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Do cryptocurrencies offer any diversification benefits?

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Abstract

This paper investigates the diversification benefits of cryptocurrencies in an already diversified portfolio between 2017-2021 using the mean-variance framework. The efficient frontier of each portfolio is constructed by adding each cryptocurrency one by one in the traditional portfolio. In addition, this work uses measures of portfolio performance such as the Sharpe ratio to evaluate each portfolio. For the majority of the cryptocurrencies investigated, there is evidence of diversification benefits; however, this is dependent on the investor's investment strategy. The examined period includes the Covid-19 pandemic, where the findings are challenging. In more detail, some portfolios experience higher portfolio performance measured by the Sharpe ratio. However, these results are also dependent on the investment strategy and the selection of the cryptocurrency.

Keywords: Cryptocurrencies, Diversification, Portfolio Choice, Risk Return

Table of Contents

List of Tables

List of Figures

1. Introduction

In the last decades, technology has shown remarkable progress in a lot of fields. The World Wide Web made information more accessible to everyone, making it easier for individuals to invest. These innovations created Blockchain, which is a term with increasing popularity in the last years, but what is Blockchain? In order not to use complicated technological terminology, which is out of the scope of this study, someone should recognize blockchain as a type of database. A database is an organized collection of data stored in a computer. In this technology, Bitcoin is based and it made its first appearance in 2008. For each transaction, the amount and the time are recorded on a decentralized blockchain ledger. However, it is important to note that there is no personal information recorded for these transactions. Another difference from the commonly used currencies is that Central banks do not intervene in the Bitcoin and cryptocurrency market in general (ECB 2012).

As cryptocurrency market capitalization surpassed the barrier of $ 2 trillion (around € 1.7 trillion), due to increasing demand by individual and institutional investors over the last months, it is important to examine the existence of any diversification benefits of this, relatively new, asset class. I focus on the five cryptocurrencies with large market capitalization: Bitcoin (BTC), Ethereum (ETH), Ripple (XRP), Tether (USDT) and Litecoin (LTC). As of April 2021, the market capitalization of these cryptocurrencies was € 830 billion, € 266 billion, € 52 billion, € 42 billion and € 14 billion respectively.

Every investor wants to construct a well-diversified portfolio to mitigate risks. While the majority of investments is still invested in traditional stock and bonds, a growing amount is being put into alternative investments (Karavas, 2000). According to Blackrock, alternative investments are divided into two main types. The first one consists of private assets such as private equity, private credit, infrastructure and real estate. Hedge funds, which is the second one, uses less traditional tools and operates mainly in public markets. Alternative investments can come up with unique return patterns, while still increasing diversification (Mulvey & Kim, 2014). Also, cryptocurrencies have several characteristics in common with alternative assets, however, according to Hafner (2020) they are characterized by high volatility and regulatory uncertainty.

In order to understand how cryptocurrencies work, it is important to investigate how their returns behave relative to other asset classes. The asset allocation across different major asset classes is very important for portfolio performance. Even though cryptocurrencies offer speculation opportunities, investors use them to diversify their portfolios more (Lee, Guo & Wang, 2018). In addition, Yermack (2015) has found evidence of close to zero correlation of Bitcoin with common currencies and gold. Also, recent research from MAN Institute (2021) supports that Bitcoin is a strong diversifier due to the low correlations with the other assets and provides a high Sharpe ratio. Hence the main research questions are:

Does the incorporation of cryptocurrencies into an investor's portfolio offer any diversification benefits? Also, can we observe any different results in the Covid-19 period?

Bitcoin and other cryptocurrencies have attracted a lot of attention in the last decade, and they have been a hot issue among investors, regulators and organizations all around the world. J.P. Morgan Chase and Nasdaq have already created indexes tracking cryptocurrencies' performance. This increasing demand for cryptocurrencies by individual and institutional investors makes it imperative the further research of this new phenomenon. In the meantime, crypto assets have evolved from a niche asset class to a critical component of the digital asset revolution, generating concerns about financial stability. Given their extreme volatility and valuations, their growing co-movement might pose a threat to financial stability, particularly in nations where crypto usage is prevalent (IMF, 2022). The present work intends to shed light on how cryptocurrencies behave relative to other asset classes and how an investor can make his portfolio more efficient. This study is crucial for current and future investors, as well as asset managers, who are considering cryptocurrency as an alternative diversifier for their portfolios, since it will determine whether they can still boost risk-adjusted returns. In addition, my research enriches the existing literature by examining the Covid-19 period, which has not been examined extensively since it occurred recently.

I realize evidence of diversification benefits for most of the examined cryptocurrencies, however, this depends on the investment strategy that an investor applies. In more detail, higher portfolio efficiency is observed in all portfolios

including cryptocurrencies, except the one including Tether. Bitcoin and Ethereum always enhance portfolio performance in terms of the Sharpe ratio regardless of the investment strategy, though the rest of them are dependent on the investment strategy. After comparing the portfolios before and during the pandemic of Covid-19, I conclude that portfolio performance measured by the Sharpe ratio increases during the pandemic.

The rest of this paper is organized as follows. In Section 2, I provide a brief overview of the related literature. Section 3 describes the data used for the portfolio construction and Section 4 presents the methodology. In Section 5, I analyze the results of the study. Finally, I conclude in Section 6.

