearch.com.

5.2. Data analysis

For our analysis, we compare return characteristics of cryptocurrencies and asset classes. To do so on an individual as well as on an aggregate basis, we compare portfolios of cryptocurrencies and individual cryptocurrencies with the six asset classes in scope. We therefore start this section with general assumptions for our analyses, followed by explaining our approach to set up different portfolios. We subsequently explain the methods we use and state the implications for using these methods.

Approach

Cryptocurrencies can be traded at all times, while trading of assets is usually limited to weekdays. In order to control for this difference in the amount of trading days, we calculate daily price returns of cryptocurrencies and asset classes based on weekdays and disregard the price development of cryptocurrencies on weekends.

For simplicity, in line with prior work on cryptocurrencies (Wang and Vergne, 2017; Eisl et al., 2015; Chuen et al., 2017; Elendner et al., 2016), we make several other assumptions: For all calculations we assume that the investor is not subject to trading fees, bid-ask spreads are non-existent, coins can be divided indefinitely and that enough liquidity exists in the market to execute each trade immediately. Besides, as commonly applied in mathematical finance, we assume that log returns of prices of cryptocurrencies and asset classes follow a normal distribution (Mota, 2012; Penza and Bansal, 2001).

5.2.1. Portfolios

In order to compare cryptocurrencies on an individual as well as on an aggregate level, we form three hypothetical portfolios reflecting different investment approaches. We construct an equally weighted portfolio (PF1), a monthly rebalanced, market value weighted portfolio (PF2) and a portfolio with medium Bitcoin focus (PF3). Each of the three portfolios consist of the five cryptocurrencies in scope. Table 2 shows the relative portfolio share per cryptocurrency, as the proportion of its value within the portfolio compared to the total portfolio value.

Table 2: Portfolio compositions

	BTC	ETH	XRP	XEM	LTC
PF1	20%	20%	20%	20%	20%
PF2	88.74%	1.00%	6.49%	0.03%	3.74%
PF3	40%	15%	15%	15%	15%

Portfolio compositions as of 10/08/2017. Note, that the composition is fixed at time of setting up the portfolio. Changes in prices result in a different composition over time.

The first portfolio (PF1) is an equally weighted portfolio with portfolio weights fixed at the time of purchase. Therefore, each cryptocurrency is represented with 20% value of the total portfolio value at the time of setting up the portfolio. Note, that the percental shares are only fixed at the time of purchase, as different price changes within time among the cryptocurrencies result in changes of the respective percental shares within the portfolio.

The second portfolio (PF2) is a market value weighted portfolio which is rebalanced every month. This means, that the relative share of the value of each cryptocurrency within the portfolio equals the relative market share of each cryptocurrency, given the market only consists of the cryptocurrencies in scope. We follow Equation 3 for the initial composition of the portfolio as well as for rebalancing it. As for the other analyses in this work, we set up the portfolio on August 10th, 2015. Therefore, the portfolio is rebalanced every 10th day of each month following August 2015 until June 9th, 2017 and hence, the portfolio is rebalanced a total of 21 times.

At the time of rebalancing, the relative market capitalization of each cryptocurrency is calculated in order to find a new portfolio target composition. By knowing the new target composition, the current prices for each cryptocurrency and the total value of the portfolio, it is possible to acquire and sell cryptocurrencies until the new target ratio is reached, while considering the capital constraint of the portfolio value at time of rebalancing. The capital constraint refers to the condition that the investor cannot invest more than his current portfolio value. By rebalancing the portfolio, we monthly align its composition according to the relative market capitalization of each cryptocurrency.

$$PFW_{it} = \frac{MC_{it}}{\sum_{i=1} MC_{it}} \tag{3}$$

where

PFW_{it} = Portfolio weight of cryptocurrency i at time t,
MC_{it} = Market capitalization of cryptocurrency i at time t.

For the third portfolio (PF3) we assume that 40% of the portfolio value is invested in Bitcoin, and the other 60% are split equally among the remaining four cryptocurrencies. We decide on this composition as we want to investigate the behavior of a hypothetical portfolio that does not invest equally in all cryptocurrencies (PF1) and that does not put a majority stake in Bitcoin at the time of set up (PF2). We are interested in a portfolio with a Bitcoin share of less then 50% and a majority focus on other cryptocurrencies than Bitcoin, while still having a large share invested in Bitcoin. As in PF1, the percental shares per cryptocurrency are only fixed at the time of setting up the portfolio and the percental composition can be influenced directly by price changes of the cryptocurrencies in the portfolio.

5.2.2. Remark.

The reason for setting up three different portfolios is to take into account different investment behaviors. It is important to note that some cryptocurrencies were launched close to the beginning of our investment period and can be considered to having had a "start-up-character" at the time of setting up the different portfolios. Therefore, the first portfolio provides a risky approach by investing the same amount in all cryptocurrencies. The second approach represents a more risk-averse behavior as the investment is based on each cryptocurrency's market share and each month the portfolio is rebalanced. Thereby, established cryptocurrencies are given a higher portfolio weight, hence neglecting the risk of investing large amounts in "less-established" cryptocurrencies. The third portfolio represents a medium risk-seeking behavior, as the investor focuses on a Bitcoin investment of 40%, the most established cryptocurrency, and equally invests the other 60% in the remaining four cryptocurrencies. Note, that our measure of risk for setting up the portfolios is solely based on how established, based on market capitalization, a cryptocurrency is in the market.

5.2.3. Methods

We follow selected methods of the approaches by Chuen et al. (2017), Elendner et al. (2016), Eisl et al. (2015) and Osterrieder et al. (2017) and calculate risk- and performance measures based on daily arithmetic returns as well as on daily log returns. To allow for comparison between the cryptocurrencies and asset classes in scope we control for differences in available data over the same time period.

Daily price returns for cryptocurrencies and asset classes are calculated similarly, as the percental price change in daily closing prices, as seen in Equation 4.

$$r_{\alpha i} = \left(\frac{P_{it+1} - P_{it}}{P_{it}}\right) * 100 \tag{4}$$

where

$r_{\alpha i}$ = Percental return of cryptocurrency/index i at time $t+1$,
P_{it} = Price of cryptocurrency/index i at time t.

In line with research by Eisl et al. (2015), we continue with the calculation of descriptive statistics, providing daily volatility, mean, different percentiles and percentage of negative returns for each cryptocurreny and asset class. We measure volatility as the standard deviation of daily returns following Equation 5.

$$\sigma_i = \sqrt{\frac{1}{N_i - 1}\sum_{i=1}^{N}(r_i - \overline{r_i})^2} \tag{5}$$

where

σ_i = Standard deviation of cryptocurrency/index i,
r_i = Return of cryptocurrency/index i,
$\overline{r_i}$ = Mean return of cryptocurrency/index i,
N_i = Number of observations of cryptocurrency/index i.

We then calculate log returns applying Equation 6. The reason for calculating log returns is that methods such as the Sharpe ratio require normally distributed data and one of the assumptions of log returns is that they follow a normal distribution (Mota, 2012; Penza and Bansal, 2001; Bodie et al., 2010).

$$r_{\lambda i} = \ln\left(\frac{P_{it+1}}{P_{it}}\right) \tag{6}$$

where

$r_{\lambda i}$ = Log return of cryptocurrency/index i at time $t+1$,
P_{it} = Price of cryptocurrency/index i at time t.

We need to adapt our data in order to calculate log returns for the asset classes equity and fixed income. These asset classes consist of multiple indices and we decided to give each index an equal weight and calculate the regular return of the asset classes as the equally weighted return of the underlying indices as categorized in Table 1. As equally weighting multiple log returns does not yield correct results, we use regular daily returns to calculate the daily development for a hypothetical investment. Thereby we are able to see how a hypothetical investment in a complete asset class behaves and we can use the development to calculate daily log returns for the respective asset classes using Equation 6.

To investigate the respective investment's risk profiles and their performance relative to their risk, we calculate measures such as value-at-risk, historical expected shortfall, Sharpe ratios and information ratios for each cryptocurrency and asset class. We calculate these measures according to Bodie et al. (2010) and take into account that this requires interpolation due to numbers not always being integers at the 1% and 5% level.

The value-at-risk framework is a downside measure that provides insights about the incurred loss given a certain probability. In line with research by Osterrieder et al. (2017), we calculate value-at-risk both at the 5% as well as on the 1% probability level following Equation 7. Therefore, calculating value-at-risk yields the highest return out of the 5% respectively 1% worst case scenarios (Maginn et al., 2007; Bodie et al., 2010).

$$VaR_{i\alpha} = \mu_i - z * \sigma_i \tag{7}$$

where

$VaR_{i\alpha}$ = Value-at-Risk of cryptocurrency/index i at probability level α,
μ_i = Mean return of cryptocurrency/index i,
z = Z-score according to normal distribution of 1.65 at 5%- and 2.33 at 1% probability level,
σ_i = Standard deviation of cryptocurrency/index i.

Another measure of downside risk is the expected shortfall. The measure is closely related to the value-at-risk framework but instead of focusing on one number, the expected shortfall measures the average loss given that we are in the 5% respectively 1% worst case scenarios. In line with research by Osterrieder et al. (2017) we calculate the historical expected shortfall as the mean of all losses that respectively exceed the 1% and 5% worst historical returns according to (Bodie et al., 2010).

