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Can cryptocurrencies enhance portfolio performance?

A broader look at the role of cryptocurrencies in a mean-variance optimal portfolio

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Abstract

This thesis utilizes mean-variance analysis and Sharpe-ratio optimization to explore the possibilities of adding cryptocurrencies to enhance portfolio performance. While earlier such research has focused on Bitcoin alone, this study examines 17 of the largest cryptocurrencies, selected based on their market capitalization. In addition to examining these cryptocurrencies' potential as investments, a brief review of the types of cryptocurrencies and each of the cryptocurrency's distinguishing features is presented. Results show that including cryptocurrencies leads to an improved Sharpe-ratio compared to a portfolio of traditional assets only, and that there is benefit in diversifying one's position in cryptocurrencies. It should be noted, that the rigour of these results is dependent on the assumption of normally distributed returns, which is rejected for both cryptocurrencies and traditional assets by the Anderson-Darling test of normality. Furthermore, cryptocurrencies are high-risk assets and speculative investments with limited historical data available, all factors which call for caution in drawing far-reaching conclusions. Nonetheless, the promising results of this study, warrants further research into the risk and return characteristics of not only Bitcoin but a larger set of cryptocurrencies.

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1 Introduction

Since the conception of Bitcoin, in a white paper by the pseudonym Satoshi Nakamoto (2008), cryptocurrencies have been on the rise. With Bitcoin prices peaking at almost 20 000 US Dollars in December 2017 and attracting mainstream media attention, its name has almost become synonymous with the cryptocurrency industry. But while most eyes have been focused on Bitcoin, the cryptocurrency market in large has seen other cryptocurrencies taking stronger positions on the market, with Bitcoin's market share weakening from 80% at the beginning of 2015 (CoinMarketCap, n.d.-a) to 52% at the beginning of 2019 (CoinMarketCap, n.d.-b).

While Bitcoin might have been launched as an "electronic cash system" (Nakamoto, 2008), research quickly suggested that even though it might function badly as money (Yermack, 2015), mainly due to its high volatility, Bitcoin might be interesting from a speculative investment perspective (Wu & Pandey, 2014). This thesis builds on this line of research, but instead of focusing only on Bitcoin, takes a broader approach and examines the investment opportunities of 17 largest cryptocurrencies through mean-variance analysis.

In this process, we aim to provide insight into the nature of cryptocurrencies from a financial perspective, going beyond only studying Bitcoin; to examine the investment opportunities of these cryptocurrencies offer using mean-variance analysis; attempt to construct an optimal cryptocurrency portfolio; and finally, explore whether the cryptocurrencies can be used to improve the risk-return profile of a traditional[1] investment portfolio. This work will be guided by the thesis research question:

> *Does the inclusion of cryptocurrencies enhance the performance of a portfolio of traditional assets?*

In answering the research question, this thesis will take the perspective of a typical private US investor.

[1] The term traditional asset is used throughout this thesis when referring to financial assets other than cryptocurrencies, for example stocks, bonds, real estate and commodities.

2 Theoretical background

This section will present the theoretical background on which this thesis is based, along with the present state of research into cryptocurrencies as investments. We will first look at the mean-variance approach to portfolio selection, also known as modern portfolio theory, which was introduced by Markowitz (1952) and how it can be combined with the Sharpe-ratio (Sharpe, 1994). This approach is the basis for the method which will later on be used to examine the investment opportunities presented by the cryptocurrencies. Secondly, we will look at how cryptocurrencies work, using Bitcoin as an example. This will entail whether cryptocurrencies uphold the properties of money, how cryptocurrency is stored, the issue of currency duplication within the digital setting, how transactions are recorded and verified, and finally how new currency is issued. After this, we will end this section with a brief literature review focusing on earlier research into whether the inclusion of cryptocurrencies can provide benefits to a traditional portfolio.

2.1 Modern portfolio theory

Markowitz (1952) introduces the mean-variance approach to portfolio selection which is based on the perspective of rational investors seeking to maximize their returns while simultaneously wanting to minimize their risk. By utilizing variance of returns as a measure of risk Markowitz develops a method on how to create an efficient portfolio of assets in such a way as to find maximized expected (mean) returns for a given level of risk.

Markowitz (1952) shows that through diversification it is possible to construct a portfolio with the same expected return, but lower variance compared to a non-diversified portfolio. This is made possible by factoring in the covariances of assets during asset selection. Using this method, Markowitz proves the existence of the efficient portfolio line on which all efficient portfolios lie, i.e. those achieving the highest possible expected return at the given level of risk. Based on the portfolio options on the efficient portfolio line, the individual investor can then select which portfolio best matches his or her preferences for return and risk.

Mathematically, the portfolio is represented by a set of weights, w_i for all assets $i = 1 \dots n$, which sum up to 1 ($\sum_{i=1}^{n} w_i = 1$). Using this notation, the expected return of the portfolio is given by

$$E(r_p) = \sum_{i=1}^{n} w_i \, E(r_i) \qquad \textit{Equation 1}$$

where $E(r_i)$ is the expected return of asset i, $E(r_i) = \frac{1}{N}\sum_{t=0}^{N} r_t$.

And the portfolio variance is given by

$$\sigma_p^2 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_i w_j \sigma_{ij} \qquad \textit{Equation 2}$$

where σ_{ij} is the covariance between assets i and j, $\sigma_{ij} = \frac{1}{N}\sum_{t=0}^{N}\left(r_{i,t} - E(r_i)\right)\left(r_{j,t} - E(r_j)\right)$.

By looking at Equation 2, we can see that adding an asset to a portfolio, which is uncorrelated or negatively correlated with the other assets in the portfolio, will have no or even negative effect on the portfolio variance.

Markowitz's method of finding efficient portfolio was advanced by Sharpe (1963) who reformulated the method line into a mathematical optimization problem, which can be easily solved by today's computers.

Further developing portfolio selection theory, Sharpe (1966) introduced a new reward-to-volatility measure for investment portfolios based on excess returns over the risk-free rate. This measure would later become known as the Sharpe-ratio (Sharpe, 1994)

$$SR_i = \frac{E(d_i)}{\sigma_{d_i}} \qquad \textit{Equation 3}$$

where d_i is the excess return of asset i, $d_{i,t} = r_{i,t} - r_{f,t}$, and,

r_f is the risk-free rate.

The Sharpe-ratio can be combined with the portfolio selection theory of Markowitz (1952) in order to find the optimal portfolio on the efficient portfolio line by selecting assets in a way that maximizes the Sharpe-ratio

$$\max SR_p = \frac{E(d_p)}{\sigma_{d_p}}.$$

where d_i is the excess return of the portfolio. This portfolio is deemed optimal compared to other portfolios on the efficient portfolio line as it maximizes the expected excess return gained per unit of risk taken on.

2.2 Cryptocurrencies

Cryptocurrencies are a form of virtual currencies, sometimes also called digital currencies, named after the cryptologic process through which ownership and authenticity of the currency are confirmed. While the name implies a similarity to physical currencies, studies on Bitcoin, such as Wu and Pandey (2014) and Yermack (2015), have shown that the cryptocurrency functions poorly as money. Yermack (2015) approaches the question on whether Bitcoin should be viewed as a currency from the basic properties of money as a medium of exchange, a unit of account and a store of value. As a medium of exchange, Bitcoin can be seen function to some degree, in the sense that a limited number of vendors accept it as payment. As a unit of account Bitcoin functions very poorly due to its high volatility, the many prices which exist for Bitcoin on different markets and the high price leading to potentially confusing prices with many leading zeros. Finally, as a store of value Bitcoin again does poorly due to its high volatility but also because of the difficulties in storing Bitcoin securely and lack of insurance or hedging possibilities. Because of these factors, Yermack (2015) concludes that Bitcoin does not conform to the traditional idea of currency but instead is more similar to speculative investment. Similar conclusions regarding Bitcoin's monetary properties are reached by Wu and Pandey (2014).

In order to fully grasp the problems with securely storing cryptocurrencies, seen by Yermack (2015) as hindering Bitcoin as a store of value, a basic understanding of cryptocurrency wallets is needed. A cryptocurrency wallet can be seen as comprised of two parts: a public key which serves as an account number; and a private key which is secret and which grants anyone who has access to it the ability to make transactions from the wallet (Segendorf, 2014). Keeping the private key secure from being both stolen by hackers and lost due to computer malfunction has proven troublesome and is one of the reasons behind the issues with Bitcoin as a store-of-value (Yermack, 2015).

To further understand how cryptocurrencies function, we need to look at how cryptocurrencies handle ownership verification and currency authenticity, problems highlighted in a Bitcoin primer by Velde (2013). In a physical monetary system, such as when using cash, the solution to the first problem is elementary as whoever holds the cash also owns the money and for the second problem there are various methods in-place to prevent currency counterfeiting. In a digital currency, this is a much more difficult problem to solve as digital files can be easily duplicated and their authenticity is hard to verify. Cryptocurrencies' solution to this problem is called the blockchain, a public ledger on which all transactions between wallets are recorded so that it is possible to track who owns what. In a centralized system, such a ledger would be held with a trusted authority but as cryptocurrencies aim to be fully decentralized these ledgers are instead kept across a network of independent nodes.