2.Literature review

2.1 Diversification

Since the 1970s several papers have been published regarding the benefits of diversification. A large part of this research focuses on international portfolio diversification, which is an investment strategy where investors invest in assets in different countries. In this way, the overall risk of the portfolio decreases, due to the low correlations between each asset. Grubel (1968), as well as Levy & Sarnat (1970), confirm the above results. For example, Grubel (1968) calculates the benefits for American investors, when investing abroad in ten developed countries like Canada and the Netherlands. He finds low or even negative correlations between the foreign assets and the U.S assets and higher rates of return for the diversified portfolio as compared to one including Moody's industrial average of common stocks. Also, Errunza (1977) expands the international diversification literature by including corporate securities of less developed countries (LDCs). These countries are characterized as LDCs if they have Gross National Product (GNP) per capita of less than $1000; such examples are Brazil and Indonesia. The author concludes that diversification benefits by investing in these countries hold true.

2.2 Diversification with cryptocurrencies

Brière et al. (2015) provide evidence of low correlations of Bitcoin with alternative investments, besides with traditional financial assets. They come to this conclusion using the mean-variance spanning (MVS) tests. More specifically, adding a 3% Bitcoin allocation to a diversified portfolio improves the risk-return trade-off substantially and the extreme volatility of Bitcoin is accompanied by a high return most of the time. In that case, they also note that due to low correlations with other assets, this high risk is compensated in diversified portfolios. However, they are cautious about the results because they have examined Bitcoin in its early stages.

The diversification benefits of Bitcoin are supported by Kajtazi & Moro (2019) in terms that the addition of Bitcoin to an optimal portfolio increases portfolio performance mainly due to the increase of the returns. Although the portfolio volatility increases too, the portfolio performance measured with risk-return ratios such as Sharpe ratio, Sortino ratio and Omega ratio improves. The portfolios of the study include U.S., European and Chinese assets.

Using a different methodology framework, such as the Conditional Value-at-Risk (CVaR), Eisl et al. (2015) support that Bitcoin can help to improve the risk-return ratios of optimal portfolios. They implemented their study by examining historical data from portfolios that include a diverse range of assets, including Bitcoin. Consequently, Bitcoin should be incorporated in an already well-diversified portfolio, which contributes to higher returns accompanied by higher risk as measured by the CVaR measure. Also, Anyfantaki & Topaloglou (2018) examined the diversification benefits of Bitcoin, Ethereum, Ripple and Litecoin by carrying out stochastic dominance spanning tests and they report investment benefits for risk-averse investors who invest in the equity and in the bond market. This finding concludes that these cryptocurrencies are segmented from the traditional stock and bond markets, where investors mainly do their business.

A more complete approach in terms of bigger cryptocurrency selection is the Trimborn et al. (2017), which is based on 39 cryptocurrencies including Bitcoin, Ripple and Litecoin. Portfolios include equity stocks from the S&P 500, DAX30 and the Portugal Stock exchange, which are examined under a combination of the mean-variance framework with liquidity constraints. The paper demonstrates that adding cryptocurrencies to a portfolio can enhance the risk-reward trade-off.

There are more studies that do not propose the classic mean-variance framework. A very interesting study was conducted by Chuen et al. (2017) regarding the incorporation of cryptocurrencies into a portfolio. In order to calculate the correlation between cryptocurrencies and the traditional asset classes, they use the Cryptocurrency Index (CRIX). CRIX is a market capitalization-weighted index constituted by eight cryptocurrencies and in order to be always up to date, it is reallocated once a month. Their results indicate a very low correlation between CRIX and traditional asset classes. Also, their results are stronger under the dynamic conditional correlation (DCC) setting. CRIX not only expands the efficient frontier of an initial portfolio constructed by traditional assets, but also produces a higher level of utility, as it is indicated by the mean-variance spanning test for the global minimum-variance portfolio (MVP), but not for the tangency portfolio (TP).

Bouri et al. (2016) examined Bitcoin's three risk management capabilities: diversification, hedging and safe haven. They implemented a dynamic conditional

correlations (DCC) model in order to calculate the correlations for the regressions. The results of this study, which includes MSCI stock indices, bonds, commodities and the US dollar index, indicate that Bitcoin is not a powerful hedge and can only be used as a diversifier. Using also DCC-GARCH model, the work of Guesmi et al. (2019) supports that the addition of Bitcoin to a portfolio offers diversification benefits. More specifically, they argue that a hedging strategy that includes emerging markets equity, gold and oil results in a significant reduction of a portfolio's variance as compared to one without Bitcoin.