In line with the approach by Chuen et al. (2017), we continue with calculating the Sharpe ratio, a commonly used risk measure that provides a ratio of an investment's risk premium relative to the investment's standard deviation (Bodie et al., 2010). Thus, it standardizes each unit of return per unit of risk, and thereby enables comparison among investments. The higher an investment's Sharpe ratio the better and vice versa (Burniske and White, 2017). The Sharpe ratio is calculated according to Equation 8. In line with prior research, we calculate the daily log risk-free rate to be 0.0015% as the average of the three month treasury-bill rate over the relevant period from August 2015 until June 2017, transformed to a daily log interest rate (Baur et al., 2015).

$$\textit{Sharpe Ratio} = \frac{\mu_i - rf}{\sigma_i} \tag{8}$$

where

μ_i = Mean return of cryptocurrency/index i,

rf = Risk-free rate,
σ_i = Standard deviation of cryptocurrency/index i.

A further measure to compare risk-adjusted returns is the information ratio (Chuen et al., 2017). The information ratio measures the excess return of an investment per unit of risk and is calculated following Equation 9 (Bodie et al., 2010). The information ratio requires the benchmark to have a lower average return compared to the investment in scope. It is common to use stock indices as benchmarks but the high average return of both equity and international equity made them unfavorable. Therefore, we decided to use the sub-class international equity as our benchmark.

$$Information\ Ratio = \frac{\mu_i - \mu_b}{S_{i-b}} \tag{9}$$

where

μ_i = Mean return of cryptocurrency/index i,
μ_b = Mean return of benchmark,
S_{i-b} = Tracking Error: Standard deviation of the difference between returns of cryptocurrency/index i and benchmark.

In order to shed light on the ability of cryptocurrencies to improve portfolio diversification, we continue with calculating correlations between log returns of cryptocurrencies and asset classes. In line with research by Osterrieder et al. (2017) and Chuen et al. (2017), we calculate Pearson correlations following Equation 10. We calculate correlations between the individual cryptocurrencies and correlations between cryptocurrencies and asset classes including correlations between the single components within each asset class. For all calculations missing values were pairwise omitted.

$$Corr_{xy} = \frac{cov(x,y)}{\sigma_x * \sigma_y} \tag{10}$$

where

$Corr_{xy}$ = Correlation coefficient between cryptocurrency/index x and cryptocurrency/index y,
$cov(x,y)$ = Covariance between cryptocurrency/index x and cryptocurrency/index y,
σ_x = Standard deviation of cryptocurrency/index x,
σ_y = Standard deviation of cryptocurrency/index y,

with

$$Cov(x,y) = \frac{\sum(r_x - \mu_x) * (r_y - \mu_y)}{\sqrt{\sum(r_x - \mu_x)^2 * \sum(r_y - \mu_y)^2}}$$

where

$Cov(x,y)$ = Covariance between cryptocurrency/index x and cryptocurrency/index y,
r_x = Return of cryptocurrency/index x,
r_y = Return of cryptocurrency/index y,
μ_x = Mean return of cryptocurrency/index x,
μ_y = Mean return of cryptocurrency/index y.

5.2.4. Rationale.

We selected these methods based on approaches of prior research on cryptocurrencies. We believe that they are useful for providing us with information regarding the return characteristics of cryptocurrencies and asset classes, and enable us to draw a conclusion on cryptocurrencies' potential to improve portfolio diversification.

6. Findings

We start this chapter with providing our findings regarding the risk-reward profile of cryptocurrencies and asset classes in Section 6.1 and continue with a correlation analysis in Section 6.2. We finish this chapter with presenting potential limitations and arguments against these limitations in Section 6.3.

6.1. Risk-reward profile

Table 3 displays descriptive statistics of daily returns of cryptocurrencies and asset classes. In line with research by Chuen et al. (2017), Eisl et al. (2015) and Elendner et al. (2016) we found larger returns but also a remarkably higher dispersion of returns for cryptocurrencies compared to those of the asset classes in scope. Especially comparing the mean returns in Table 3 shows the large difference of returns that were generated by cryptocurrencies compared to those by traditional asset classes.

The first unexpected finding is that for all cryptocurrencies under investigation, except for Ripple, we found both a positive median and mean. This implies, as can be inferred from the row "Neg" in Table 3, that most returns were of positive nature. This challenges findings by Elendner et al. (2016) which found more negative than positive returns. However, this might be due to their focus on a different time period.

We furthermore found, that for all cryptocurrencies the upper decile is of higher magnitude than the lower decile and also that, except for Ripple, the upper quartile is of higher magnitude than the lower quartile. In line with research by Elendner et al. (2016), these findings imply that positive returns of cryptocurrencies are of higher magnitude than negative returns.

Comparing the different portfolios, we found that return characteristics highly differ. While PF1 and PF3 show similar characteristics concerning negative returns as well as for deciles and quartiles, PF2 shows quite different results. Although PF2 generated lower mean returns compared to the other two portfolios, we see that its median is relatively closer to that of the other portfolios and that values for the lower quartile are remarkably lower. This difference in mean return is likely to be explained by returns of large magnitude by cryptocurrencies with larger weights in PF1 and PF3 than in PF2.

It is also interesting to note that PF2 exhibited the lowest percentage of negative returns among the portfolios with only 31.73%. This implies that there was a positive effect on the amount of positive returns when rebalancing a portfolio based on the market capitalization of its components. This can be explained by the mechanism used for rebalancing. When rebalancing, the weight of a cryptocurrency is increased if its relative market capitalization has increased. The relative market capitalization of any cryptocurrency only increases if its absolute market capitalization increases faster than the average absolute market capitalization of the other cryptocurrencies in the "market"[12]. Put simple, rebalancing based on relative market share results in increasing the weight of a cryptocurrency that has had a better performance compared to its peers.

When looking at asset classes, we found quite different results. For all asset classes except commodities the median and mean are positive and positive returns occurred more frequently than negative returns. However, compared to cryptocurrencies, the magnitude of daily returns is far lower. We further found that the magnitude of the upper and lower decile are quite similar and that three asset classes show a higher magnitude for the upper than for the lower decile. For the remaining three asset classes, however, the lower deciles are of larger or equal magnitude. It is interesting that for all asset classes the upper quartile is of larger magnitude than the lower one. This is quite different compared to our results for the respective deciles as both quartiles and deciles measure return behavior for extreme events.

Table 4 shows multiple risk- and performance measures of cryptocurrencies and asset classes. We found large differences in terms of volatility, skewness and excess kurtosis. Cryptocurrencies show high levels of volatility compared to asset classes. This is especially the case for NEM with a daily volatility of over 11%. For Bitcoin, as the most established cryptocurrency, we found relatively low volatility compared to other cryptocurrencies in scope. This might be due to its relatively long existence compared to cryptocurrencies such as NEM. This argument is reinforced when looking at Litecoin, the second oldest cryptocurrency in scope, for which we also found a relatively low volatility compared to the remaining cryptocurrencies.

In addition to high levels of volatility, all cryptocurrencies and cryptocurrency portfolios except Bitcoin and PF2 are positively skewed while for asset classes only commodities are positively skewed. Positive skew implies that the right tail of the probability density function of the log returns of an investment is longer and fatter than the left tail. This provides information about the downside risk of the investment, as positive skew implies that negative outcomes occur less frequently and extreme negative returns are not as likely and vice versa.

[12] In our case the market consists of the five cryptocurrencies in scope.

We also found positive excess kurtoses for all cryptocurrencies including cryptocurrency portfolios and asset classes. The excess kurtosis provides information regarding the historical return distribution. A normal distribution has a kurtosis of 3 and hence the excess kurtosis provides a measure of how the distribution of the data in scope differs from a normal distribution. A positive excess kurtosis refers to a leptokurtic distribution which is more peaked and has longer and fatter tails than a normal distribution. Thus, large returns occur more frequent and are potentially larger in magnitude compared to those of a normal distribution, which is in line with findings by Osterrieder et al. (2017) and Eisl et al. (2015). However, these results deviate from findings by Elendner et al. (2016) and Chuen et al. (2017), which respectively found negatively skewed returns for Litecoin and Ethereum and for Litecoin only.

The risk measures we calculated provide clear insights about the respective risk profiles. Comparing value-at-risk and expected shortfall at both the 1% and 5% level yields large differences for cryptocurrencies and asset classes. Remarkably are the high expected shortfall values for Ethereum and NEM. The magnitude of measures of both value-at-risk and expected shortfall are in line with findings by Osterrieder et al. (2017) but are generally smaller than those of Elendner et al. (2016). Recall that value-at-risk and expected shortfall can be interpreted as percentage losses that occur on a single day and thus these differences show the high risk profile of investments in cryptocurrencies compared to investments in asset classes.

To measure risk-adjusted returns, we calculated Sharpe ratios for all cryptocurrencies and asset classes. We found high Sharpe ratios for all cryptocurrencies and cryptocurrency portfolios we investigate. It is interesting to note that although Ethereum's returns are highly volatile with high levels of value-at-risk and expected shortfall, it yields the highest Sharpe ratio among the individual cryptocurrencies. This implies that Ethereum generated higher daily excess returns relative to its volatility compared to the remaining cryptocurrencies we investigate. We further found, except for fixed income, low Sharpe ratios for equity, commodities, hedge funds and private equity, and a negative Sharpe ratio for real estate, which did not generate mean excess return. Surprisingly, we found an equal Sharpe ratio for fixed income and for Litecoin, which can be explained by the low volatility of fixed income investments. According to the calculated Sharpe ratios, an investor should clearly favor investments in cryptocurrencies over investments in traditional asset classes.