These network nodes are also tasked with validating all transactions made in the cryptocurrency. Whenever a transaction is to be made, it is broadcast by the participants to the network of nodes which then validate the transaction, making sure that the funds are available, before adding it to the blockchain. The details of how this process works differ between cryptocurrencies. Segendorf (2014) explains how this process works within Bitcoin which serves as an illustrative example. First, transactions are grouped into blocks which contain the last 10 minutes' transactions. These blocks are then validated through a computationally expensive process. After the block is validated it is broadcast to the network which verifies it, a much easier process[2]. Finally, when a majority of network nodes have validated the block, it is added to the blockchain and the transaction is settled.

The process of validating blocks is called mining and the node performing it a miner, named as the node is often rewarded with an amount of currency for the work performed and thus the process has been likened to gold-mining (Segendorf, 2014). The method used to validate and verify the blocks before adding them to the blockchain varies between cryptocurrencies and is called the cryptocurrency's consensus model. Mukhopadhyay et al. (2016) survey the consensus models used by different currencies. The model used by Bitcoin is called proof-of-

[2] Segendorf (2014) gives an excellent example of a mathematical problem which is hard to solve but easy to verify, namely factorization: to find the factors of a large number is a difficult process but multiplying them together to verify the solution is a simple calculation.

work, named after the work required for the computation. Proof-of-stake is another model, in which nodes are allowed to validate blocks based on their stake in the currency, i.e. by holding a large amount of the cryptocurrency, instead of by virtue of having spent computational resources. There are also trust based models where nodes are initially trusted but punished if they validate improper blocks.

A final important concept within money is how new money is issued. In a traditional setting, the issuing of new money is controlled by a central bank but in the decentralized world of cryptocurrencies, no such central authority exists. Instead, the rules for issuing new money are set in the cryptocurrencies' program code. Again using the example of Bitcoin from Segendorf (2014), miners are currently rewarded with newly issued currency when validating a block. However, there is a cap on total Bitcoins that can exist and when this cap is reached no new currency will be issued.

2.3 Earlier research

As cryptocurrencies are a relatively recent addition to the financial world, there has been a limited amount of prior research into whether cryptocurrencies can be an interesting investment to a more traditional asset portfolio. The last few years have, however, seen an increase in published articles, and other well cited literature such as working papers, on the matter. The literature found has focused mainly on Bitcoin, presumably as it is the oldest and most well-known cryptocurrency. Provided here, is a short overview of research on cryptocurrencies as performance enhancers or diversifiers in an investment portfolio. For a more thorough literature review, one can consult Corbet et al. (2018a).

As seen in the previous section, early research into Bitcoin has focused on its function as currency and authors seem to agree that Bitcoin is not viable as money, mainly because of its high volatility (Yermack, 2015; Wu & Pandey, 2014). Wu and Pandey (2014), however, show that Bitcoin might have the potential to enhance the performance of a portfolio and thus be of interest from an investment perspective. Baek and Elbeck (2015) study what factors drive the price of Bitcoin and find that returns are highly volatile and driven by internal factors rather than fundamental economic factors. This leads them to the conclusion that Bitcoin should be considered a speculative asset rather than an investment as. Looking at Bitcoin correlations with other assets, Briere et al. (2015) conclude that Bitcoin offers diversification possibilities due to low correlations and again show that including a small proportion of Bitcoin in a well-diversified portfolio can improve the risk-return profile.

Following further studies into Bitcoin's diversification opportunities a discussion arises regarding whether Bitcoin should be considered a diversifier, hedge and/or safe haven. Dyhrberg (2016a) looks at Bitcoin as a hedge against stock in the Financial Times Stock Exchange (FTSE) Index and US Dollar and concludes that Bitcoin has good hedging capabilities. This, however, is disputed by Baur et al. (2018) after a replication study showing that, even though uncorrelated, Bitcoin does not function as a hedge against the FTSE Index or the US Dollar. Bouri et al. (2017) show similar results as Baur et al. (2018) when looking at the diversification, hedge and safe haven capabilities of Bitcoin against a range of assets concluding that Bitcoin is a good diversifier for most of the assets while a hedge and safe haven in only a few cases. Klein et al. (2018) once again corroborate that Bitcoin is not a particularly good hedge and show that this also holds for the broad cryptocurrency index CRIX. CRIX was constructed by Trimborn and Härdle (2016), and is a market-weighted cryptocurrency index with a variable number of included cryptocurrencies, aiming to fill a role similar to that of the S&P500 or the DAX30 on the cryptocurrency market.

More studies have since followed the path of looking at Bitcoin as a diversifier and portfolio performance enhancer. Aggarwal et al. (2018) conclude that this seems to hold for the Indian market and likewise do Kajtazi and Moro (2018) for European, Chinese and US markets. Both studies however noting the volatile nature of Bitcoin and that it might not be a suitable asset for all investors. Corbet et al. (2018b) expand this line of research by two more cryptocurrencies in addition to Bitcoin in a study on relationships between cryptocurrencies and other financial assets on the US market.

3 Methodology

3.1 Selection of assets

3.1.1 Cryptocurrencies

In line with the thesis purpose of providing insight a broad range of cryptocurrencies and their potential as additions to traditional investments, it was decided to include the 25 largest cryptocurrencies, measured by market capitalization, in this study. Ranking cryptocurrencies by market capitalization is a common approach and has been used in several studies of the cryptocurrency market (see, e.g., Feng et al., 2018; Fry & Cheah, 2016; Gandal & Halaburda, 2016; Hileman & Rauchs, 2017; White, 2015). Furthermore, it was decided to limit the study to only include the currencies which traded directly in US Dollars.

Including the top 25 cryptocurrencies ensured that the major cryptocurrencies were to be included regardless of any temporary fluctuations in market capitalization and that a broad approach was taken while keeping the number of assets within practical limits for this type of study. Limiting the cryptocurrencies to those traded in US Dollars was done in order to prevent issues arising from the prices being calculated through conversions via other cryptocurrencies.

An issue arose when selecting the cryptocurrencies as the reported market capitalization for some of the cryptocurrencies was found to differ greatly between different cryptocurrency data providers. This was due to differences in how market capitalization was calculated. In these cases, the organization behind a cryptocurrency held a portion of the tokens in reserve, which means market capitalization can be calculated either using the total number of tokens created or using the number tokens available on the market. If a large portion of tokens is held in reserves this means that the market capitalization can differ greatly depending on the method used. In order to alleviate this problem, it was decided to use market capitalization data from two different providers, CryptoCompare (www.cryptocompare.com) and CoinMarketCap (coinmarketcap.com), and to include only the cryptocurrencies which were ranked top 25 by both.

Selection of assets was done using market capitalization data retrieved on 11th December 2018. After excluding any cryptocurrencies which did not meet the aforementioned criteria 17 cryptocurrencies were selected. This was done by initially selecting the 25 cryptocurrencies with highest market capitalization according to CryptoCompare. These 25 cryptocurrencies were then reduced to 18 as those which did not trade in US Dollars were excluded. Market capitalization data from CoinMarketCap was then gathered and one additional cryptocurrency was excluded as it did not rank top 25.

3.1.2 Traditional assets

Traditional assets were selected with the goal of being representative of different investment opportunities available to a private investor in the US. This meant including US and global stock market indexes, a broad commodities index, a US real estate market fund and a US government bond fund. Along with these assets, two more assets were chosen due to having some possibly similar investment qualities as the cryptocurrencies. A gold fund was included due to the suggested, but disputed, similarity between gold and Bitcoin because of their proposed shared properties as possible hedges or safe havens (Bouri et al., 2017; Baur et al., 2018; Dyhrberg, 2016b). Secondly, an emerging markets fund was included as emerging markets could present a high-risk investment with diversification opportunities (Harvey, 1995), similar to that which the cryptocurrencies might offer.

In order to capture the width of different investment opportunities offered to an investor broad exchange-traded funds or notes (ETFs/ETNs) were selected. ETFs and ETNs were favoured over data on the underlying index where applicable, as these represent the real investment opportunities available for investors to buy and sell on the market. All traditional assets are traded on NYSE Arca at the New York Stock Exchange.

3.1.3 Risk-free rate

The 3-month US Treasury Bill daily rate was selected as proxy for the risk-free rate.

3.2 Data collection and sources

Cryptocurrency data was collected from CryptoCompare on 11th December 2018. For each of the cryptocurrencies, daily observations were collected from the first available date until the collection date, with total number of observations varying depending on when the cryptocurrencies were launched. The data was collected using a small program written in Python which downloaded the data from the CryptoCompare API.