2.3 Correlation of cryptocurrencies with the other asset classes

Correlation has attracted a lot of attention because it is such a vital part of formatting an optimal portfolio. Liu & Tsyvinski (2021) support that cryptocurrencies behave differently as compared to the standard asset classes. In more detail, cryptocurrencies are not affected by the most common stock market and macroeconomic factors because only factors peculiar to the cryptocurrency market explain fluctuations in cryptocurrency performance. Research implemented by Burniske and White (2016), who have calculated the correlation between Bitcoin and several financial assets, such as S&P 500, US bonds, gold, US real estate and emerging market currencies, concludes that Bitcoin can become potentially a differentiator among assets and there is a possibility to change the financial community as a whole. The work of Tiwari et al. (2019) includes more cryptocurrencies such as Ethereum, Litecoin, Ripple and more finding that the time-varying correlations of the six cryptocurrencies of the study are low against the S&P 500. In more detail, Litecoin is considered the strongest safe haven against the U.S. equity index. However, there is evidence of positive correlation between cryptocurrencies, in terms of Bitcoin is a major driver of cryptocurrency returns (Smales, 2020).

2.4 Cryptocurrency portfolios and Covid-19

Some papers investigate the recent period of the Covid-19 pandemic. Chen (2021) supports that cryptocurrency cannot be used by an investor in order to limit the risk of the portfolio during market stress, because correlations between cryptocurrencies escalate during the Covid-19 outbreak. This is confirmed in a bear market situation by Gkillias et al. (2018) who have found results that the distribution tails of some of the most widely used cryptocurrencies demonstrate patterns of considerably high

bivariate dependence. As a result, investors should avoid holding positions in more than one of the cryptocurrencies of the study above. Conlon and McGee (2020) support that Bitcoin is not a safe haven during that period and a small exposure to Bitcoin significantly raises portfolio risk. They implement their study with a dataset from March 2019 to March 2020, including Bitcoin and S&P 500. The above study is reinforced by Corbet et al. (2020), which concludes that cryptocurrencies do not serve as hedges, but perhaps more as contagion amplifiers during financial instability. Their dataset includes Chinese equity, the Dow Jones Industrial Average, WTI oil, gold and Bitcoin. In addition, Goodell & Goutte (2021) examine the diversification benefits of cryptocurrencies for equity portfolios during the pandemic. They examine the co-movements between cryptocurrencies and equity indices and support that Tether is the best diversifier of their study during a market turmoil. In addition, the paper of Mariana et al. (2021) answers the question about the existence of cryptocurrency correlation with other asset classes during the pandemic of Covid-19. They examine Bitcoin and Ethereum correlation against the S&P 500 and they conclude that both cryptocurrencies are suitable short-term diversifiers due to negative correlations.

2.5 Do cryptocurrencies contain any risk?

Cryptocurrencies have created serious economic and sociological issues due to their quickly growing popularity and widespread public attention. Wu & Pandey (2014) state that Bitcoin has the potential to increase portfolio performance and be a part of a diversified portfolio. However, investors should hold Bitcoin as a minor component of a portfolio due to its high risk and volatility. Concerns have also been expressed that cryptocurrency may be used to finance criminal activity, associated with the anonymity of these assets. In addition, a lot of concerns have been raised regarding the speculative nature of cryptocurrencies. It is confirmed that Bitcoin returns are vulnerable to speculative bubbles (Cheah & Fry, 2015). However, it is important to mention that in both regular and extreme periods, the returns of Bitcoin have a low correlation with all major asset classes, providing significant diversification benefits. From a macroeconomic view, this low correlation means minimal risk. More specifically, if Bitcoin had bubble-like characteristics, a substantial drop in the value of the cryptocurrency may be a secluded event in the case that correlation stayed at zero and the other asset classes were not affected. Also, the

work of Baur et al. (2017) does not perceive an imminent risk to financial or monetary stability because the size of Bitcoin investments and transactions are insignificant in comparison to other assets. Nevertheless, this conclusion should be reevaluated regularly due to the increasing market capitalization of cryptocurrencies. In the case that Bitcoin will grow to a point that it will be able to replace fiat currency, then central banks will lose control on the monetary policy (Reber & Feuerstein, 2014). Despite the restricted supply of Bitcoin, its demand is very changeable; this volatility results in a volatile price of the asset and results in a bubble-bust cycle in the Bitcoin market (Dowd, 2015).

2.6 Hypotheses development

The hypotheses are set based on the existing literature. The first hypothesis comes from the Modern Portfolio Theory (Markowitz, 1952). Modern Portfolio Theory describes how a risk-averse investor can maximize the return of his portfolio with a certain level of market risk. This fundamental theory argues that investors can reduce the risk of the portfolio by adding assets that have low or even negative correlation with the existing assets. As a result, the portfolio diversification increases, without sacrificing return. According to this theory, the efficient frontier of the cryptocurrency portfolio moves to the north west, indicating more efficiency (Markowitz, 1952). The first hypothesis is the below:

Hypothesis 1: *The traditional portfolio with cryptocurrency is more efficient, in terms of the efficient frontier framework.*

For the second hypothesis, I use measures of portfolio performance like the Sharpe ratio (Sharpe, 1966) in order to evaluate the different portfolios. A more diversified portfolio should have a higher Sharpe ratio.

Hypothesis 2: *The incorporation of cryptocurrency in the portfolio, leads to a higher Sharpe ratio.*

Also, I compare different investment strategies based on Brauneis et al. (2019) and see if the results are robust to these investment strategies. For example, some of these strategies are: the naive diversification, the maximum return, the minimum variance and the tangency portfolio.