The information ratio provides another measure to compare returns relative to their level of risk. We found high information ratios for cryptocurrencies, with Ethereum providing the largest with 0.137. For Litecoin we found the lowest information ratio among cryptocurrencies, which is not surprising given its low mean return. Surprisingly, the information ratios for asset classes are very low compared to our results for cryptocurrencies. Equity has the highest information ratio among asset classes with 0.054, which is even significantly lower than Litecoin's information ratio. The in-

Table 3: Descriptive statistics of daily returns for cryptocurrencies and asset classes

Crypto	Max	D90	Q75	Median	Mean	Q25	D10	Min	SD	Neg	N
PF 1	29.73	5.44	2.75	0.73	1.16	-0.81	-2.86	-14.52	4.34	37.16	479
PF 2	15.23	3.99	1.76	0.53	0.64	-0.26	-2.00	-17.02	3.35	31.73	479
PF 3	24.15	4.87	2.47	0.66	1.01	-0.62	-2.19	-15.03	3.79	36.33	479
BTC	15.90	3.73	1.60	0.52	0.55	-0.29	-2.51	-17.91	3.43	30.69	479
ETH	57.10	11.07	4.20	0.74	1.62	-1.93	-6.42	-32.00	8.69	40.29	479
XRP	110.34	4.97	1.31	-0.04	1.00	-1.45	-3.78	-18.67	8.33	51.15	479
XEM	98.36	11.46	4.53	0.82	2.06	-2.90	-8.02	-22.75	10.97	43.01	479
LTC	40.96	4.17	1.36	0.26	0.57	-0.64	-3.32	-21.86	5.53	36.74	479
Assets	Max	Q90	Q75	Median	Mean	Q25	Q10	Min	SD	Neg	N
EQT	2.87	0.92	0.47	0.03	0.03	-0.33	-0.88	-4.77	0.80	47.60	479
FI	1.26	0.31	0.16	0.02	0.02	-0.13	-0.25	-1.25	0.26	45.26	475
CMT	3.09	1.17	0.57	-0.02	0.03	-0.54	-1.07	-2.56	0.92	50.68	444
REIT	2.77	1.12	0.60	0.08	0.00	-0.55	-1.28	-4.69	1.00	46.28	443
HF	0.76	0.25	0.14	0.02	0.00	-0.10	-0.25	-1.13	0.22	47.07	444
PE	3.09	1.05	0.59	0.06	0.03	-0.39	-1.07	-5.97	1.01	45.51	479

Descriptive statistics of daily returns (in percent) of the five cryptocurrencies and six asset classes in scope over the time period 08/10/2015 until 06/09/2017. EQT refers to Equity, FI refers to Fixed Income, CMT refers to Commodities, REIT refers to Real Estate, HF refers to Hedge Funds and PE refers to Private Equity.

Table 4: Risk- and performance measures of cryptocurrencies and asset classes

Crypto	Mean (%)	SD	Skew	Kurt	VaR 1%	ES 1%	VaR 5%	ES 5%	SR	IR
PF 1	1.065	0.042	0.972	6.470	0.087	0.118	0.058	0.096	0.254	0.248
PF 2	0.581	0.034	-0.938	7.235	0.073	0.143	0.050	0.112	0.172	0.167
PF 3	0.934	0.037	0.431	5.971	0.077	0.119	0.052	0.098	0.251	0.244
BTC	0.494	0.037	-0.570	6.252	0.081	0.148	0.056	0.118	0.133	0.130
ETH	1.250	0.090	0.960	5.608	0.198	0.258	0.136	0.221	0.138	0.137
XRP	0.728	0.077	3.698	25.388	0.172	0.145	0.119	0.118	0.095	0.094
XEM	1.540	0.115	2.243	14.044	0.253	0.205	0.175	0.177	0.134	0.133
LTC	0.421	0.057	2.261	17.852	0.130	0.171	0.091	0.141	0.073	0.072
Assets	Mean (%)	SD	Skew	Kurt	VaR 1%	ES 1%	VaR 5%	ES 5%	SR	IR
EQT	0.023	0.008	-0.818	5.014	0.018	0.033	0.013	0.026	0.027	0.054
FI	0.021	0.003	-0.416	4.316	0.006	0.009	0.004	0.008	0.073	0.022
CMT	0.029	0.009	0.203	0.380	0.021	0.023	0.015	0.021	0.030	0.028
REIT	-0.002	0.010	-0.577	1.717	0.023	0.036	0.017	0.029	-0.004	-0.003
HF	0.002	0.002	-0.865	3.331	0.005	0.009	0.004	0.007	0.003	0.001
PE	0.029	0.010	-1.247	6.557	0.023	0.047	0.016	0.035	0.027	0.040

Risk- and performance measures, including value-at-risk, Sharpe ratio and information ratio for daily log returns and expected shortfall for daily returns of the cryptocurrency portfolios, individual cryptocurrencies and asset classes over the time period 08/10/2015 until 06/09/2017. EQT refers to Equity, FI refers to Fixed Income, CMT refers to Commodities, REIT refers to Real Estate, HF refers to Hedge Funds and PE refers to Private Equity.

formation ratio of real estate returns cannot be interpreted as the asset class did not generate positive daily mean returns. Based on our results, we can conclude that investments in cryptocurrencies yield much better risk-adjusted returns than investments in traditional asset classes, reinforcing our implications from the calculated Sharpe ratios. However, comparing our results with those by Chuen et al. (2017) highlights large deviations, as they found remarkably lower values for Sharpe- and information ratios.

6.2. Correlation analysis

Table 5 presents correlation coefficients between the cryptocurrencies in scope. The correlation coefficient measures the linear relationship between two variables and thus provides insights on how the returns historically behaved. Out of the total of ten correlations we calculated, we found eight to be significant at the 5% level. In line with findings by Osterrieder et al. (2017), all correlations between cryptocurrencies are of positive nature. A potential explanation for this result could be that individuals start to invest in cryptocurrencies in times of positive market movement as it was the case in the dotcom bubble in the late 1990s (Scherbina, 2013). This increase in demand usually results in positive price movements and hence implies positive returns for investors.

We found the strongest relationship between the returns of Bitcoin and Litecoin with a correlation of 0.53. This result is not surprising, taking into account that Litecoin emerged as a clone of Bitcoin with only minor changes. Our results further show that Bitcoin and Litecoin are both positively correlated with all cryptocurrencies in scope. This can potentially be explained by individuals to invest in times of positive movement of Bitcoin and Litecoin as they are the oldest cryptocurrencies under investigation. It is also interesting, that Ripple's returns show significant correlations with three out of the four correlations we investigate. This might be due to Ripple's use as an exchange for transferring cryptocurrencies. Hence, its importance could be correlated to the overall acceptance of cryptocurrencies.

According to Markowitz's Modern Portfolio Theory (Markowitz, 1952), individual investments within a portfolio have a diversifying effect if the investments provide a low correlation. Therefore, similar to findings by Osterrieder et al. (2017), we can conclude that when considering to invest in cryptocurrencies, at least for the cryptocurrencies we investigate in this work, combining different cryptocurrencies in a portfolio provides beneficial diversification effects. This can also be derived from our findings in Section 6.1 when looking at the results presented in Table 3 and Table 4. Comparing our findings regarding individual cryptocurrencies and the portfolios we set up, we can see that we found far larger risk-adjusted returns for our portfolios than for individual cryptocurrencies. Thereby, we can also conclude that the cryptocurrencies in scope provide a diversifying effect when combined in a portfolio.

Table 6 displays correlations between the five cryptocurrencies and six asset classes in scope including their individual components. We found significant negative correlations between the returns of Ethereum and international equity, represented by the EAFE Index, as well as between Ethereum and private equity returns. Therefore, we can conclude that for investments in international equity and private equity, including Ethereum in a portfolio provides the possibility to generate higher returns under the same level of risk compared to not including Ethereum (Fraser-Sampson, 2011; Credit Suisse Group AG, 2014). Furthermore, the negative correlations of international equity and private equity with Ethereum imply that these investments can be used as hedge assets. This allows to invest in international equity or private equity in order to hedge the risk of holding Ethereum, irrespecitve of Ethereum's intendet use (Bodie et al., 2010).

However, we could not find statistically significant results at the 5% level for the remaining correlations. This means that the respective returns of the variables are statistically independent and thus, we cannot confirm prior research which found that including these cryptocurrencies in a portfolio does improve portfolio diversification.

Although we did not find more than two significant correlations between the returns of cryptocurrencies and asset classes, we can say that adding cryptocurrencies to a portfolio does have a positive impact on the overall risk of a portfolio. This is due to the decreased exposure to systematic risk when adding an additional asset class to a portfolio (Fraser-Sampson, 2011).

6.3. Limitations

Our analysis is subject to several limitations that could potentially influence our results. Our main limitation is that we relied on Coinmarketcap as our primary source for data on cryptocurrencies. This implies that we need to trust Coinmarketcap's mechanisms in charge for calculating the data we extracted. We were not able to prove the validity of all mechanisms that Coinmarketcap uses due to missing access to exchanges and as this would be too time consuming. We therefore have to assume that data from Coinmarketcap is valid. This assumption is reinforced by the prominence of Coinmarketcap in the cryptocurrency community.

As explained in Section 5.1, Coinmarketcap does not act as an exchange but calculates prices from other exchanges. Therefore, the prices we used for our analyses are volume weighted average prices and not prices from a specific exchange. This implies that research that is based on data from other providers of cryptocurrency metrics or based on data from specific exchanges can differ from our findings due to the different mechanisms used for calculating the cryptocurrency metrics. However, the volume weighted average price measures the average prices paid on a variety of exchanges according to the cryptocurrency's trading volume on the respective exchange. We believe that this provides a better approximation of general market prices than solely relying on data from a single exchange.

We further made several assumptions in our methodology that are not accurate when considering actual investments in cryptocurrencies.

First, we assumed that trading is not subject to fees, which is not the case as fees have to be paid on the network per transaction and some exchanges require trading fees as well. However, these fees are considerably low and hence we neglected them.