The downloaded data was cleaned in two ways. Firstly, some of the time series contained duplicate observations which were removed. Secondly, for the cryptocurrencies DASH and USDT, there was a long period at the beginning of the time series in which price data was available but there were no trades recorded. For these cryptocurrencies, price data up until the first recorded trade was removed as it affected means and volatility measures even though this price information was meaningless as the prices had never been used.

Non-financial data regarding cryptocurrencies was primarily collected from the cryptocurrencies' respective websites or other documentation provided such as whitepapers. This approach was chosen in order to collect first-hand descriptions of the currency, as well as up-to-date information in a quickly changing environment, but also due to a lack of academic literature on most of the cryptocurrencies. In cases where there was deemed to be a high risk of bias, such as regarding conflicts within cryptocurrency communities that led to spin-off cryptocurrencies being created, information was sought from both parties to the conflict. News articles were also used as a supplemental source of information regarding such events if the information provided by the organizations behind the cryptocurrencies was insufficient.

For the traditional assets, along with the risk-free rate, daily observations were collected from Yahoo Finance (finance.yahoo.com) on 11th January 2019. The data period for the traditional assets was set to match that of the Bitcoin data, as this was the longest data period of the cryptocurrencies. This meant that data for the period 19th July 2010 until 11th December 2018 was collected, totalling 2116 observations for each asset. The data from Yahoo Finance was collected manually through the Yahoo Finance website. Information about the characteristics of the assets was collected from the asset's respective prospectuses, downloaded from the asset providers' websites.

3.3 Data analysis

Data analysis was done using the Python programming language, with the help of the data analysis library Pandas (pandas.pydata.org), the plotting library Matplotlib (matplotlib.org) and the library Scipy (www.scipy.org/scipylib/index.html) which provided a numerical solver used for the optimization problems and statistical methods for normality testing.

3.3.1 Descriptive statistics

Returns were calculated based on the daily prices for all data series using log-returns

$$r_{i,t} = \ln\left(\frac{P_{i,t}}{P_{i,t-1}}\right)$$

For the traditional assets, these calculations were made using split- and dividend adjusted prices from Yahoo Finance.

The daily returns were then annualized before calculating descriptive statistics (mean, variance, skewness and kurtosis) for the assets. As the log-returns are additive this could simply be done by multiplication

$$r_{annual} = (trading\ days) * r_{daily}$$ *Equation 4*

For the traditional assets 252 trading days were assumed and for the cryptocurrencies 365 trading days were used as they are traded all days of the year.

The mean and volatility, measured as standard deviation, were then computed using the respective functions provided by the Pandas library. The skew and kurtosis (as excess kurtosis) were also computed using the Pandas library. The Anderson-Darling test was also used in order to test whether the log-returns followed a normal distribution. The Anderson-Darling test statistic and critical values were calculated using the Scipy library.

For each of the assets, the Sharpe-ratio was also calculated using the excess returns for the asset using the formula presented in Equation 3. When calculating the cryptocurrencies' excess returns for observations on weekends and holidays the most recent available observation for the risk-free rate was used since observations of the risk-free rate are only available on non-holiday weekdays.

3.3.2 Portfolio optimization

Four sets of portfolio optimizations were run on different data sets, each time constructing three portfolios optimized using different criteria: a portfolio maximizing Sharpe-ratio under short sale restrictions ($\max SR_p \middle| w_i \geq 0 \; for \; all \; i$); a portfolio maximizing Sharpe-ratio with short-selling allowed ($\max SR_p \middle| -1 \leq w_i \leq 2 \; for \; all \; i$); and the minimum variance portfolio under short sale restrictions ($\min \sigma_p^2 \middle| w_i \geq 0 \; for \; all \; i$). The weight restrictions applied when short-selling was allowed were due to practical reasons as no restrictions on weights seemed to lead to difficulties in finding a single optimal solution. In order to make sure the solution found was stable all optimizations were run 3 times with randomized initial weights. A maximum of 100 000 iterations were set for the optimizer.

The three portfolios were first constructed for the traditional assets by themselves, which was later used as a baseline for comparison when adding cryptocurrencies. Next, portfolios were constructed using only the cryptocurrencies in order to identify interesting cryptocurrencies for investment. When constructing the minimum variance portfolio for the cryptocurrencies this portfolio loaded almost completely on a stablecoin, a cryptocurrency designed to have zero volatility. Because of this, a second minimum variance portfolio was also constructed without this currency.

Traditional assets and cryptocurrencies were then combined in two ways. Firstly, the cryptocurrencies which were included in the maximum Sharpe-ratio portfolio without short sales were combined with the traditional assets and portfolios were generated. Secondly, portfolios were also constructed for a combination of only Bitcoin, for which the longest data set was available, and the traditional assets.

4 Data

4.1 Presentation of cryptocurrencies

	Function	Market capitalization	First observation	Last observation	Number of observations
BTC	Virtual currency	58 950 230 398 USD	2010-07-19	2018-12-11	3068
XRP	Financial network	29 887 564 202 USD	2015-01-21	2018-12-11	1421
ETH	Decentralized applications platform	9 070 302 124 USD	2015-08-07	2018-12-11	1223
XLM	Financial network	2 148 438 256 USD	2017-01-17	2018-12-11	694
EOS	Decentralized applications platform	1 905 380 192 USD	2017-06-29	2018-12-11	531
USDT	Stablecoin	1 841 013 436 USD	2017-04-01	2018-12-11	620
BCH	Virtual currency	1 639 155 847 USD	2017-08-01	2018-12-11	498
LTC	Virtual currency	1 398 195 086 USD	2013-10-24	2018-12-11	1875
TRX	Decentralized applications platform	898 301 706 USD	2017-10-10	2018-12-11	428
ADA	Decentralized applications platform	747 995 985 USD	2017-12-30	2018-12-11	347
XMR	Virtual currency	707 567 024 USD	2015-01-29	2018-12-11	1413
XEM	Decentralized applications platform	644 130 000 USD	2017-06-02	2018-12-11	558
IOT	Virtual currency / Other	623 170 689 USD	2017-06-13	2018-12-11	547
DASH	Virtual currency	556 945 536 USD	2015-09-01	2018-12-11	1198
ETC	Decentralized applications platform	417 123 543 USD	2016-07-27	2018-12-11	868
NEO	Decentralized applications platform	382 200 000 USD	2017-08-05	2018-12-11	494
MKR	Other	313 909 600 USD	2017-01-30	2018-12-11	681

Table 1 – Summary of cryptocurrencies' function, market capitalization and observations

Data source: CryptoCompare (n.d.)

Table 1 above summarize information on the include cryptocurrencies including market capitalization, first, last and number of observations and as well as categorization of the cryptocurrencies based on their main function. Four categories have been identified: virtual currency, which are cryptocurrencies that aim to provide a similar functionality to that of regular money; decentralized applications platform, which are cryptocurrencies used in running applications on the decentralized network of the blockchain; financial networks, which aim to provide service such as instant global payments in real-world currencies through cryptocurrency technology; and stablecoins, which aim to hold a constant price in order to be a safe store of value. Two of the cryptocurrencies were hard to categorize under this scheme and has therefore been given the label other. A more thorough presentation of the goals, functionality and important technical points for each of the cryptocurrencies selected for inclusion in this study follows below. The cryptocurrencies are here presented in chronological order of launch as many of the currencies build on each other.

4.1.1 Bitcoin (BTC)

Bitcoin was conceived in a whitepaper released under the pseudonym Satoshi Nakamoto (2008). As earlier presented, Bitcoin is based on a proof-of-work consensus model with 10-minute blocks which means that transactions are not instant. Transactions on the network are anonymous in the sense that it is very difficult to link a user to a wallet but if the identity should be revealed all transactions made by the wallet will be available for viewing on the public ledger (Segendorf, 2014).

4.1.2 Litecoin (LTC)

Litecoin is uses technology similar to Bitcoin but groups transactions into 2,5-minute blocks in order to increase transaction speed and rate. Litecoin also uses a different cryptographic algorithm which makes specialized hardware more expensive and less efficient compared to ordinary computers for mining Litecoin. (Litecoin Project, n.d.)

4.1.3 Ripple (XRP)

XRP is the currency of RippleNet which is a decentralized financial network, aimed mainly at banks and payment providers, offering global payments and cross-border liquidity without the need for holding reserves in foreign accounts. Ripple offers fast transactions (4 seconds) at a low cost while providing higher certainty regarding fees and payment status than traditional payments. RippleNet has over 200 connected banks and payments providers worldwide and claims to be able to handle the same transaction throughput as Visa. (Ripple, n.d.-b; Ripple, n.d.-a)

4.1.4 Monero (XMR)

Monero is a cryptocurrency focusing on privacy for the users. While many other cryptocurrencies, for example Bitcoin and Ethereum, employ a pseudo-anonymous approach where all transactions are public and traceable between accounts but contain no information about the person behind the account, Monero obfuscates the amount along with the sender and receiver of transactions by default. This means that it is not possible to follow transactions between accounts and that if the identity of participants of one transaction should be revealed it is still not possible to identify other transactions they have done. Monero also upholds this as an important aspect of currency fungibility, as a unit of currency should not be affected by its transaction history which requires anonymous transactions. (The Monero Project, n.d.)