Hypothesis 3: *The results remain robust, when comparing different investment strategies of portfolios including cryptocurrencies.*

Finally, it is important to examine the Covid-19 period and see if there are any different patterns during this bear market period. Conlon & McGee (2020) report that Bitcoin is not a safe haven during that period. However, it is beneficial to assess the performance and the correlations of other cryptocurrencies too and understand if this relatively unresearched period has something to contribute to the literature.

Hypothesis 4: *During the pandemic there is a higher increase of the Sharpe ratio.*

3.Data

The dataset of the thesis consists of the daily returns of 16 different assets, such as cryptocurrencies, equity, fixed-income and alternative investments. Table 1 includes all of the examined assets of the study, sorted by asset class. The paper aims to examine a recent period from the 1st August 2017 to the 28th May 2021. Since cryptocurrencies are traded continuously, I have excluded the days when the stock exchanges are closed. This results in 962 daily return observations for the full sample and the descriptive statistics of them are presented in Table 2. Descriptive statistics for the two sub-samples are available in the Appendix.

Asset	Asset Class
Bitcoin (BTC)	Cryptocurrency
Ethereum (ETH)	Cryptocurrency
Tether (USDT)	Cryptocurrency
Ripple (XRP)	Cryptocurrency
Litecoin (LTC)	Cryptocurrency
Royalton CRIX Index (CRIX)	Cryptocurrency Index
MSCI International World Price Index	Equity
MSCI Emerging Markets Price Index	Equity
MSCI Frontier Markets Price Index	Equity
SPDR Bbg Barclays International Treasury Bond ETF	Fixed-income
iShares Broad USD Investment Grade Corporate Bond ETF	Fixed-income
iShares iBoxx $ High Yield Corporate Bond ETF	Fixed-income
iShares S&P GSCI Commodity-Indexed Trust ETF	Commodities
MSCI International World Real Estate Price Index	Real Estate
MSCI All Country World Transportation Infrastructure Industry Price Index	Infrastructure
S&P Listed Private Equity Index	Private Equity

Table 1, Asset summary

The cryptocurrency dataset includes five cryptocurrencies and one index, according to Table 1. Bitcoin (BTC) is the cryptocurrency with the largest market capitalization (€830 billion as of April 2021). Bitcoin made its first appearance through a paper that was published in 2008 by a person or a group of people using the identity Satoshi Nakamoto. It is a decentralized and peer-to-peer cryptocurrency, the latter means that all transactions are carried out directly between equal network members, without the requirement of an administrator to control these transactions. Ethereum (ETH) has the second-largest market capitalization (€266 billion as of April 2021). It is characterized as a decentralized open-source blockchain system based on the cryptocurrency ether. Ethereum was first introduced in 2013 by Vitalik Buterin and it adheres to the following guidelines: simplicity, universality, modularity, agility and non-discrimination. Tether (USDT) is the most distinctive cryptocurrency of this

study. The characteristic that makes Tether unique is that it is a stablecoin, in other words, it is a stable-value cryptocurrency that reflects the price of the U.S. Dollar. This is accomplished by supporting the cryptocurrency's reserves with cash and cash equivalents. As a result, Tether is characterized by low volatility and Baur & Hoang (2021) argue that it works as a safe haven for crypto-investors. XRP (XRP) was launched in 2013 as an alternative to Bitcoin, however, it does not require mining. XRP also depends on a public ledger, named XRP Ledger, where all transactions are registered. In addition, the digital payment network based on XRP Ledger is called RippleNet. The objective was to use RippleNet financial network relationships to replace the need for banks and support cross-border money transfers. This resulted in high-level partnerships with financial institutions like Banco Santander and Bank of America to use RippleNet services. Litecoin (LTC) was created in 2011 with the intention of complementing rather than competing with Bitcoin's economy. As a simplified version of Bitcoin, Litecoin can execute transactions much faster and avoid payment delays. For example, Bitcoin payments are executed in around ten minutes, while Litecoin payments need only two and a half minutes. However, the cost of faster payments with Litecoin comes with less security as compared to Bitcoin. The Cryptocurrency Index (CRIX) is a benchmark for the cryptocurrency market. It tracks the performance of eight cryptocurrencies like Bitcoin, Ethereum, Binance Coin and more. Nevertheless, this index has not a fixed number of constituents and a specific methodology is used to revise the index constituents, taking into account liquidity parameters. The reallocation is taking place every month.

In addition to cryptocurrencies, I use the daily returns of major asset classes such as equities, fixed-income and alternative asset classes. For example, commodities, real estate, infrastructure and private equity. Alternative asset classes provide portfolio diversification advantages, according to academics. More specific, diversification benefits occur when commodities (Belousova & Dorfleitner (2012), Daskalaki et al., 2017), real estate (Gordon et al., 1998), infrastructure (Dechant & Finkenzeller, 2011) and private equity (Schmidt, 2003) are part of a portfolio.