Second, we assumed that no bid-ask spreads exists. This refers to the ability to acquire and sell a cryptocurrency for the same price. However, on actual exchanges, the required purchase price is usually above the price one can sell a cryptocurrency for. This only has a relatively strong impact on

Table 5: Correlations between cryptocurrencies

	BTC	ETH	XRP	XEM	LTC
BTC	1	0.22*	0.19*	0.29*	0.53*
ETH	0.00	1	0.00	0.01	0.11*
XRP	0.00	0.94	1	0.20*	0.22*
XEM	0.00	0.77	0.00	1	0.19*
LTC	0.00	0.01	0.00	0.00	1

The upper triangular displays the correlations of cryptocurrencies against each other and the lower triangular shows the corresponding $p-values$ over the time period from 08/10/2015 until 06/09/2017. Correlations with an asterisk are significant at the 5% level.

Table 6: Correlations between cryptocurrencies and asset classes

	BTC	ETH	XRP	XEM	LTC
Equity	-0.02	-0.07	0.00	-0.05	-0.01
U.S.	-0.01	-0.02	0.00	-0.02	-0.01
International	-0.03	-0.10*	0.00	-0.07	0.00
Emerging Markets	-0.02	-0.06	0.01	-0.04	-0.02
Fixed Income	0.02	-0.02	0.01	-0.02	-0.02
U.S.	0.02	0.01	0.03	0.03	-0.03
Global	0.02	0.00	0.01	-0.01	-0.02
High Yield	0.01	-0.07	-0.02	-0.05	0.00
Commodities	0.05	-0.06	-0.01	0.03	-0.01
Real Estate	0.00	-0.02	0.00	0.00	0.01
Hedge Funds	-0.02	-0.03	0.00	-0.05	0.00
Private Equity	-0.02	-0.10*	-0.01	-0.04	-0.02

Correlations between cryptocurrencies and asset classes including their components over the time period from 08/10/2015 until 06/09/2017. Correlations with an asterisk are significant at the 5% level. Tables in the Appendix provide information regarding the corresponding $p-values$.

PF2, as the assumption of no bid-ask spreads was required for rebalancing. This is also a relevant limitation for the descriptive statistics calculated in Table 3, but only given that an investor would have realized his return at the end of our investigation period. This would only impact the last of the 479 daily returns per cryptocurrency and hence does not result in a significant deviation of our results.

We additionally assumed that coins can be divided indefinitely for setting up our different portfolios. As stated in Section 3.4, there is a smallest unit for each cryptocurrency and thus this impacts our results. However, each coin can be traded in the smallest unit they are denoted in and all cryptocurrencies we investigate can be at least divided by one million. Therefore, this difference is only marginal.

Another potential limitation might be our assumption that the market provides enough liquidity to enable executing each trade immediately, which is usually not the case for large orders. This was relevant for rebalancing the portfolio and for potentially realizing returns. After considering daily trading volumes of the cryptocurrencies we investigate, we found this assumption to have barely any impact on our results.

Finally, we selected the cryptocurrencies under investigation based on their current market capitalization, implying that we selected cryptocurrencies which were already established in the market by the time of selection. This means that our analysis is based on the past performance of currently successful cryptocurrencies and we thereby neglected the possibility to select cryptocurrencies that decrease in value over the time period we considered. Therefore, our analysis does not account for all risks involved when investing in cryptocurrencies but provides information about the risks of currently prominent cryptocurrencies.

Although there are several limitations to our work, several other studies on cryptocurrencies (Wang and Vergne, 2017; Eisl et al., 2015; Chuen et al., 2017; Elendner et al., 2016) are subject to the same limitations. We therefore believe that neglecting these limitations does not alter the results of this work but is relevant to enable comparison with other research on cryptocurrencies.

7. Technological risks of cryptocurrencies

In this chapter we start with providing information regarding selected attacks on cryptocurrencies in Section 7.1 and continue with information regarding general threats in Section 7.2. We finish this chapter with explaining potential implications of the presented attacks and threats in Section 7.3.

7.1. Attacks

In this section we provide an overview of selected attacks that can put users of cryptocurrencies at risk.

7.1.1. Majority mining attack.

Cryptocurrencies are decentralized and rely on a large network of individuals to preserve the system by validating transactions. The validation is done through the respective consensus protocol of the cryptocurrency which is energy consuming but validators are rewarded by the network as an incentive to preserve the system. This opens the opportunity to monetize on the consensus mechanism and invest in equipment for validating. Therefore, the majority of validators choose to operate in countries where electricity is cheap, which leads to centralization of the network. This threatens a cryptocurrency in its key strength, decentralization, and opens the opportunity to a majority mining attack, the most known attack on cryptocurrencies. In this attack validators collude, if necessary, to generate more than 50% of the computational power in the network. Blockchain consensus mechanisms rely on a majority to verify transactions to be added to the blockchain. If a single group controls the majority, it can undergo the consensus mechanism. By doing so, the parties controlling the majority of the computational power have the ability to block transactions of others, double spend coins and also prevent other individuals from mining (Eyal and Sirer, 2014; Bonneau et al., 2015). This is especially threatening, as single mining pools are already controlling major stakes of the overall computational power within some of the cryptocurrencies' networks. As of September 15th, 2017 the four largest Bitcoin mining pools combined controlled over 50% of the computational power, while only two mining pools would be needed to collude for both Litecoin and Ethereum to enable a majority mining attack (Blockchain Luxembourg S.A., 2017; Litecoinpool.org, 2017; Etherchain, 2017; Conti et al., 2017).

Research by Eyal and Sirer (2014) found that this is especially threatening for Bitcoin. They propose the concept of *Selfish-mining attacks*, a strategy by which a minority mining pool receives more rewards than the ratio of its computational power. This in turn provides an incentive for individual miners to join mining pools pursuing this strategy as it provides larger financial benefits compared to mining individually. If individual miners have an incentive to join the selfish mining pool, this leads to a mining pool to grow towards a majority that threatens the decentralization of the cryptocurrency. Therefore, a majority mining attack poses an extreme risk for cryptocurrencies, especially with the development of mining pools causing cryptocurrencies to lose one of their greatest features: decentralization.

7.1.2. Sybil attack.

A Sybil attack refers to an attacker attempting to fill the network with nodes that are controlled by him. This can result in individuals that are on the network to only connect to nodes which are controlled by the attacker. Thereby, the attacker can disconnect individuals from the network and also has the ability to exercise double spending attacks. Sybil attacks are possible on public blockchains and thus Bitcoin, Ethereum, NEM and Litecoin are subject to this attack (NEM.io Foundation Ltd, 2015a; Conti et al., 2017).

7.1.3. Denial of service attack.

In a denial of service attack an attacker spams the network in order to slow it down or eventually cause it to crash. This results in transactions not being validated and is a vulnerability of all cryptocurrencies we investigate in this work. However, as discussed in Section 3.4, transactions on the network are subject to fees and thus a denial of service attack can be very costly for an attacker to succeed.

Although it might be expensive for an attacker to pursue the attack, the opportunity exists and attackers that could potentially monetize on a slowdown of the network of a particular cryptocurrency could still benefit while bearing the large costs involved in the attack. While it might be financially rewarding to directly attack a specific cryptocurrency, denial of service attacks are more commonly observed on cryptocurrency exchanges as this seems to be easier while having a strong impact on the prices of the cryptocurrencies traded on the exchange (Conti et al., 2017; Buntinx, 2017).

7.1.4. IP identification.

When a transaction is sent on the network, it is broadcasted to all miners which have to verify the transaction. As miners are based in different locations around the world, the time until the transaction reaches each miner differs according to their respective distance to the person executing the transaction. For each transaction a miner receives, a log file is created in which the IP address of the individual executing the transaction is saved (Bonneau et al., 2015). Research by Biryukov et al. (2014) found that, at least for Bitcoin, the possibility exists to combine the time required until a transaction arrives at the respective mining nodes and the respective log files, to de-anonymize the individual that executed a certain transaction.

7.1.5. Transaction graph screening.

In order to receive or send a transaction on a blockchain an address is required. This address is unique and can be compared to an email address, through which users can receive or send cryptocurrencies. If an individual provides her address publicly, as it is e.g. the case for many authors on cryptocurrency related topics asking for donations, it is possible to explore her complete transactional history through a blockchain explorer[13]. Although it is suggested to use different addresses for each transaction, some merchants only use one address for receiving payments. This allows to explore the timing and value of each transaction sent to the merchant. If a person communicates her purchase at a merchant that uses only one address, it is possible to either narrow down or to find out her specific address, depending on the amount of information provided (Bonneau et al., 2015; Ron and Shamir, 2013; Ober et al., 2013; Bruno, 2017).

7.1.6. Exchange attack.

In order to receive an initial amount of a cryptocurrency there are numerous possibilities individuals can choose. The most convenient approach is to purchase cryptocurrencies on an exchange using a credit card (Wu et al., 2014). Due to legal requirements, many exchanges require individuals to pass certain security measures that require uploading identification documents such as a driver's license or passport. This implies that if an attacker is able to access the database of an exchange on which documents are stored and further finds out which blockchain address an individual used, the attacker has all personal information and can track all transactions of the individual. In addition to anonymity at risk, if a cryptocurrency exchange is subject to an attack this can also cause theft of coins stored on the exchange. This was the case for Mt. Gox, an exchange that became victim of a hacker attack resulting in the theft of over 740,000 BTC (Barber et al., 2012; Popper and Abrams, 2014).

7.2. General threats

In this section we provide an overview of selected general threats of cryptocurrencies, namely cryptographic breakthroughs, potential issues with open source code and security vulnerabilities in codes.

7.2.1. Cryptographic breakthroughs.

Cryptocurrencies rely on the security of cryptography. Advancements in cracking cryptographic codes are therefore a potential threat to the security of a cryptocurrency. Especially the development of quantum computers poses a threat as these computers are far more efficient than regular computers and could enable to decrypt cryptographic systems used by cryptocurrencies (Ethereum Foundation, 2017). However, the development of quantum computers is currently performed by a few large corporations such as IBM (Kandala et al., 2017) and Bergen (2017) and we do not believe that they would use their quantum computers for decrypting the algorithms that secure cryptocurrencies.