4.1.5 Ethereum (ETH)

Ethereum aims to provide a decentralized platform for running “smart contracts” in a distributed manner using similar blockchain technology to that of Bitcoin. The “smart contracts” are applications which are run on the nodes of the network and can be programmed using a fully featured custom programming language. The Ethereum Whitepaper divides these applications into three classes and provides examples: financial applications, for instance custom currencies, futures contracts or a will; semi-financial applications exemplified by “self-enforcing bounties for solutions to computational problems”; and non-financial applications such as online voting. Running an application on the Ethereum network is paid for with the Ether currency through transaction costs on the network. (Ethereum Foundation, n.d.)

4.1.6 Dash (DASH)

Dash is based on Bitcoin but seeks to make improvements within two key areas: privacy and transaction speed. This is in response to problems seen with Bitcoin’s pseudo-anonymous public ledger and the waiting time for confirming transactions (due to the 10-minute blocks) which impedes point-of-sale use of Bitcoin without an intermediary. (Duffield & Diaz, 2018)

The improvements are made by introducing a secondary network of so-called masternodes. The masternodes are granted special privileges such as locking inputs for a specific transaction meaning that the transaction can be secured almost instantly even though it has yet to be written onto the blockchain. The masternode network also provides a “mixing service” which mixes inputs and outputs in a group of transactions ensuring a higher degree of anonymity. (Duffield & Diaz, 2018)

4.1.7 Ethereum Classic (ETC)

Ethereum Classic is a spin-off from Ethereum and was created in July and August of 2016 after a conflict within the Ethereum community. The conflict arose due to disagreements regarding the handling of security vulnerabilities within an Ethereum application that lead to the theft of 50 million USD in Ether. In order to refund the Ether stolen a decision was made to make a change to the Ethereum blockchain which deleted the stolen Ether and provided a way to those affected to withdraw new Ether created specifically for this purpose. This decision meant that a split would be created in the Ethereum blockchain, a so-called hard-fork. As a large part of the community was against such a split due to beliefs that the blockchain must never be changed they instead decided to continue on the old blockchain path instead of the newly created path and thus Ethereum Classic was created. (Wilcke, 2016; Moskov, 2018; Ethereum Classic, n.d.; Buterin, 2016a; Buterin, 2016b)

4.1.8 Lumen (Stellar Network) (XLM)

Lumen is the native currency of the Stellar Network which provides a decentralized financial network that can be used by anyone in the world. Transactions on the network are made fast (2-5 seconds), by utilizing a custom consensus protocol, and transaction fees are low ("$0.01 fee handles ~600,000 transactions"). Through a system of offers published on the Stellar ledger, the network can seamlessly handle transactions between different currencies by utilizing intermediaries for currency conversion. The conversion between Lumen and real world (or other digital) currencies is handled by user-trusted entities called "anchors", Users deposit money with an anchor for which they are issued credits which can be used on the Stellar network. Areas of use for the network include global transactions, micropayments and other financial services. (Stellar Development Foundation, n.d.-a; Stellar Development Foundation, n.d.-b)

4.1.9 MKR token / Maker (MKR)

Maker is focused on creating a stablecoin called Dai, that can be used as a normal currency, something which Maker deems not currently possible with many other cryptocurrencies because of their high volatility. Instead of a dollar backed stablecoin Maker has created a system where users put up collateral, currently in the form of Ether, in exchange for Dai. The price ratio between the collateral and Dai is kept at a minimum by the system automatically selling off collateral if the price should fall too low. The MKR token has two uses within the

Maker ecosystem. Firstly, it functions as a governance token allowing holders to vote on important aspects of the system, such as the collateral to Dai ratio. Secondly, if the total collateral should not cover the Dai value, more MKR tokens are created and auctioned off until the missing value is covered. As reward for taking on risk and their governance task, holders of MKR are awarded dividends in the form of transaction fees from Dai transactions. (Maker, n.d.)

4.1.10 Tether (USDT)

Tether is a stablecoin, designed to be a stable currency with a price always being equal to one US Dollar. This is achieved by backing all Tether tokens in circulation one-to-one with US Dollars in reserves held by Tether Limited, the company behind Tether. Technically, Tether exists on either the Bitcoin or Ethereum blockchain utilizing the respective network as a transport protocol. (Tether, 2018)

4.1.11 XEM / NEM (XEM)

XEM is the currency of the NEM project and is used for transactions on its network. XEM uses a modified proof-of-stake consensus model, called proof-of-importance, in which not only account balance but also other factors such as economic activity are included when deciding which user is eligible to produce the next block. The block producer is paid through transaction fees as the total amount of XEM tokens is fixed in order to prevent inflation. Through NEM users can register digital assets on the blockchain which can then be tracked. Examples of usage areas include private tokens, such as reward points or a private currency, secure voting, encrypted messaging and logistics systems for supply chain management. (NEM.io Foundation, 2018; NEM.io Foundation, n.d.)

4.1.12 IOTA (IOT)

IOTA aims to provide a network for data transfer as well as fast and feeless microtransactions focused on the Internet of Things (IoT). Backing IOTA is a custom distributed ledger implementation, called “The Tangle”, which replaces the blockchain with a system of interconnected transactions. The system employs a “pay-it-forward” approach in which every user helps validate previous transactions and as a reward, their own transactions are verified for free. The system also enables a high transaction rate as increased activity by definition brings more validators to the network. (IOTA Foundation, n.d.)

4.1.13 EOS (EOS)

EOSIO is a platform for running decentralized applications with the potential of scaling up to handling millions of transactions per second. It is built by a company called Block.one and stands out from similar platforms by having no transaction fees. Instead, the system is stake based, meaning that in order to run an application one has to own EOS tokens and costs of running an application are covered through inflation as new tokens are issued to the nodes of the network that run the application. The amount of resources dedicated to an application is decided by the size of the stake of the account running it. (Block.one, n.d.; Block.one, 2018)

4.1.14 Bitcoin Cash (BCH)

Bitcoin Cash was created in August 2017 after a two-year conflict within the Bitcoin community due to scaling problems. As Bitcoin had gained in popularity the Bitcoin block size had become a hard-limit for the rate at which transactions could be processed. In order to mitigate this problem parts of the community wanted to increase the block size which would allow a higher transaction rate and lower transaction costs as more transactions would be included per block (a block being processed at roughly fixed time intervals and at a cost increasing as blocks get full). The conflict came to an end, as Bitcoin was split into two on the 1st of August 2017, with every holder of Bitcoin receiving an equal amount of the newly created Bitcoin Cash. (The Economist, 2017) As a fork from Bitcoin, Bitcoin Cash operates on the same base as Bitcoin but seeks to make improvements to allow further scaling and faster transactions (Bitcoin Cash, n.d.).

4.1.15 NEO (NEO)

NEO network aims to create a “smart economy” through digitized assets, digital identity and smart contracts, used to manage the digital assets automatically. NEO is the main token of the network and represents management rights through voting. A secondary token called GAS is used for transactions costs. Smart contracts on the NEO network run on the Neo Virtual Machine which can run programs written in well-established programming languages such as Java or C#. (NEO, n.d.)

4.1.16 Tronix / Tron Project (TRX)

Tronix is the currency of the Tron project, a decentralized application platform which aims to solve scalability problems seen with earlier similar projects such as Ethereum. The main improvements made to scalability come from using a delegated proof-of-stake consensus model in which 27 so-called "super representatives" are chosen as block producers through voting every 6 hours. The consensus model supports 2000 transactions per second and uses 3-second blocks. Applications on the Tron network are run on the Tron Virtual Machine which is based on the Ethereum Virtual Machine and mostly compatible. (TRON Foundation, 2018)

4.1.17 Ada / Cardano (ADA)

Ada is the currency of Cardano which aims to be a platform for running financial (and other) decentralized applications. Cardano emphasizes having a scientific and research-based approach and claims to have the first mathematically proven secure and peer-reviewed proof-of-stake consensus model. The Cardano project is still under heavy development and currently only the currency part of the project, called the "settlement layer" has been implemented with the application platform being the next step. (Cardano, n.d.-a; Cardano, n.d.-b)

4.2 Presentation of traditional assets

Below follows a presentation of the traditional assets chosen for inclusion in this study. For all traditional assets, daily observations were collected from 19th July 2010 until 11th December 2018, for a total of 2116 observations.

4.2.1 SPDR S&P 500 ETF (SPY)

The SPDR S&P 500 ETF (SPY) seeks to replicate the performance of the S&P 500 Index. The S&P 500 Index includes 500 US companies in different industries and is used as an indicator of the US economy at large by the US Department of Commerce (PDR Services LLC, 2018). Within this thesis, the SPDR S&P 500 ETF serves the purpose of representing investments in a US stock portfolio.