	N	Mean	Median	St. Deviation	Kurtosis	Skewness	Minimum	Maximum
BTC	962	0.00271	0.00162	0.05064	4.71587	-0.45143	-0.31595	0.24987
ETH	962	0.00269	0.00231	0.06547	5.39198	-0.68740	-0.42357	0.26957
USDT	962	0.00000	0.00000	0.00405	15.98014	-0.01101	-0.02617	0.03457
XRP	962	0.00164	0.00006	0.08488	13.39335	1.14596	-0.54102	0.61832
LTC	962	0.00147	0.00016	0.07145	9.96308	0.22487	-0.48678	0.52766
CRIX	962	0.00377	0.00327	0.13761	346.06697	-0.70490	-2.81084	2.74772
MSCI_WRLD	962	0.00040	0.00077	0.01159	20.73729	-1.50535	-0.10671	0.07792
MSCI_EM	962	0.00022	0.00081	0.01087	8.08656	-1.16434	-0.07975	0.04959
BWX	962	0.00002	0.00003	0.00396	42.72519	-0.49496	-0.04700	0.04623
USIG	962	0.00007	0.00019	0.00477	43.64528	-0.25166	-0.04406	0.05043
GSCI	962	0.00007	0.00133	0.01423	13.07980	-1.54875	-0.12875	0.06558
MSCI_RE	962	0.00013	0.00067	0.01216	32.45653	-2.44038	-0.15018	0.07359
MSCI_INFRA	962	0.00007	0.00133	0.01423	13.07980	-1.54875	-0.12875	0.06558
PE	962	0.00058	0.00104	0.01453	24.30074	-1.44888	-0.13720	0.12043
MSCI_FRONTIER	962	0.00011	0.00067	0.00772	83.83926	-5.73611	-0.12689	0.02357
HY	962	-0.00005	-0.00003	0.00711	18.78548	-0.64903	-0.06336	0.05688

BTC: Bitcoin, ETH: Ethereum, USDT: Tether, XRP: Ripple, LTC: Litecoin, CRIX: Cryptocurrency Index, MSCI_WRLD: MSCI International World Price Index, MSCI_EM: MSCI Emerging Markets Price Index, BWX: SPDR Bbg Barclays International Treasury Bond ETF, USIG: iShares Broad USD Investment Grade Corporate Bond ETF, GSCI: iShares S&P GSCI Commodity-Indexed Trust ETF, MSCI_RE: MSCI International World Real Estate Price Index, MSCI_INFRA: MSCI All Country World Transportation Infrastructure Industry Price Index, PE: S&P Listed Private Equity Index, MSCI_FRONTIER: MSCI Frontier Markets Price Index, HY: iShares iBoxx $ High Yield Corporate Bond ETF

Table 2, Full sample descriptive statistics

Table 1 provides also the rest of the assets included in the thesis. The equity market is represented by three indexes provided by Morgan Stanley Capital International. In more detail, these are the MSCI International World Price Index, MSCI Emerging Markets Price Index and MSCI Frontier Markets Price Index, providing a large spectrum of the equity market worldwide. The fixed-income market is represented by three Exchange Traded Funds: SPDR Bbg Barclays International Treasury Bond ETF, iShares Broad USD Investment Grade Corporate Bond ETF and iShares iBoxx $ High Yield Corporate Bond ETF, provided by Standard and Poor's and Blackrock. Regarding commodities, I use the iShares S&P GSCI Commodity-Indexed Trust ETF, which provides access to energy, industrial and precious metals, agricultural, and livestock markets. The MSCI World Real Estate Price Index tracks the Real Estate market by including equity across 23 Developed Markets countries. The MSCI All Country World Transportation Infrastructure Industry Price Index represents different infrastructure sectors, such as Telecommunications, Utilities, Energy, Transportation and Social. Finally, the S&P Listed Private Equity Index contains the leading listed private equity companies that meet specific requirements.

	BTC	ETH	USDT	XRP	LTC	CRIX	MSCI_WRLD	MSCI_EM	BWX	USIG	GSCI	MSCI_RE	MSCI_INFRA	PE	MSCI_FRONTIER	HY	TIPS
BTC	1																
ETH	0.7371	1															
USDT	-0.0874	-0.1139	1														
XRP	0.0482	0.1155	0.0274	1													
LTC	0.1559	0.1865	-0.0556	0.0767	1												
CRIX	0.2937	0.2707	-0.0432	0.0335	0.0858	1											
MSCI_WRLD	-0.0315	-0.0242	0.0059	-0.0097	0.2033	-0.0112	1										
MSCI_EM	0.0737	0.1149	0.0340	0.0126	0.1431	0.0484	0.6607	1									
BWX	-0.0226	0.0022	-0.0087	-0.0835	0.0551	-0.0304	0.1157	0.1369	1								
USIG	-0.0395	-0.0509	0.0138	-0.0073	0.1113	-0.0302	0.2089	0.1448	0.2462	1							
GSCI	0.0782	0.0733	0.0186	0.0108	0.1108	0.0955	0.4601	0.3649	0.0802	0.1264	1						
MSCI_RE	-0.0259	-0.0332	0.0025	-0.0177	0.1420	-0.0023	0.8196	0.5582	0.1536	0.2964	0.3385	1					
MSCI_INFRA	0.0903	0.1005	0.0119	-0.0181	0.1429	0.0290	0.6296	0.6966	0.1299	0.2355	0.3229	0.6599	1				
PE	0.0408	0.0504	0.0015	-0.0061	0.1795	-0.0051	0.8450	0.6268	0.1507	0.2794	0.4430	0.7496	0.6799	1			
MSCI_FRONTIER	0.1324	0.1081	0.0113	0.0191	0.1075	0.0494	0.4167	0.4783	0.0001	0.1275	0.3690	0.3723	0.4476	0.4569	1		
HY	-0.0768	-0.0884	0.0207	-0.0397	0.1128	-0.0575	0.8035	0.5248	0.2570	0.3073	0.3564	0.7630	0.5147	0.6745	0.2794	1	
TIPS	0.0520	0.0337	-0.0003	0.0296	0.0579	0.0110	-0.0711	0.0230	0.3911	0.5500	0.1236	0.0083	0.1149	0.0482	0.0965	-0.0299	1