7.2.2. Open source.

Four of the cryptocurrencies we investigate in this work (Bitcoin, Ethereum, Litecoin and Ripple) rely on open source-software and NEM plans to be open source in the near future (Ethereum Foundation, 2017; Bitcoin Project, 2017b; Litecoin Project, 2016; Wong, 2016; Williams, 2017). This poses the threat that individuals working on the code of the cryptocurrency may potentially, either accidentally or on purpose, introduce security vulnerabilities into its code that can be exploited by attackers (Ethereum Foundation, 2017).

7.2.3. Security vulnerabilities in the code

As discussed in Section 3.4, a cryptocurrency may serve as a platform to develop applications on top of its blockchain. Therefore, risks may arise for the cryptocurrency itself due to security vulnerabilities of applications that are built on its platform, as it was the case for The DAO, built on Ethereum. When The DAO was attacked, the price for Ether fell by more than 50% within 48 hours (Bovaird, 2016). This in turn has an impact on other applications that run on the cryptocurrency's platform as the cryptocurrency itself is used as an internal pricing mechanism and its price determines the cost of operating on the platform (Ethereum Foundation, 2017).

7.3. Implications

After explaining specific attacks on cryptocurrencies and general threats inherent in using cryptocurrencies, we continue with the explanation of potential implications of the presented attacks and threats.

7.3.1. Double spending.

We believe double spending to be the most severe threat for cryptocurrencies. Despite mechanisms being in place prohibiting double spending, individuals can double spend their coins when reaching a majority in the network. This is especially important for merchants that accept the cryptocurrency. In the case of a double spend attack, a merchant believes to have received a payment and then provides the customer with his product or service. However, the attacker has the power to reverse the transaction and keep the product or service he received, which leaves the merchant without a payment. Therefore, if merchants perceive the likelihood of double spending as too large, they will stop using cryptocurrencies and thus it will drive honest users away from the network. However, one way to decrease the likelihood of this potential threat can be done by developers of cryptocurrencies through the breakup of mining pools (Barber et al., 2012).

7.3.2. Block transactions.

The goal of cryptocurrencies is to enable almost instant payments online. If this ability is not granted, users cannot rely on the ability of the network to ensure transactions. This can affect companies that operate on a platform e.g. a business using Ethereum's blockchain for smart contracts, as they will perceive the platform to be not reliable enough for using it for business purposes and hence cease operations. However, this can have a more severe implication. Prices of cryptocurrencies are determined by supply and demand (Narayanan et al., 2016). If there is a decrease in the demand for a cryptocurrency, due to users leaving the network,

[13] A Bitcoin blockchain explorer can be accessed at `https://blockexplorer.com/`.

while there is no change in the supply, we can expect the price of a cryptocurrency to fall. Therefore, this will have a direct impact on individuals that purchased a cryptocurrency, independent of their intended use, as the cryptocurrency is expected to lose in value.

7.3.3. Prevent mining.

Preventing individuals from mining refers to miners not being able to add blocks to the blockchain. This, however, does not mean that these miners do not provide computational power to the network, for which they have to pay the electricity. This means, that their blocks are simply not added to the blockchain and hence, they do not receive a reward for their efforts. This is a crucial threat for the decentralization of a network. All other things being equal, if miners perceive this possibility on one network to be larger than on another network, they will leave the vulnerable network and join the network that does not face this threat. Therefore, if honest miners leave the network, it will be left to those that initiated preventing others from mining. Thus, the amount of nodes in the network will be reduced, causing a decrease in the level of decentralization. This will on the one hand increase the threat of a majority mining attack and on the other hand also impact the price of the cryptocurrency, as demand is likely to decrease.

7.3.4. Network disconnection.

The threats arising from being able to disconnect users from the network are similar to those of blocking transactions on the network. If individuals cannot be assured that they will be able to participate in the network, they will disregard a certain cryptocurrency. Hence, if network participants are subject to this threat and decide to leave the network, this will cause the cryptocurrency's demand to decrease. This will likely cause prices to decrease, affecting all individuals that purchased a cryptocurrency, independent of their intended use.

7.3.5. De-anonymization.

It is difficult for individuals to find out whether their identity is known to an attacker or not. However, if individuals find out that their anonymity is not granted because an exchange is not able to provide the required level of security, these individuals are likely to switch to another exchange. This is likely to have a direct impact on prices of cryptocurrencies. Many exchanges specifically trade only few cryptocurrencies and if a majority of users leave such an exchange, the demand for a specific cryptocurrency is likely to decrease, hence affecting the price of the cryptocurrency. However, when wanting to obtain cryptocurrencies, individuals can pursue different approaches that decrease the likelihood of de-anonymization. Individuals that mine receive cryptocurrencies as a reward and it is not required to provide personal information for mining. A different approach is to purchase cryptocurrencies in cash, which can be done through e.g. the purchase of Bitcoin gift cards. Individuals can furthermore open a cryptocurrency wallet and accept payments in cryptocurrencies, thus receiving cryptocurrencies without the need to provide personal identification documents (Barber et al., 2012).

7.3.6. Cryptographic breakthroughs.

Although we believe that quantum computers will not be used for decrypting cryptocurrencies' security algorithms in the short term, we believe that in the long term these computers may pose a severe threat. This is because cryptocurrencies were not developed to exist only temporarily. After large corporations will have progressed further in the field of quantum computers, they are likely to monetize on their developments and sell quantum computers to the general public. Although we cannot estimate when this will happen, we believe this is a potential future scenario. It implies for developers of cryptocurrencies to keep their encryption at the highest level possible, and to consider employing new encryption mechanisms that cannot be decrypted by quantum computers. For users of cryptocurrencies we believe this is currently only a low threat, as all cryptocurrencies are subject to this problem and, as mentioned before, we do not believe large corporations to misuse their technological developments for decrypting cryptocurrencies' security algorithms.

7.3.7. Code vulnerabilities.

Depending on the extent of the vulnerability, this can result in minor impacts such as temporary inability to create new addresses but can also have major impacts such as loss of coins in user accounts. Therefore, the estimation of the extent of an impact is difficult. However, code vulnerabilities can have severe implications as was the case when The DAO was hacked. Therefore, developers should continuously review and improve their code in order to minimize potential code vulnerabilities that could be exploited by an attacker.

8. Conclusion

We started this work with providing information regarding the overall cryptocurrency market and explained five cryptocurrencies in more detail, namely Bitcoin, Ethereum, Ripple, NEM and Litecoin. We then continued with an explanation of common asset classes including insights on what asset classes are used for. Consequently, we explained our approach for collecting data and presented the methods used for analyzing the data including why we decided to use selected methods. We continued with presenting our findings regarding the risk-reward profile of cryptocurrencies and asset classes, provided a correlation analysis and stated potential limitations of our analyses. We finished this work with explaining selected technological risks of cryptocurrencies including potential implications of these risks.

The aim of this work was to investigate return characteristics of cryptocurrencies in relation to traditional asset classes and the potential of cryptocurrencies to improve portfolio diversification.

We found that cryptocurrencies provide larger returns with a higher dispersion than traditional asset classes and at the same time show a higher level of volatility. We further identified that the relation of the magnitude for positive returns and negative returns is larger for cryptocurrencies compared to asset classes. The skewness of the returns of cryptocurrencies and asset classes reinforce prior results: cryptocurrency returns are mostly positively skewed while for asset classes this is only the case for commodities. We furthermore discovered positive excess kurtoses for all cryptocurrencies and asset classes with generally larger kurtoses for cryptocurrencies. This means that cryptocurrencies provide large returns more frequently and of potentially larger magnitude compared to traditional asset classes.

For investigating the risk associated with investments in cryptocurrencies we calculated value-at-risk and expected shortfall. Compared to asset classes, we found far larger values for cryptocurrencies for both measures, thus reinforcing the high level of risk involved with investments in cryptocurrencies. We additionally calculated risk-adjusted returns to improve comparison between cryptocurrencies and asset classes. Our results for both Sharpe ratios and information ratios of cryptocurrencies are generally larger compared to those of traditional asset classes. From these results we can argue that investing in cryptocurrencies provides larger returns per unit of risk compared to investing in traditional asset classes.

We set up three three portfolios to investigate different investment approaches. Surprisingly, for the portfolio which we assumed to provide the lowest level of risk (PF2), we found the lowest risk-adjusted returns among cryptocurrency portfolios. However, it does show the lowest level of volatility among cryptocurrency portfolios, but its comparably high values for value-at-risk and expected shortfall do not provide evidence that rebalancing a portfolio has a positive impact on its level of risk. For PF2 we had large investments in Bitcoin and only small investments in the remaining cryptocurrencies, and in PF1 and PF2 the investments were more distributed among all cryptocurrencies. Therefore, we can argue that broadly investing, with more equal shares in different cryptocurrencies has a positive impact an a portfolio's risk-return ratio.

In order to determine whether cryptocurrencies can improve portfolio diversification we calculated correlation coefficients between the cryptocurrencies in scope and between cryptocurrencies and asset classes including the single components of the respective asset classes. We found significant positive correlations between most individual cryptocurrencies and can thus argue that, when investing in cryptocurrencies, combining different cryptocurrencies in a portfolio provides beneficial diversification effects. For correlations between the returns of cryptocurrencies and asset classes including their individual components, we found significant correlations between Ethereum and international equity, and also between Ethereum and private equity. Therefore, we can argue that adding Ethereum to a portfolio that consists of international equity or private equity investments has a positive effect on portfolio diversification. This also implies that it is possible to hedge the price development of Ethereum with investments in international equity or private equity. However, we did not find the remaining correlations to be significant at the 5% level.