4.2.2 Vanguard Total World Stock ETF (VT)

Vanguard Total World Stock ETF (VT) seeks to replicate the performance of the FTSE Global All Cap Index. The FTSE Global All Cap Index is a stock index including 7781 stocks in 41 countries, both developed and emerging, as of 31st October 2017. The stocks respective weights are calculated from their float-adjusted market capitalization. (The Vanguard Group, 2018b) Within this thesis, the Vanguard Total World Stock ETF serves the purpose of representing investments in a global stock portfolio.

4.2.3 UBS ETRACS Bloomberg Cmdty Tot Ret ETN (DJCI)

UBS ETRACS Bloomberg Cmdty Tot Ret ETN seeks to replicate the performance of the Bloomberg Commodity Index Total Return (formerly branded as the Dow Jones-UBS Commodity Index). The Bloomberg Commodity Index is a diversified index which includes up to 24 potential commodities including metal, energy and agricultural commodities through futures contracts. (UBS AG, 2018) Within this thesis, the UBS ETRACS Bloomberg Cmdty Tot Ret ETN serves the purpose of representing investments within the commodities market.

4.2.4 Vanguard Real Estate ETF (VNQ)

Vanguard Real Estate ETF (VNQ) seeks to replicate the performance of the MSCI US Investable Market Real Estate 25/50 Index which consists of stocks of companies within the US real estate sector (The Vanguard Group, 2018a). Within this thesis, the Vanguard Real Estate ETF serves the purpose of representing investments in US real estate.

4.2.5 iShares TIPS Bond ETF (TIP)

iShares TIPS Bond ETF (TIP) seeks to replicate the performance of the Bloomberg Barclays U.S. Treasury Inflation Protected Securities (TIPS) Index (Series-L). The Bloomberg Barclays U.S. Treasury Inflation Protected Securities (TIPS) Index measures the performance of US Treasury Inflation Protected Securities, bonds that offer inflation-protected returns through consumer price index adjusted payments. (BlackRock Inc., 2018c) In this thesis, the Vanguard Real Estate ETF serves the purpose of representing investments in US government bonds.

4.2.6 iShares Gold Trust ETF (IAU)

iShares Gold Trust ETF (IAU) seeks to reflect the performance of the price of gold and provide a simple and cost-effective way for investors to gain access to investments in gold. Fund shares are backed by physical gold held by the Trust. (BlackRock Inc., 2018a) Within this thesis, the iShares Gold Trust ETF serves the purpose of representing investments in gold.

4.2.7 iShares MSCI Emerging Markets ETF (EEM)

iShares MSCI Emerging Markets ETF (EEM) seeks to replicate the performance of the MSCI Emerging Markets Index. The MSCI Emerging Markets Index consists of large- and mid-cap equity from 24 emerging market countries. (BlackRock Inc., 2018b) Within this thesis, the iShares MSCI Emerging Markets ETF serves the purpose of representing investments in emerging markets.

4.3 Descriptive statistics

	Number of observations	Mean return	Standard deviation	Skewness	Kurtosis, excess	Anderson-Darling Test	Mean excess return	Sharpe-ratio
Cryptocurrencies								
ADA	347	-319,0%	26,49	0,33	4,00	6,0973***	-320,9%	-0,1211
BCH	498	-112,5%	33,12	0,45	5,13	9,7499***	-114,2%	-0,0345
BTC	3068	126,7%	24,77	2,87	94,02	196,3202***	126,3%	0,0510
DASH	1198	98,0%	27,74	0,13	31,07	36,7741***	97,1%	0,0350
EOS	531	53,9%	36,88	2,39	22,92	14,2387***	52,3%	0,0142
ETC	868	37,5%	26,40	0,52	6,43	16,8532***	36,3%	0,0138
ETH	1223	100,8%	28,25	-1,16	18,75	30,426***	99,9%	0,0354
IOT	547	-64,0%	33,42	0,14	2,98	4,3677***	-65,7%	-0,0196
LTC	1875	40,1%	28,22	0,64	34,29	121,4992***	39,5%	0,0140
MKR	681	95,4%	81,53	-0,07	87,35	105,2092***	94,0%	0,0115
NEO	494	-64,5%	31,37	0,71	4,68	6,0353***	-66,1%	-0,0211
TRX	428	141,4%	45,10	1,52	8,22	13,5876***	139,6%	0,0310
USDT	620	-0,5%	3,72	1,25	35,25	49,6457***	-2,0%	-0,0055
XEM	558	-72,3%	29,93	1,93	20,51	10,9253***	-73,9%	-0,0247
XLM	694	205,8%	37,95	1,22	8,01	12,6494***	204,4%	0,0539
XMR	1413	127,3%	56,91	0,03	24,10	114,5278***	126,5%	0,0222
XRP	1421	76,6%	40,87	0,80	21,80	91,7469***	75,8%	0,0185
Traditional assets								
DJCI	2116	-5,6%	2,34	-0,05	3,20	14,3582***	-6,0%	-0,0255

EEM	2116	2,1%	3,35	-0,34	2,86	8,7954***	1,7%	0,0050
IAU	2116	0,3%	2,51	-0,60	6,43	20,6448***	-0,1%	-0,0002
SPY	2116	12,7%	2,28	-0,59	4,78	30,9268***	12,3%	0,0541
TIP	2116	2,4%	0,81	-0,16	2,69	7,4573***	2,0%	0,0244
VNQ	2116	10,4%	2,72	-0,35	6,59	19,5048***	10,0%	0,0369
VT	2116	8,5%	2,49	-0,62	5,39	28,0535***	8,1%	0,0325

Table 2 – Descriptive statistics for all assets

**** (**, *) denotes rejection of normality at 1% (5%, 10%) significance level*

Data source: CryptoCompare (n.d.) for cryptocurrencies and Yahoo Finance (n.d.) for traditional assets

Table 2 above shows descriptive statistics for the cryptocurrencies and traditional assets. The mean and standard deviation have been annualized as described in Equation 4. The statistics show how the cryptocurrencies showcase much more extreme price movements compared to the traditional assets, with the exception of the stablecoin Tether (USDT). This confirms that the cryptocurrencies are high-risk assets with the possibility of both extreme losses and profits. However, as the price movements come with increased risk, the cryptocurrencies do not provide a much-improved reward-to-volatility ratio compared to the traditional assets, shown by Sharpe-ratios in the same order of magnitude.

Furthermore, the excess kurtosis of the cryptocurrencies is high to very high demonstrating large tail-risk. For some of the assets their high kurtosis was somewhat explained from a few extreme outliers in the data. Whether these observations were due to data issues or actual prices could not be concluded but nonetheless, the cryptocurrencies should not be regarded as anything but having high to very high tail-risk. The excess kurtosis, along with skewness for some assets, suggest that the returns are not normally distributed. This is confirmed by the Anderson-Darling test of normality which was rejected for all assets at the 1% significance level, meaning that is unlikely that the returns are normally distributed.