BTC: Bitcoin, ETH: Ethereum, USDT: Tether, XRP: Ripple, LTC: Litecoin, CRIX: Cryptocurrency Index, MSCI_WRLD: MSCI International World Price Index, MSCI_EM: MSCI Emerging Markets Price Index, BWX: SPDR Bbg Barclays International Treasury Bond ETF, USIG: iShares Broad USD Investment Grade Corporate Bond ETF, GSCI: iShares S&P GSCI Commodity-Indexed Trust ETF, MSCI_RE: MSCI International World Real Estate Price Index, MSCI_INFRA: MSCI All Country World Transportation Infrastructure Industry Price Index, PE: S&P Listed Private Equity Index, MSCI_FRONTIER: MSCI Frontier Markets Price Index, HY: iShares iBoxx $ High Yield Corporate Bond ETF

Table 3, Correlation table

In line with the work of Burniske & White (2017), the correlation table (Table 3) presents weak correlations of the cryptocurrencies with the rest of the assets of the study. The majority of these correlations are close to zero or even negative. Litecoin experiences the highest correlation among cryptocurrencies with the other assets, however, they are still low and the largest one is 0.2033 with MSCI International World Price Index. Correlation tables for the sub-samples are available in the Appendix.

4. Methodology

This work investigates the effectiveness of adding cryptocurrencies in an already diversified portfolio, which consists of not only the major asset classes but also alternative investments. The underlying theory of this study is the standard mean-variance (MV) portfolio selection framework (Markowitz, 1952). The impact of cryptocurrencies on the risk-return characteristics of a multi-asset portfolio can be evaluated by employing modern portfolio theory. More specifically, I research the possibility of creating an ideal portfolio that will reward the investor with the maximum returns, while accepting the optimal risk level. This approach is a useful tool for optimizing portfolios and allocating assets optimally. Under this framework, an investor is concerned about the mean and the variance of the portfolio. So, I use the mean, the variance and the covariance of each asset returns as an input.

The natural logarithm, which is defined by the equation below, is used to construct the return series.

Equation 1: Asset return

$$R_t = \ln(p_t \,/\, p_{t-1})$$

One portfolio consists of a lot of different assets. Each asset has its own return, variance and specific weight in the portfolio. As a result, the expected return of the portfolio is the weighted average of the returns of each different asset.

Equation 2: Portfolio expected return for n assets

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

In equation 2, the $\sum_{i=1}^{n} w_i$ always equals one, because all of the funds are invested in assets, n is the total number of assets in the portfolio. $E(r_\rho)$ and $E(r_i)$ are the expected returns of the portfolio and asset i respectively.

The variance of a two-asset portfolio is given by the following formula (Equation 3):

$$\sigma_p^2 = w_x^2 \sigma_x^2 + w_y^2 \sigma_y^2 + 2 w_x w_y Cov(r_x, r_y)$$

The above formula makes it clear that the variance of a portfolio is not simply the sum of the weighted variances of each asset. The covariance component also influences the variance of the two-asset portfolio. For example, a negative covariance can offset the loss from the X asset with a profit from the Y asset, which counterbalances the portfolio return and finally decreases the volatility. The above formula can be expanded for n assets and it is presented by equation 4.

Equation 4: Portfolio variance for n assets

$$\sigma_p^2 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_i w_j Cov(r_i, r_j)$$

In equation 4, the portfolio variance is a function of the weights of each asset in the portfolio and the covariance between the returns of the portfolio's n assets. According to the above equations, the next step is to construct the covariance matrix, which is used in order to create the different portfolios and it is available in Appendix for the full-sample and the sub-samples.

It is worth noting that investors are interested in the expected excess returns that they can achieve. The relevance of the trade-off between reward (the risk premium) and risk (as measured by the standard deviation or SD) implies that the ratio of risk premium to SD of excess returns should be used to determine the attractiveness of a portfolio. The above is measured by the Sharpe ratio, which is the reward to volatility measure and is expressed by the following formula.

Equation 5: Sharpe ratio

$$SR_p = \frac{E(r_p) - r_f}{\sigma_p}$$

In equation 5, the numerator expresses the excess portfolio returns above the risk-free rate (r_f) and the denominator is the standard deviation of the portfolio. The risk-free rate (r_f) represents the inflation-protected U.S. Treasury bonds.

By using the returns, the variance–covariance matrix and the portfolio weights, I continue my research at a portfolio level. In particular, the Minimum Variance portfolio is constructed by minimizing Equation 4. In addition, the Maximum return

portfolio is created by maximizing Equation 2. Furthermore, in order to generate the

Maximum Sharpe Ratio portfolio, I maximize equation 5.