These results mostly validate prior research but our correlation analysis could only partially validate prior work on cryptocurrencies.

Research by Chuen et al. (2017), Eisl et al. (2015), Osterrieder et al. (2017) and Elendner et al. (2016) found almost similar return characteristics of cryptocurrencies. Our results, however, partially contradict prior work by Elendner et al. (2016) and Chuen et al. (2017), which respectively found negatively skewed returns for Litecoin and Ethereum and Litecoin only. Our results for risk measures are very close to prior work by Osterrieder et al. (2017) and are generally of larger magnitude compared to research by Elendner et al. (2016). Our findings for Sharpe ratios and information ratios differ to those of prior research: Chuen et al. (2017) found remarkably lower Sharpe ratios and information ratios, and significantly lower differences in their results for cryptocurrencies and asset classes.

With our correlation analysis we can confirm research by Osterrieder et al. (2017), which also found positive correlations between different cryptocurrencies. Our results for correlations between cryptocurrencies and asset classes are partially in line with work by Elendner et al. (2016) which also found correlations between Ethereum and other asset classes. However, due to statistical insignificance, we can neither validate nor invalidate research that found correlations between the remaining cryptocurrencies and asset classes.

We believe that deviations of prior work compared to our results are mainly caused by the dynamics of the cryptocurrency market. Our findings of high levels of volatility reinforce this belief, as large price changes are not surprising for cryptocurrencies. This also implies that future research will differ according to the time period under investigation. This should be taken into account when comparing results of work on cryptocurrencies based on different sample periods.

Research on cryptocurrencies is still in its beginning and we believe there is a lot of potential for future research on cryptocurrencies. As a means of payment it would be interesting to find out what the effect of an increase of the adoption of cryptocurrencies has on the value of fiat currencies in specific countries. Besides, it would be interesting to find out if there is a change in an individual's spending behavior when starting to use cryptocurrencies. When focusing on cryptocurrencies as an investment, we believe one of the most interesting research topics is to find causal relationships between different cryptocurrencies or other market metrics. This could provide investors with potential information that could result in large positive returns. Other interesting research topics are the potential of blockchain technologies to decrease operating costs for businesses and also to analyze success rates of start-ups that received funds through an ICO compared to those that were funded by venture capital firms.

Although it might be too early to conduct research regarding some of these topics, as the market might not be mature enough to provide enough relevant data, we believe that there will be a strong increase in the amount of publications, especially with the positive current price development of cryptocurrencies.

Our work can provide value to individuals and firms already using cryptocurrencies and to those considering using cryptocurrencies, independent of their intended use.

For investment purposes we believe our work identified the large return potential of cryptocurrencies accompanied, however, with high levels of risk. In addition, our correlation analysis can be useful for asset allocation decisions as we have shown that cryptocurrencies can be used to improve portfolio diversification.

We believe investors should follow different approaches dependent on whether they want to solely invest in cryptocurrencies or if they want to add cryptocurrencies to a portfolio consisting of traditional assets.

For strict cryptocurrency-investments our findings provide insights about the high return potential of cryptocurrencies and that an investor can improve diversification of a portfolio consisting of the analyzed cryptocurrencies. We suggest that investors compare different risk measures when considering to invest in cryptocurrencies. Especially the high levels of value-at-risk and expected shortfall should be taken into account when evaluating investments in different cryptocurrencies.

When adding cryptocurrencies to a portfolio of established assets, potential investors can use our findings regarding the correlation of Ethereum with international equity and private equity investments to improve portfolio diversification.

We believe that price developments of cryptocurrencies are mainly driven by their assumed future usability. This implies that if an investor wants to directly invest in selected cryptocurrencies he should analyze and compare the potential of the underlying technology before investing. A more convenient method an investor can pursue is to invest in a cryptocurrency fund to benefit from diversification and guidance from an investment professional.

When considering using cryptocurrencies as a means of payment, we believe it is best to use Bitcoin. This is based on its comparatively broad acceptance. However, it is crucial to take into account the potential threats that go along with using Bitcoin or any other cryptocurrency. Large price fluctuations result in changes of the value of an individual's holdings and the technological risks of cryptocurrencies cannot be neglected. Especially businesses considering using cryptocurrencies need to have a sound understanding of this risk. Since the possibility to de-anonymize users of blockchain technologies exists, firms need to ensure that their anonymity is preserved. If they are unable to do so, it could lead to leaking of information that could potentially influence a company's stock price and hence would keep firms from using cryptocurrencies.

For individuals or firms that want to use a cryptocurrency's technology, it is important to evaluate how evolved the cryptocurrency's business model is. The market capitalization usually provides insights about the market's perception of a cryptocurrency and this is the first metric that should be taken into account. Additionally, we found high volatilities for all cryptocurrencies we analyzed. This should also be considered as it implies large changes in the costs of operating on a cryptocurrency's blockchain. If the price of the cryptocurrency in use increases, the operating costs of a firm increase and if the price decreases, the operating costs decrease but also the value of the cryptocurrency holdings of the firm decrease. The inability to predict future operating costs is a large drawback for blockchain technologies as it is likely to keep firms from adopting such technologies. However, our findings support that, at least for Ethereum, it is possible to hedge the risk of price changes by investing in international and private equity. Thereby, cost fluctuations for operating on a blockchain platform can be optimized, making it more useful for business purposes.

The market for cryptocurrencies has experienced tremendous growth over the past years and we believe this trend is not likely to stop. The adoption of cryptocurrencies is continuously increasing, thereby making cryptocurrencies even more usable on a daily basis. We have further discussed that cryptocurrencies enable innovative features such as smart contracts. The ability of individuals to build applications on top of a blockchain that enables to replace a trusted third party will push the market even further. Therefore, we believe that this growth is unlikely to stop and will keep providing investors with interesting investment opportunities.

We conclude that investments in cryptocurrencies provide large return potentials with high levels of volatility while at the same time providing a higher level of return per level of risk compared to traditional assets. Besides, the low correlations among cryptocurrencies and the correlations between Ethereum and investments in international equity and private equity provide beneficial diversification effects for investors. However, the risks arising with investments in cryptocurrencies, both financial and technological, can have large impacts on one's portfolio value. This implies that investors should take into account different investment approaches and investigate the potential risks and future purpose of a cryptocurrency. Therefore, individuals and investors that consider investing in this alternative asset class should follow market developments and consider all risks associated before investing in cryptocurrencies.

References

Antonopoulos, A. M. *Mastering Bitcoin: Programming the Open Blockchain*. O'Reilly Media, Inc., 2017.

Armknecht, F., Karame, G. O., Mandal, A., Youssef, F., and Zenner, E. Ripple: Overview and outlook. In *International Conference on Trust and Trustworthy Computing*, pages 163–180. Springer, 2015.

Australian Securities and Investments Commission. Thinking of trading contracts for difference (cfds)? https://www.moneysmart.gov.au/media/173820/thinking-of-trading-in-contracts-for-difference-cfds.pdf, 2012. [Online, accessed 10.09.2017].

Barber, S., Boyen, X., Shi, E., and Uzun, E. Bitter to better—how to make bitcoin a better currency. In *International Conference on Financial Cryptography and Data Security*, pages 399–414. Springer, 2012.

Baur, D. G., Hong, K. J., and Lee, A. D. Bitcoin: Currency or asset? 2015.

Beck, R., Czepluch, J. S., Lollike, N., and Malone, S. Blockchain-the gateway to trust-free cryptographic transactions. In *ECIS*, page 153, 2016.

Beikverdi, A. Nem launches, targets old economy with proof-of-importance. https://cointelegraph.com/news/nem-launches-targets-old-economy-with-proof-of-importance, 2015. [Online, accessed 19.08.2017].

Bergen, M. Google's quantum computing push opens new front in cloud battle. https://www.bloomberg.com/news/articles/2017-07-17/google-s-quantum-computing-push-opens-new-front-in-cloud-battle, 2017. [Online, accessed 22.09.2017].

Biryukov, A., Khovratovich, D., and Pustogarov, I. Deanonymisation of clients in bitcoin p2p network. In *Proceedings of the 2014 ACM SIGSAC Conference on Computer and Communications Security*, pages 15–29. ACM, 2014.

Bitcoin Project. Bitcoin developer guide. https://bitcoin.org/en/developer-guide, 2017a. [Online, accessed 10.09.2017].

Bitcoin Project. Bitcoin is an innovative payment network and a new kind of money. https://bitcoin.org/en/, 2017b. [Online, accessed 19.09.2017].

Blockchain Luxembourg S.A. Hashrate distribution. https://blockchain.info/pools, 2017. [Online, accessed 15.09.2017].

BlockchainTechnologies.com. Blockchain technology glossary - industry definitions and explanations. http://www.blockchaintechnologies.com/blockchain-glossary, 2016. [Online, accessed 11.09.2017].

Bloomberg L.P. Bloomberg barclays global high yield total return index value unhedge. https://www.bloomberg.com/quote/LG30TRUU:IND, 2017a. [Online, accessed 18.09.2017].

Bloomberg L.P. Index methodology - the bloomberg commodity index family. https://www.etfsecurities.com/documents/index%20methodology%20-%20dow%20jones-ubs%20commodity%20indexes.pdf, 2017b. [Online, accessed 18.09.2017].

Bodie, Z., Kane, A., and Marcus, A. *Investments, 9th edt*. McGraw-Hill/Irwin Publishing, 2010.

Bonneau, J., Miller, A., Clark, J., Narayanan, A., Kroll, J. A., and Felten, E. W. Sok: Research perspectives and challenges for bitcoin and cryptocurrencies. In *Security and Privacy (SP), 2015 IEEE Symposium on*, pages 104–121. IEEE, 2015.