4.4 Correlations among assets

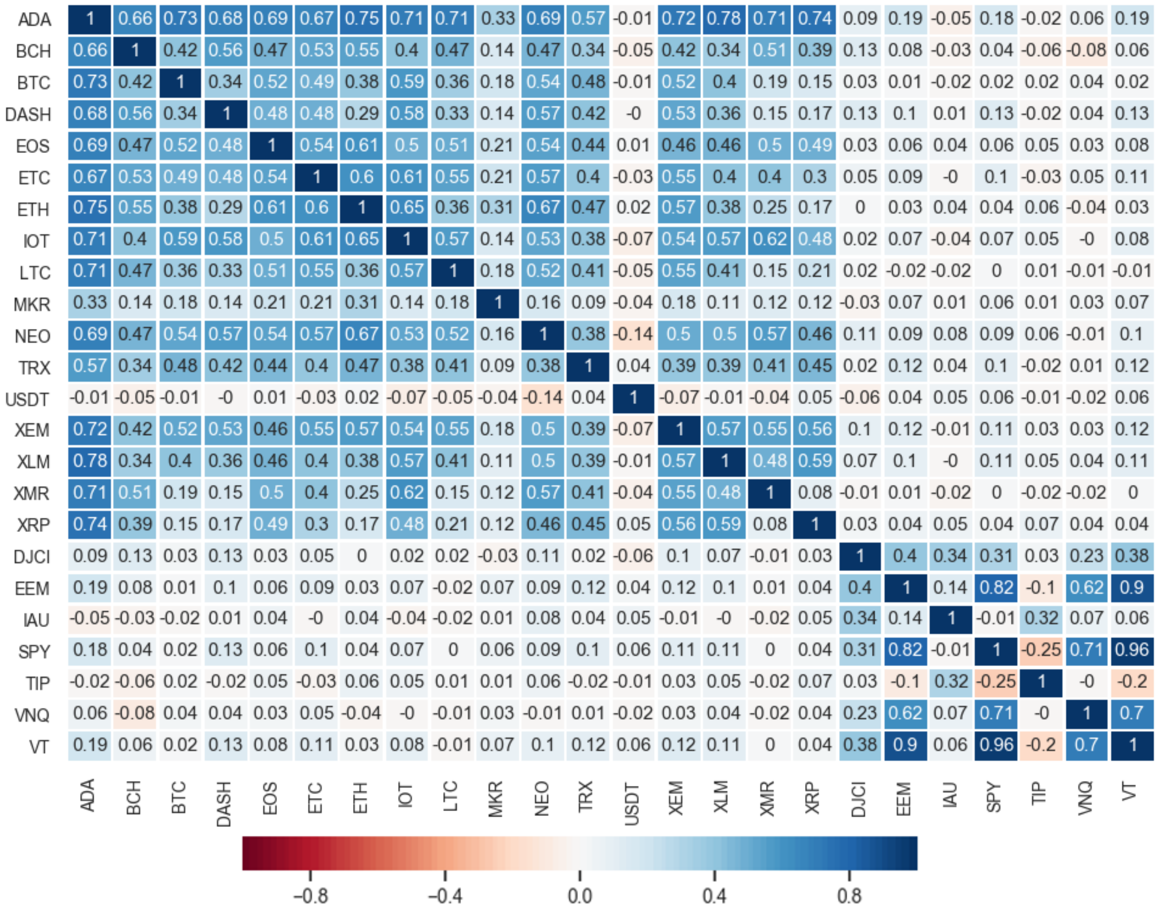

Figure 1 – Correlation matrix for all assets

Data source: CryptoCompare (n.d.) for cryptocurrencies and Yahoo Finance (n.d.) for traditional assets

Figure 1 above shows the correlations between all the assets included in the study. As can be seen in the figure, the cryptocurrencies and traditional assets are generally uncorrelated. This is consistent with earlier research (Baur et al., 2018; Corbet et al., 2018a; Guesmi et al., 2018) and suggests that the cryptocurrencies might present a diversification opportunity for a portfolio composed of the traditional assets. Within the cryptocurrencies, there is generally mild to moderate correlation. The exception to this again being Tether (USDT), which is designed to be price stable and therefore shows no correlation with the other cryptocurrencies. The traditional assets show more varying correlations between themselves.

5 Results

The following sections present the optimal portfolios constructed for the four asset groups: the cryptocurrencies; the traditional assets; the combination of traditional assets and cryptocurrencies present in the Sharpe-ratio maximizing cryptocurrency portfolio under short sale restrictions; and the combination of traditional assets and Bitcoin. Portfolio weights, along with annualized return statistics, are presented in the tables for each of the three portfolios solved for: maximum Sharpe-ratio without short sales (Max SR), maximum Sharpe-ratio with short sales (Max SR w/ SS) and the minimum variance portfolio (MVP). The efficient frontier, along with the placement of the portfolios and assets, can be seen in the figures, which plot return over volatility.

5.1 Optimal portfolio of traditional assets

	Max Sharpe-ratio (no short sales)	Max Sharpe-ratio (with short sales)	Min Variance
DJCI		-14,99%	3,05%
EEM		-24,24%	
IAU		7,67%	
SPY	36,38%	127,70%	15,30%
TIP	63,62%	65,88%	81,65%
VNQ		-4,41%	
VT		-57,62%	
Return	6,14%	12,81%	3,72%
Volatility	0,86	1,11	0,69
Excess return	5,75%	12,41%	3,32%
Sharpe-ratio	0,0666	0,1120	0,0483

Table 3 – Portfolio compositions and performance statistics for traditional assets

As can be seen in Table 3, all the optimal portfolios for the traditional assets hold large weights in the S&P 500 fund (SPY) and the bonds fund (TIP) with the bond fund unsurprisingly having a larger weight in the minimum variance portfolio as it is a lower risk investment. When short-sales are allowed a small position is taken in gold (IAU) and short positions taken in the other assets allowing for a leveraged position in the S&P 500.

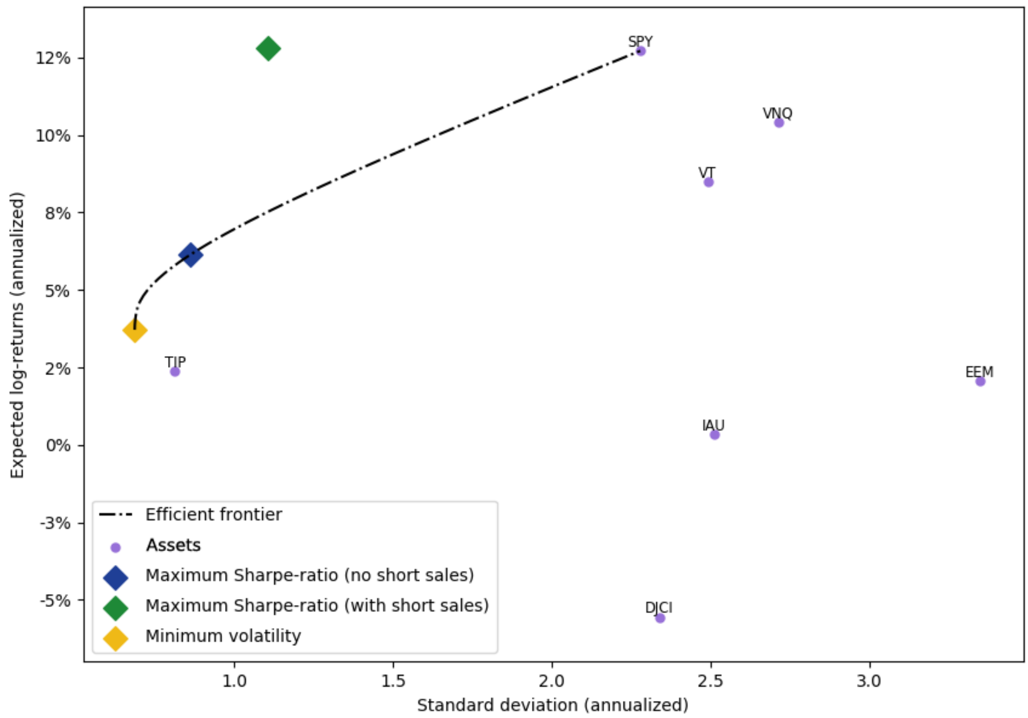

Figure 2 – Plot of efficient frontier with optimal portfolios for traditional assets

5.2 Optimal portfolio of cryptocurrencies

	Max Sharpe-ratio (no short sales)	Max Sharpe-ratio (with short sales)	Min Variance	Min Variance excl. USDT
ADA		-100,00%		
BCH		-34,37%	0,18%	
BTC	42,14%	65,79%	0,69%	30,16%
DASH	14,14%	83,30%		20,76%
EOS		-25,03%		
ETC		59,46%		4,49%
ETH	12,79%	72,83%		17,09%
IOT		-58,98%	0,05%	
LTC		53,65%	0,53%	13,43%
MKR		-2,62%	0,12%	
NEO		-38,30%	1,93%	
TRX		-15,84%		
USDT		-6,53%	95,92%	
XEM		-27,87%	0,52%	
XLM	26,65%	7,72%		
XMR	4,28%	19,65%	0,07%	4,05%
XRP		47,14%		10,02%
Return	140,44%	761,13%	-1,06%	95,68%
Volatility	20,33	12,62	3,59	17,24
Excess return	139,62%	763,08%	-2,56%	94,97%
Sharpe-ratio	0,0687	0,6048	-0,0071	0,0551

Table 4 - Portfolio compositions and performance statistics for cryptocurrencies

The Sharpe-ratio maximizing portfolio of cryptocurrencies without short sales takes positions in 5 of the 17 cryptocurrencies as shown in Table 4. Like the individual cryptocurrencies the high expected return of the portfolio comes at high volatility and the Sharpe-ratio is comparable to that of the same strategy portfolio in traditional assets. Removing the short sale restrictions lead to a theoretical ten-fold increase in Sharpe-ratio by lowering volatility through diversification and holding short positions held in assets with negative yield such as Cardano (ADA).

Two minimum variance portfolios were constructed as the first portfolio was almost fully made up of Tether (USDT) which is equivalent to holding cash if Tether works as intended. In Figure 3 shows that this is not quite the case with Tether having a positive volatility, though almost no expected return. Because of the theoretical cash-equivalency of Tether, a second portfolio was constructed without Tether. Even if this portfolio was constructed to minimize risk it showed a very high volatility, showcasing the risk of cryptocurrencies across the board.