5. Results

5.1 Analysis of the full sample

The analysis starts by creating a portfolio without cryptocurrencies to be able to identify the portfolio's risk-return characteristics with and without cryptocurrencies. I name the aforementioned portfolio the "Reference Portfolio" and its results are presented in Table 4. The top three rows include the portfolio's Expected return, Standard deviation and Expected Sharpe ratio, while the rest of them indicate the portfolio weights for each asset. I employ four different portfolio strategies, influenced by Brauneis et al. (2019). The first one is the naive 1/N portfolio, which means that an investor who invests in N assets, allocates 1/N of his cash to each asset. The second one is the minimum variance portfolio, which has the minimum standard deviation (risk) for a given level of return. The third one is the maximum return portfolio, which offers the maximum level of return for a given level of standard deviation (risk). The fourth one is the tangency portfolio, which has the highest Sharpe Ratio. In order to calculate the results of the portfolios that require optimization techniques, I use the Microsoft Excel Solver. It is important to note that short sales are not allowed in the examined portfolios. As a result, each portfolio's weight is positive.
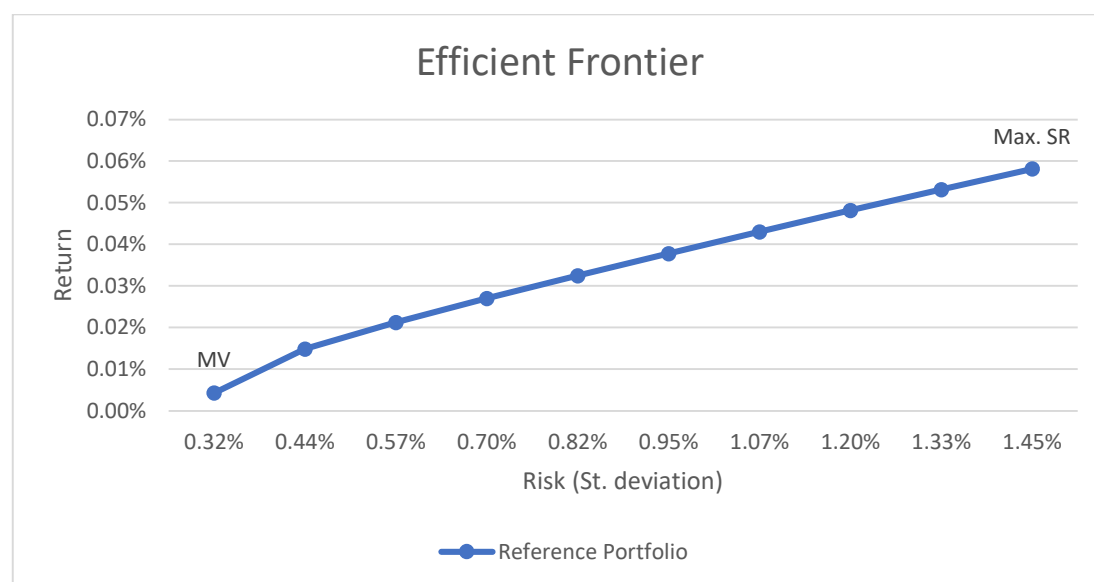
Figure 1, Efficient Frontier of the Reference portfolio

In the naive diversified portfolio, the investor invests 10% of his money in each asset; this results in a Sharpe Ratio of 0.0168. Regarding the minimum variance portfolio, the optimal investment is at treasury bonds, corporate bonds, frontier markets and high yield with a Sharpe ratio of 0.0081.

	1/N	MinVariance	MaxReturn	Tangency
Portfolio Expected Return	0.0140%	0.0043%	0.0582%	0.0582%
Portfolio StDev	0.7288%	0.3175%	1.4532%	1.4532%
Expected Sharpe Ratio	0.0168	0.0081	0.0388	0.0388
MSCI_WRLD	10.00%	-	-	-
MSCI_EM	10.00%	-	-	-
BWX	10.00%	54.70%	-	-
USIG	10.00%	29.39%	-	-
GSCI	10.00%	-	-	-
MSCI_RE	10.00%	-	-	-
MSCI_INFRA	10.00%	-	-	-
PE	10.00%	-	100.00%	100.00%
MSCI_FRONTIER	10.00%	14.15%	-	-
HY	10.00%	1.77%	-	-

MSCI_WRLD: MSCI International World Price Index, MSCI_EM: MSCI Emerging Markets Price Index, BWX: SPDR Bbg Barclays International Treasury Bond ETF, USIG: iShares Broad USD Investment Grade Corporate Bond ETF, GSCI: iShares S&P GSCI Commodity-Indexed Trust ETF, MSCI_RE: MSCI International World Real Estate Price Index, MSCI_INFRA: MSCI All Country World Transportation Infrastructure Industry Price Index, PE: S&P Listed Private Equity Index, MSCI_FRONTIER: MSCI Frontier Markets Price Index, HY: iShares iBoxx $ High Yield Corporate Bond ETF

Table 4, Reference Portfolio results

For the maximum return and the tangency portfolio, the risk-return relationship is the same, resulting in 100% investment in private equity and the Sharpe ratio is 0.0388, which is the highest for this portfolio. Figure 1 represents the efficient frontier for the Reference Portfolio. The first point to the left (MV) is the minimum variance portfolio with 0.0043% return and 0.3175% standard deviation. The last point to the right (Max. SR) is the tangency portfolio with 0.0582% return and 1.4532% standard deviation. This part of the efficient frontier is used for the rest of the analysis.