Bouoiyour, J. and Selmi, R. Ether: Bitcoin's competitor or ally? *arXiv preprint arXiv:1707.07977*, 2017.

Bovaird, C. Classic and the dao: What drove ether prices in 2016. https://www.coindesk.com/classic-dao-drove-ether-prices-2016/, 2016. [Online, accessed 19.09.2017].

Bradbury, D. The problem with bitcoin. *Computer Fraud & Security*, 2013 (11):5–8, 2013.

Bradbury, D. Blockchain's big deal [financial it]. *Engineering & Technology*, 11(10):44–44, 2016.

Brière, M., Oosterlinck, K., and Szafarz, A. Virtual currency, tangible return: Portfolio diversification with bitcoin. *Journal of Asset Management*, 16 (6):365–373, 2015.

Bruno. How anonymous are cryptocurrencies like bitcoin? https://bitfalls.com/2017/09/18/anonymous-cryptocurrencies-like-bitcoin/, 2017. [Online, accessed 22.09.2017].

Buntinx, J. Top 5 cryptocurrency exchanges hit by ddos attacks. https://themerkle.com/top-5-cryptocurrency-exchanges-hit-by-ddos-attacks/, 2017. [Online, accessed 26.09.2017].

Burniske, C. and White, A. Bitcoin: Ringing the bell for a new asset class. http://research.ark-invest.com/hubfs/1_Download_Files_ARK-Invest/White_Papers/Bitcoin-Ringing-The-Bell-For-A-New-Asset-Class.pdf, 2017. [Online, accessed 20.05.2017].

Buterin, V. Ethereum: A next-generation cryptocurrency and decentralized application platform. https://bitcoinmagazine.com/articles/ethereum-next-generation-cryptocurrency-decentralized-application-platform-1390528211/, 2014. [Online, accessed 19.08.2017].

CFA Institute. *Cfa Program Curriculum 2018 Level III*. John Wiley & Sons, 2017.

Chaum, D. Blind signatures for untraceable payments. pages 199–203, 01 1982.

Chaum, D. Security without identification: Transaction systems to make big brother obsolete. *Commun. ACM*, 28(10):1030–1044, October 1985. ISSN 0001-0782. doi: 10.1145/4372.4373.

Chen, S., Chen, C. Y.-H., Härdle, W. K., Lee, T., and Ong, B. A first econometric analysis of the crix family. 2016.

Chuen, D. L. K. Fintech tsunami: Blockchain as the driver of the fourth industrial revolution. 2017.

Chuen, D. L. K., Guo, L., and Wang, Y. Cryptocurrency: A new investment opportunity? 2017.

CoinMarketCap. Cryptocurrency market capitalizations. https://coinmarketcap.com/charts/, 2017. [Online, accessed 27.09.2017].

CoinMarketCap. Frequently asked questions. https://coinmarketcap.com/faq/, 2017. [Online, accessed 10.07.2017].

Condon, S. Judge spares e-gold directors jail time. 2008. [Online, accessed 22.08.2017].

Conti, M., Lal, C., Ruj, S., et al. A survey on security and privacy issues of bitcoin. *arXiv preprint arXiv:1706.00916*, 2017.

Credit Suisse Group AG. Real estate as an asset class. https://www.credit-suisse.com/media/production/asset-management/docs/real-estate/white-paper-real-estate-as-an-asset-class.pdf, 2014. [Online, accessed 15.09.2017].

Crosby, M., Pattanayak, P., Verma, S., and Kalyanaraman, V. Blockchain technology: Beyond bitcoin. *Applied Innovation*, 2:6–10, 2016.

Dannen, C. Mining ether. In *Introducing Ethereum and Solidity*, pages 111–137. Springer, 2017.

Dean. Litecoin - what is a litoshi? http://cryptorials.io/glossary/litecoin/, 2015. [Online, accessed 27.09.2017].

Decker, C. and Wattenhofer, R. Information propagation in the bitcoin network. In *Peer-to-Peer Computing (P2P), 2013 IEEE Thirteenth International Conference on*, pages 1–10. IEEE, 2013.

Dwyer, G. P. The economics of bitcoin and similar private digital currencies. *Journal of Financial Stability*, 17:81–91, 2015.

Eisl, A., Gasser, S. M., and Weinmayer, K. Caveat emptor: Does bitcoin improve portfolio diversification? 2015.

ElBahrawy, A., Alessandretti, L., Kandler, A., Pastor-Satorras, R., and Baronchelli, A. Bitcoin ecology: Quantifying and modelling the long-term dynamics of the cryptocurrency market. 2017.

Elendner, H., Trimborn, S., Ong, B., and Lee, T. M. The cross-section of crypto-currencies as financial assets: An overview. Technical report, SFB 649 Discussion Paper, 2016.

Elison, M. Sbi ripple asia announces japanese bank consortium. https://ripple.com/insights/sbi-ripple-asia-announces-japanese-bank-consortium/, 2016. [Online, accessed 31.08.2017].

Etherchain. Mining statistics (last 24h). https://etherchain.org/statistics/miners, 2017. [Online, accessed 15.09.2017].

Ethereum Community. Ether - denominations. http://ethdocs.org/en/latest/ether.html, 2016. [Online, accessed 27.09.2017].

Ethereum Foundation. Ethereum - legal agreement. https://ethereum.org/agreement, 2017. [Online, accessed 19.09.2017].

Extance, A. Bitcoin and beyond. *Nature*, 526(7571):21, 2015.

Eyal, I. and Sirer, E. G. Majority is not enough: Bitcoin mining is vulnerable. In *International conference on financial cryptography and data security*, pages 436–454. Springer, 2014.

Fraser-Sampson, G. *Alternative Assets-Investments for a post-crisis world*. John Wiley & Sons, 2011.

Gao, K. The cryptocurrency funds have arrived, and they're bringing wall street money. https://seekingalpha.com/article/4052276-cryptocurrency-funds-arrived-bringing-wall-street-money, 2017. [Online, accessed 20.09.2017].

Glaser, F., Zimmermann, K., Haferkorn, M., Weber, M. C., and Siering, M.

Bitcoin-asset or currency? revealing users' hidden intentions. 2014.

Greer, R. J. What is an asset class, anyway? *The Journal of Portfolio Management*, 23(2):86–91, 1997.

Hameed, S. and Farooq, S. The art of crypto currencies. *(IJACSA) International Journal of Advanced Computer Science and Applications*, 2016.

Hayden, T. What is ripple? - a study guide for cryptocoins news. https://medium.com/@haydentiff/what-is-ripple-efc179bc02ae, 2017. [Online, accessed 31.08.2017].

Hedge Fund Research, Inc. Hfrx indices - index descriptions. https://www.hedgefundresearch.com/hfrx-indices-index-descriptions, 2017. [Online, accessed 18.09.2017].

Helms, K. Japan's largest c2c ticket marketplace with 5 million users accepts bitcoin. https://news.bitcoin.com/japans-largest-c2c-ticket-marketplace-accepts-bitcoin/, 2017. [Online, accessed 20.09.2017].

Hern, A. Initial coin offerings: cryptocurrency's next high-risk big money maker. https://www.theguardian.com/technology/2017/jul/10/initial-coin-offerings-cryptocurrency-next-high-risk-big-money-maker, 2017. [Online, accessed 20.09.2017].

Hildenbrandt, E., Saxena, M., Zhu, X., Rodrigues, N., Daian, P., Guth, D., and Rosu, G. Kevm: A complete semantics of the ethereum virtual machine. Technical report, 2017.

Hileman, G. and Rauchs, M. Global cryptocurrency benchmarking study. *Cambridge Centre for Alternative Finance*, 2017.

Hodl the Moon. Ripple (xrp) - key facts. https://hodlthemoon.com/ripple, 2017. [Online, accessed 27.09.2017].

Holmes, J. Segwit activated, bitcoin price rests above $ 4200. https://btcmanager.com/segwit-activated-bitcoin-price-rests-4200/, 2017. [Online, accessed 30.08.2017].

Hughes, S. J. and Middlebrook, S. T. Regulating cryptocurrencies in the united states: Current issues and future directions. 2014.

Iddo. Comparison between litecoin and bitcoin. https://litecoin.info/index.php?title=User:Iddo/Comparison_between_Litecoin_and_Bitcoin, 2014. [Online, accessed 30.08.2017].

Iwamura, M., Kitamura, Y., and Matsumoto, T. Is bitcoin the only cryptocurrency in the town? economics of cryptocurrency and friedrich a. hayek. 2014.

Kandala, A., Mezzacapo, A., Temme, K., Takita, M., Brink, M., Chow, J. M., and Gambetta, J. M. Hardware-efficient variational quantum eigensolver for small molecules and quantum magnets. *Nature*, 549(7671):242–246, 2017.

Kißling, J. *Zahlung mit elektronischen Werteinheiten: eine zivilrechtliche Untersuchung des Zahlungsakts bei Verwendung soft-und hardwarebasierter elektronischer Geldbörsen*, volume 24. LIT Verlag Münster, 2003.

Kräussl, R. Art as an alternative asset class: Risk and return characteristics of the middle eastern & northern african art markets. *CFS Working Paper Series*, 2014.

Lee, C. Creating litecoin. http://bit.ly/coinbaseltc, 2017. [Online, accessed 30.08.2017].

Leinwand Leger, D. How fbi brought down cyber-underworld site silk road. https://www.usatoday.com/story/news/nation/2013/10/21/fbi-cracks-silk-road/2984921/, 2014. [Online, accessed 20.09.2017].

Li, M. August 1st and the end of bitcoin? https://seekingalpha.com/article/4081991-august-1st-end-bitcoin, 2017. [Online, accessed 10.09.2017].