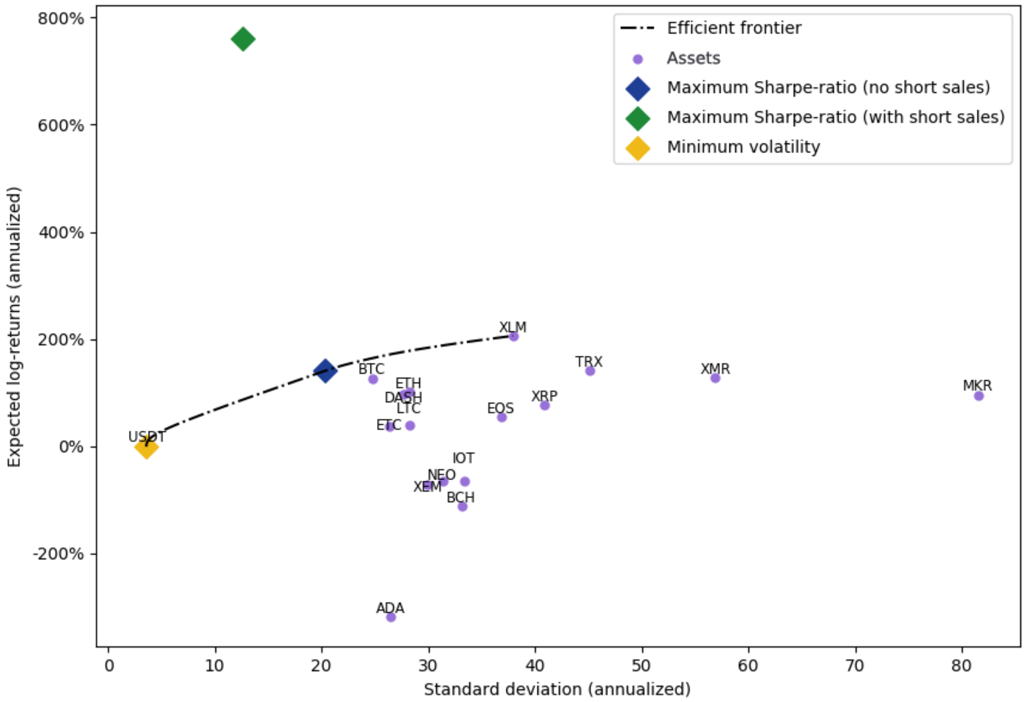

Figure 3 - Plot of efficient frontier with optimal portfolios for cryptocurrencies

5.3 Adding cryptocurrencies to traditional assets

	Max Sharpe-ratio (no short sales)	Max Sharpe-ratio (with short sales)	Min Variance
BTC ^{CC}	1,96%	1,58%	
DASH ^{CC}	0,38%	0,36%	
ETH ^{CC}	0,52%	0,26%	
XLM ^{CC}	1,05%	0,80%	
XMR ^{CC}	0,24%	0,20%	0,03%
DJCI ^{TA}		-17,17%	3,07%
EEM ^{TA}		-25,40%	
IAU ^{TA}		9,04%	
SPY ^{TA}	34,71%	128,87%	15,29%
TIP ^{TA}	61,14%	63,68%	81,61%
VNQ ^{TA}		-3,41%	
VT ^{TA}		-58,81%	
Return	11,71%	17,53%	3,75%
Volatility	1,24	1,33	0,69
Excess return	11,30%	17,12%	3,36%
Sharpe-ratio	0,0914	0,1286	0,0488

Table 5 - Portfolio compositions and performance statistics for combination of traditional assets and cryptocurrencies
^{CC} denotes cryptocurrencies, ^{TA} denotes traditional assets

As seen in Table 5, Cryptocurrencies were included in all three portfolios combining the cryptocurrencies and traditional assets, although minimally in the minimum variance portfolio.

Comparing with allocations when using only traditional assets from Table 3, the maximum Sharpe-ratio portfolio with short-sale restrictions showed a 37% increase in Sharpe-ratio when including cryptocurrencies. All five cryptocurrencies were added, in total making up 4,15% of portfolio value, with weights in S&P 500 (SPY) decreasing by 4,5% and by 3,9% in the bonds fund (TIP).

Again comparing to Table 3, a smaller performance increase of 17% was seen when including cryptocurrencies with short-selling available. The new portfolio included all five cryptocurrencies at a total weight of 3,20% and saw a rebalancing of the positions in the traditional assets. Short positions were similar to that of the traditional asset only portfolio, with these positions allowing a leveraged position in the S&P 500 (SPY). The slightly smaller position in the bonds fund and somewhat large short positions made room in the portfolio for the cryptocurrencies.

For the minimum variance portfolio, the very small position in Monero (XMR) led to a very small increase in return with unchanged volatility.

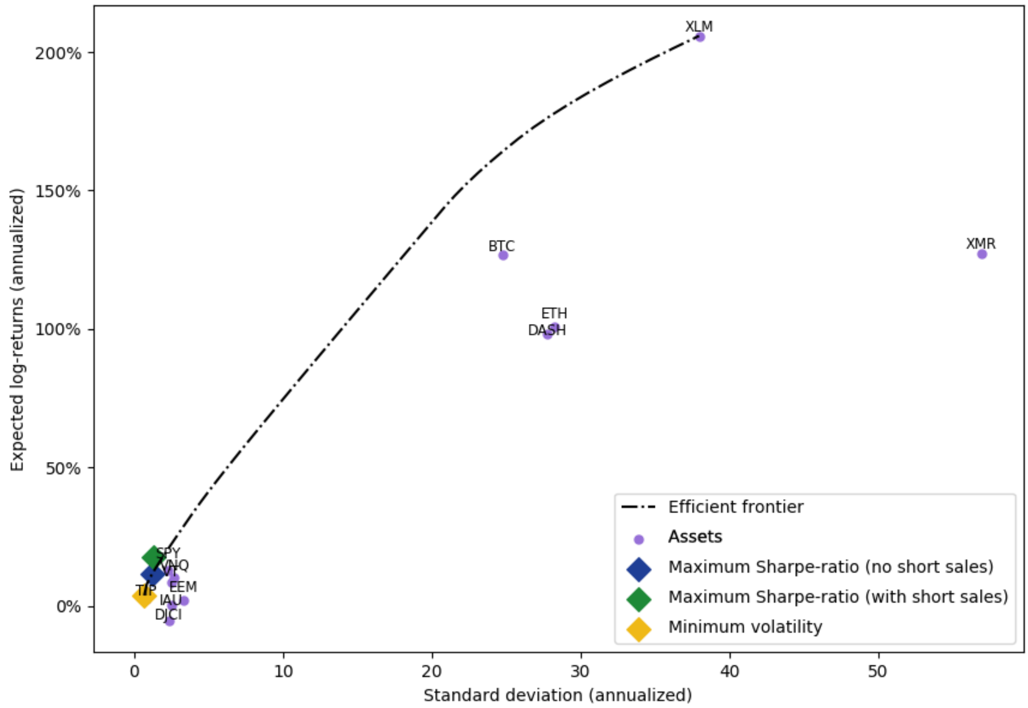

Figure 4 - Plot of efficient frontier with optimal portfolios for combination of traditional assets and cryptocurrencies

5.4 Adding Bitcoin to traditional assets

	Max Sharpe-ratio (no short sales)	Max Sharpe-ratio (with short sales)	Min Variance
BTC [CC]	2,56%	2,02%	
DJCI [TA]		-15,87%	3,06%
EEM [TA]		-23,25%	
IAU [TA]		8,57%	
SPY [TA]	35,68%	129,45%	15,30%
TIP [TA]	61,75%	64,38%	81,64%
VNQ [TA]		-5,32%	
VT [TA]		-59,98%	
Return	9,25%	15,33%	3,72%
Volatility	1,07	1,22	0,69
Excess return	8,85%	14,94%	3,32%
Sharpe-ratio	0,0826	0,1228	0,0483

Table 6 - Portfolio compositions and performance statistics for combination of traditional assets and Bitcoin
[CC] denotes cryptocurrencies, [TA] denotes traditional assets

As the available data for all cryptocurrencies included in the portfolios seen in the previous section is very limited, a second set of portfolios were created using the traditional assets and Bitcoin, for which more data is available.

Creating an optimal portfolio using this group of assets lead to small weights in Bitcoin for both Sharpe-ratio maximizing portfolios as seen in Table 6. Under short sale restrictions, a 2,56% position was held in Bitcoin, with the position in the S&P 500 (SPY) decreasing by 2% and in the bonds fund (TIP) by 3%. This led to a 24% increase in Sharpe-ratio. Without short sale restrictions, a 2,02% position was held in Bitcoin with 5-10% changes to positions in traditional assets. Bitcoin was not included in the minimum variance portfolio which remained virtually unchanged. Figure 5 shows the extreme position of Bitcoin in terms of expected return and standard deviation compared to the traditional assets.