Litecoin Project. What is litecoin? https://litecoin.org/, 2016. [Online, accessed 19.09.2017].

Litecoinpool.org. Hash rate distribution. https://www.litecoinpool.org/pools, 2017. [Online, accessed 15.09.2017].

LPX AG. Lpx50. http://www.lpx-group.com/lpx/lpx-index-family/global-indices/lpx50.html, 2017. [Online, accessed 18.09.2017].

Luca, A., Prokop, G., Sully, L., Tannebaum, D., Lowy, M., and Kashyap, M. Money is no object:understanding the evolvingcryptocurrency market. https://www.pwc.com/us/en/financial-services/publications/assets/pwc-cryptocurrency-evolution.pdf, 2015. [Online, accessed 20.09.2017].

Maginn, J. L., Tuttle, D. L., McLeavey, D. W., Pinto, J. E., et al. *Managing investment portfolios: a dynamic process*, volume 3. John Wiley & Sons, 2007.

Mankiw, N. G. *Principles of macroeconomics*. Cengage Learning, 2014.

Margaret, A. Breaking it down: Bitcoin units of measurement. https://blog.blockchain.com/2016/07/01/breaking-it-down-bitcoin-units-of-measurement/, 2016. [Online, accessed 27.09.2017].

Marian, O. A conceptual framework for the regulation of cryptocurrencies. *U. Chi. L. Rev. Dialogue*, 82:53, 2015.

Markowitz, H. Portfolio selection. *The journal of finance*, 7(1):77–91, 1952.

Markowitz, H. *Portfolio selection: efficient diversification of investments*, volume 16. Yale university press, 1968.

Meiklejohn, S., Pomarole, M., Jordan, G., Levchenko, K., McCoy, D., Voelker, G. M., and Savage, S. A fistful of bitcoins: characterizing payments among men with no names. In *Proceedings of the 2013 conference on Internet measurement conference*, pages 127–140. ACM, 2013.

Merriam-Webster, Incorporated. "cryptography". https://www.merriam-webster.com/dictionary/cryptography, 2017. [Online, accessed 13.09.2017].

Miller, M. *The ultimate guide to Bitcoin*. Pearson Education, 2014.

Mota, P. P. Normality assumption for the log-return of the stock prices. *Discussiones Mathematicae Probability and Statistics*, 32(1-2):47–58, 2012.

MSCI Inc. Msci usa equity indexes. https://www.msci.com/us-equity-indexes, 2017a. [Online, accessed 18.09.2017].

MSCI Inc. Msci eafe index (usd). https://www.msci.com/documents/10199/822e3d18-16fb-4d23-9295-11bc9e07b8ba, 2017b. [Online, accessed 18.09.2017].

MSCI Inc. Msci emerging markets index (usd). https://www.msci.com/documents/10199/c0db0a48-01f2-4ba9-ad01-226fd5678111, 2017c. [Online, accessed 18.09.2017].

Nakamoto, S. Bitcoin: A peer-to-peer electronic cash system. 2009. [Online, accessed 21.08.2017].

Narayanan, A., Bonneau, J., Felten, E., Miller, A., and Goldfeder, S. *Bitcoin and Cryptocurrency Technologies: A Comprehensive Introduction*. Princeton University Press, 2016.

NEM.io Foundation Ltd. Nem - technology. https://nem.io/technology/, 2014. [Online, accessed 28.08.2017].

NEM.io Foundation Ltd. Nem - technical reference - version 1.0. https://www.nem.io/wp-content/themes/nem/files/NEM_techRef.pdf, 2015a. [Online, accessed 11.08.2017].

NEM.io Foundation Ltd. Nem newsletter 8 - a happy xem year! https://medium.com/@nemcoin/nem-newsletter-8-303765572f00, 2015b. [Online, accessed 27.09.2017].

NEM.io Foundation Ltd. What is proof-of-importance (poi) and why is it better, and what is vesting? https://blog.nem.io/what-are-poi-and-vesting/, 2017. [Online, accessed 21.08.2017].

Ober, M., Katzenbeisser, S., and Hamacher, K. Structure and anonymity of the bitcoin transaction graph. *Future internet*, 5(2):237–250, 2013.

Ogundeji, O. Litecoin, silver to bitcoin's gold, now aims at $50 goal. https://cointelegraph.com/news/litecoin-silver-to-bitcoins-gold-now-aims-at-50-goal, 2017. [Online, accessed 29.09.2017].

Osterrieder, J., Strika, M., and Lorenz, J. Bitcoin and cryptocurrencies—not for the faint-hearted. *International Finance and Banking*, 4(1):56, 2017.

PC.net. Glossary - ip address. https://pc.net/glossary/definition/ip_address, 2017. [Online, accessed 23.09.2017].

Penza, P. and Bansal, V. K. *Measuring market risk with value at risk*, volume 17. John Wiley & Sons, 2001.

Pisa, M. and Juden, M. Blockchain and economic development: Hype vs. reality. 2017.

Poon, J. and Dryja, T. The bitcoin lightning network: Scalable off-chain instant payments. *Technical Report (draft)*, 2015.

Popper, N. and Abrams, R. How anonymous are cryptocurrencies like bitcoin? https://www.nytimes.com/2014/02/25/business/apparent-theft-at-mt-gox-shakes-bitcoin-world.html?mcubz=1, 2014. [Online, accessed 23.09.2017].

Reutzel, B. Disruptor chris larsen returns with a bitcoin-like payments system. https://www.paymentssource.com/news/disruptor-chris-larsen-returns-with-a-bitcoin-like-payments-system, 2012. [Online, accessed 31.08.2017].

Ron, D. and Shamir, A. Quantitative analysis of the full bitcoin transaction graph. In *International Conference on Financial Cryptography and Data Security*, pages 6–24. Springer, 2013.

Scherbina, A. Asset price bubbles: a selective survey. 2013.

Schueffel, P. *The Concise Fintech Compendium*. School of Management Fribourg, Switzerland, 2017.
Skinner, C. Celebrating paypal's centenary. 2007. [Online, accessed 22.08.2017].
S&P Dow Jones Indices LLC. S&p global reit. https://us.spindices.com/indices/equity/sp-global-reit-us-dollar, 2017. [Online, accessed 18.09.2017].
Svetina, M. and Wahal, S. Exchange traded funds: Performance and competition. 2008.
T. Rowe Price Investment Services Inc. Benchmark definitions. https://www3.troweprice.com/fb2/fbkweb/benchmarkDefinitions.do, 2017. [Online, accessed 18.09.2017].
Tech Bureau Corporation. About mijin. http://mijin.io/en/about-mijin, 2017. [Online, accessed 30.08.2017].
Thomas, S. How we are further decentralizing the xrp ledger to bolster robustness for enterprise use. https://ripple.com/insights/how-we-are-further-decentralizing-the-ripple-consensus-ledger-rcl-to-bolster-robustness-for-enterprise-use/, 2017. [Online, accessed 31.08.2017].
Thune, K. The barclays capital us aggregate bond index. https://www.thebalance.com/the-barclays-capital-aggregate-bond-index-2466398, 2016. [Online, accessed 18.09.2017].
Tuwiner, J. Bitcoin mining pools. https://www.buybitcoinworldwide.com/mining/pools/, 2017. [Online, accessed 15.09.2017].
Ueland, S. 10 bitcoin-like cryptocurrencies. http://www.practicalecommerce.com/10-Bitcoin-like-Cryptocurrencies, 2013. [Online, accessed 30.08.2017].
UniSuper Management Pty Ltd. Asset classes explained. https://www.unisuper.com.au/investments/investment-basics/asset-classes-explained, 2017. [Online, accessed 20.08.2017].
Utopianfuture. [nem] nem - new economy movement - no envy movement - updates+discussion thread. https://bitcointalk.org/index.php?topic=426303.0, 2014. [Online, accessed 28.08.2017].
van Wirdum, A. Litecoin has now deployed segregated witness. https://bitcoinmagazine.com/articles/litecoin-has-now-deployed-segregated-witness/, 2017. [Online, accessed 30.08.2017].
Wang, S. and Vergne, J.-P. Buzz factor or innovation potential: What explains cryptocurrencies' returns? *PloS one*, 12(1):e0169556, 2017.
Weiss, N. A. *Introductory Statistics 9th Edition*. Pearson Higher Ed, 2011.
Wells Fargo Asset Management. Understanding asset classes. https://www.wellsfargofunds.com/ind/investing-basics-and-planning/understanding-asset-classes.html, 2017. [Online, accessed 20.08.2017].
White, L. H. The market for cryptocurrencies. *Cato J.*, 35:383, 2015.
Wilcox, J. W. and Fabozzi, F. J. *Financial Advice and Investment Decisions: A Manifesto for Change*, volume 195. John Wiley & Sons, 2013.
Williams, D. *Cryptocurrency Compendium: A Reference for Digital Currencies*. Lulu.com, 2017.
Wong, L. Nem catapult. 2016.
Wood, G. Ethereum: A secure decentralised generalised transaction ledger. *Ethereum Project Yellow Paper*, 151, 2014.
Wu, C. Y., Pandey, V. K., and DBA, C. The value of bitcoin in enhancing the efficiency of an investor's portfolio. *Journal of financial planning*, 27(9): 44–52, 2014.
Xie, L. A beginner's guide to litecoin - what is litecoin? https://blog.coinbase.com/a-beginners-guide-to-litecoin-d9b455d44cd3, 2017. [Online, accessed 30.08.2017].
Yoshikawa, E. Sumitomo mitsui banking corporation and japan post bank join sbi ripple asia's bank consortium. https://ripple.com/insights/sumitomo-mitsui-banking-corporation-and-japan-post-bank-join-sbi-ripple-asias-bank-consortium/, 2017. [Online, accessed 31.08.2017].