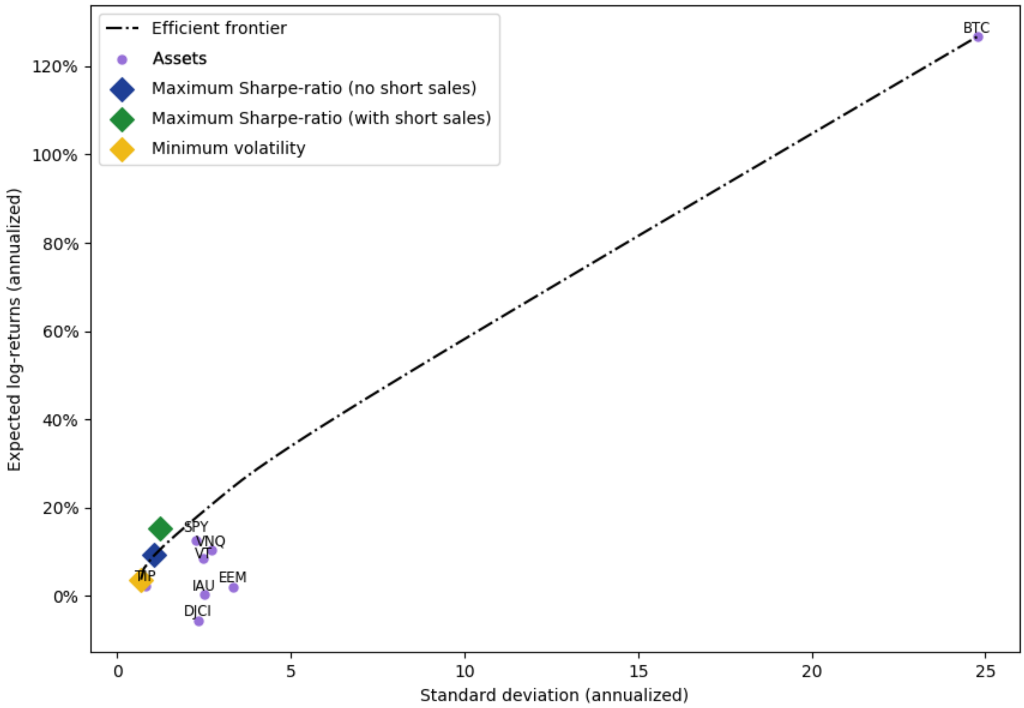

Figure 5 - Plot of efficient frontier with optimal portfolios for combination of traditional assets and Bitcoin

6 Discussion of results

6.1 Findings

The results from the portfolio optimizations show that adding small proportions of cryptocurrencies to a portfolio of traditional assets can enhance portfolio performance in terms of Sharpe-ratio. While the addition of these high-risk assets leads to higher portfolio volatility, this effect is exceeded by the high expected return and diversification benefits provided. The results also show that including all cryptocurrencies from the optimal portfolio is preferable to only including Bitcoin. This suggests that diversification amongst the cryptocurrencies is to at least some degree possible and advantageous.

In the portfolios were short selling is available, including the cryptocurrencies has a somewhat reduced effect but is still present. It is worth noting that since the positions in the cryptocurrencies are all long positions short selling need only be available for the traditional assets.

These findings confirm and expand on earlier research mainly in two ways. The results confirm that previous suggestions of Bitcoin's use as a performance enhancer in traditional portfolios still hold, even though Bitcoin has seen a sharp fall in prices recently. Expanding on previous research, this study has taken a wider perspective by including 17 cryptocurrencies in total. Corbet et al. (2018b) have suggested that other cryptocurrencies could be of interest and our results show that this is also the case.

Aside from the investment related findings, we have also shown the range of different cryptocurrencies available on the market. While this might seem like technical details, the investment opportunities presented by a cryptocurrency which aims to keep a one-to-one exchange rate with the US Dollar are clearly very different from those offered by the cryptocurrency which is to be used on a global financial network. When technology and market mature, we can probably expect this distinction to become more important as differently designed cryptocurrencies will behave differently on the market.

6.2 Implementation

While investments in cryptocurrencies still require some technical know-how, the investment strategy proposed through our results should be implementable for a moderately tech-savvy investor. Buying cryptocurrency requires setting up an account with a market as well as wallets for storing the different cryptocurrencies off the market. A problem with trading cryptocurrencies has previously been high transaction costs and long transaction times between fiat currency and cryptocurrency. This has to some extent been resolved with the introduction of US Dollar pegged stablecoins such as Tether (USDT). By using these stablecoins, it is possible to move money from a highly volatile asset such as Bitcoin into a stable asset and thereby securing one's investment. The stablecoins are however still new and by no means guaranteed risk-free. The traditional assets are traded on the New York Stock Exchange and are commonly traded assets with high liquidity.

There have also been some developments in alternative ways of investing in cryptocurrencies which could make the cryptocurrency market more available for the general populace. Bitcoin futures are available on the Chicago Mercantile Exchange (CME Group, n.d.) and cryptocurrency ETFs and ETNs available on the Toronto (Owram & Wilson, 2018) and Stockholm (XBT Provider, n.d.) stock exchanges. Within the US, an application one such ETF is currently being considered by the Securities and Exchange Commission (SEC) after the decision was postponed (Kauflin, 2018).

6.3 Shortcomings

While our results show that cryptocurrencies can enhance the performance of a traditional investment portfolio it is also necessary to discuss some shortcomings of the methodology used. By using the Sharpe-ratio as our measure of portfolio performance, it is implicitly assumed that the standard deviation is a correct measure of portfolio risks. While this holds true if returns are normally distributed, the results of the Anderson-Darling test show that the returns are in fact very unlikely to be normally distributed. This would mean that our performance measure does not fully capture the risk in a portfolio and thus does not correctly rank the portfolios. As this study has focused on identifying possible investment opportunities within a large set of cryptocurrencies, we have chosen to still use the Sharpe-ratio due to its ease-of-use but recommend that further studies look at measures which could more accurately capture portfolio performance.

Due to the relatively short history of many of the cryptocurrencies, we are also basing our results on limited data. This means that estimations of means, standard deviations and correlations are less likely to provide the true values of the measures. This could lead to incorrect results arising from our models. As with any estimates made from historical observations, it is also only possible to predict from history such events that have occurred before. With recent innovations such as cryptocurrencies, it is therefore not unlikely that events might arise that are hard to predict from historical data.

6.4 Risks

In addition to the high standard deviations seen for almost all cryptocurrencies, they have also often exhibited very high excess kurtosis. This means that there is a high tail-risk, or in other words, that extreme events are more common than if the returns were normally distributed.

Besides the financial risks discussed, cryptocurrencies also present some unique types of risk due to how they work. As previously mentioned, all cryptocurrency holdings are associated with a wallet, which is comprised of a public address and a private key. Whoever has access to the private key also has access to the currency linked to it and should the key be lost then so will any currency linked to the wallet. This means that an investor is highly susceptible to financial loss in case of a hacker attack or data loss. While some preventative measures are available such as special encrypted wallet USB-drives this risk is not entirely preventable.

Matters are further complicated as in order to trade cryptocurrency on a market one must transfer the cryptocurrency to a wallet held by that market. This makes markets very attractive targets for hackers as gaining access to the wallets they hold for customers could be very profitable. Once again, markets try to prevent hacks and other forms of data loss by for example storing wallets offline when not in use (iFinex Inc, n.d.). There is also the risk of the market going bankrupt, a risk which was realised when the market Mt Gox filed for bankruptcy after the loss of Bitcoin then equal to a value of 480 million US Dollars (Takemoto & Knight, 2014).

Finally, the legal status of cryptocurrencies is often unclear and there is a regulatory risk present with any investment. In the US, for example, cryptocurrency investments are treated differently by different government agencies and recent rumours regarding regulation have had a large effect on prices (Corbet et al., 2018a).

7 Conclusions

Our research suggests that cryptocurrencies can play a role within an otherwise traditional investment portfolio as including cryptocurrencies in an investment portfolio seems to provide a boost to returns which outweighs the increased volatility. It should, however, be noted that cryptocurrencies are new and risky assets and as such traditional methods of assessing risk might not be sufficient. The research also shows that not only Bitcoin but several cryptocurrencies should be considered and that there is likely benefit in diversifying one's position within cryptocurrencies.

While cryptocurrency investments are currently mainly available to technically minded investors there are coming developments within the market. The launch of Bitcoin futures and exchange-traded product on different markets suggest an interest in more easily accessible cryptocurrency investments. One can expect further developments in this area.

Through our perspective of looking at several different cryptocurrencies, we have also showcased the variety of different cryptocurrencies available. Excluding stablecoins, the different types of currencies have appeared in terms of mean, variance, skewness and kurtosis on the surface, but a deeper look might give further insight. New cryptocurrencies are also constantly appearing and the distinction between types might become more important looking forward.

7.1 Suggestions for further research

In order to confirm that the findings of this study hold true, we suggest that further research into accurately estimating cryptocurrency risk from an investment standpoint should be considered. Bitcoin prices have also been in decline for the past year and how the price develops in the coming years might affect whether it continues to be of interest to investors or not which warrants further studies in the future.

Finally, we would like to suggest that further research not only focus on Bitcoin, but include other cryptocurrencies as they mature. It is our belief that different cryptocurrencies might be different in nature also from a financial perspective and as such, past opinions based on Bitcoin might need to be re-evaluated.

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