5.1.1 Bitcoin

In this section, I analyze the addition of Bitcoin (BTC) to the Reference portfolio. The new portfolio consists of eleven assets and its characteristics are displayed in Table 5. Figure 2 presents the efficient frontier before and after the addition of Bitcoin. The first hypothesis for the Bitcoin portfolio is accepted because the efficient frontier shifts to the left and up and it is formulated as follows: the traditional portfolio with Bitcoin is more efficient, in terms of the efficient frontier framework.
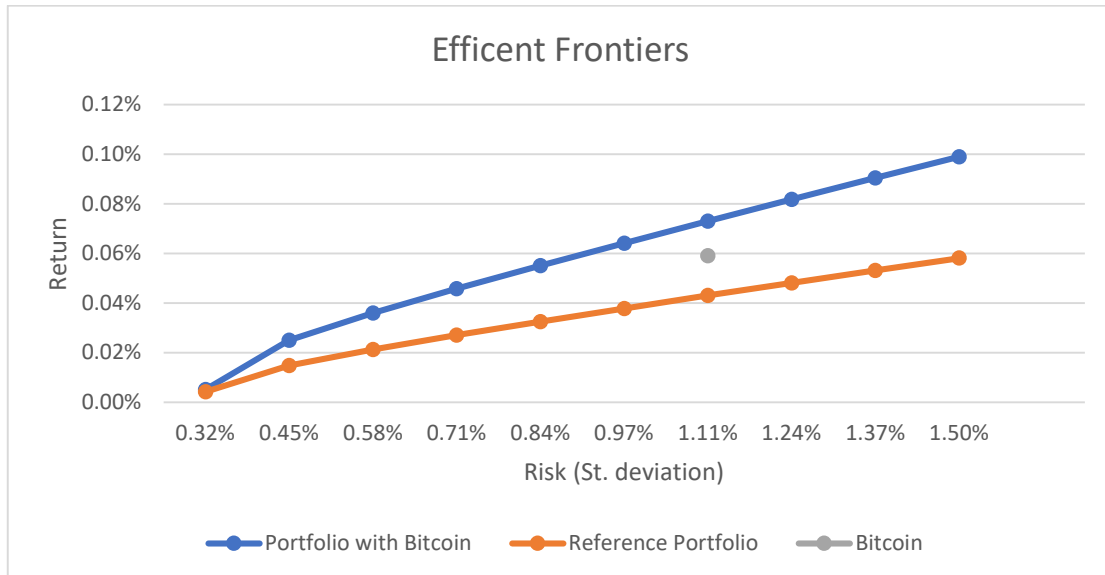
Figure 2, Efficient Frontiers before and after Bitcoin addition

In addition, the incorporation of Bitcoin results in higher portfolio expected return and Sharpe ratio for all the different investment strategies, which means that the second hypothesis is accepted, due to a higher Sharpe ratio after Bitcoin incorporation.

	1/N	MinVariance	MaxReturn	Tangency
Portfolio Expected Return	0.0373%	0.0052%	0.2706%	0.0990%
Portfolio StDev	0.8228%	0.3171%	5.0643%	1.4995%
Expected Sharpe Ratio	0.0432	0.0109	0.0531	0.0649
BTC	9.09%	0.34%	100.00%	23.96%
MSCI_WRLD	9.09%	-	-	23.64%
MSCI_EM	9.09%	-	-	-
BWX	9.09%	54.58%	-	-
USIG	9.09%	29.51%	-	10.98%
GSCI	9.09%	-	-	-
FTSE_EPRA	9.09%	-	-	-
MSCI_INFRA	9.09%	-	-	-
PE	9.09%	-	-	41.42%
MSCI_FRONTIER	9.09%	13.79%	-	-
HY	9.09%	1.77%	-	-

*BTC: Bitcoin, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GS**CI: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 5, Portfolio results with Bitcoin

The second hypothesis supports that the addition of Bitcoin in the Reference portfolio, increases the Sharpe ratio. The highest increase of the Sharpe ratio is

observed at the naive portfolio and it is 157%. However, the incorporation of Bitcoin increases the portfolio's standard deviation with the exemption of the minimum variance strategy, where it declines slightly. Regarding the Bitcoin allocation of the portfolio, the results present a very poor allocation for the minimum variance portfolio (0.34%), an 100% investment for the maximum return strategy, and a more balanced asset allocation (23.96%) for the tangency portfolio strategy. The results remain robust between the four different investment strategies because in all cases Sharpe ratio increases. Based on this, the third hypothesis is accepted, which requires the same results for all the Bitcoin portfolios.

5.1.2 Ethereum
In this section, I analyze the addition of Ethereum (ETH) to the Reference portfolio.
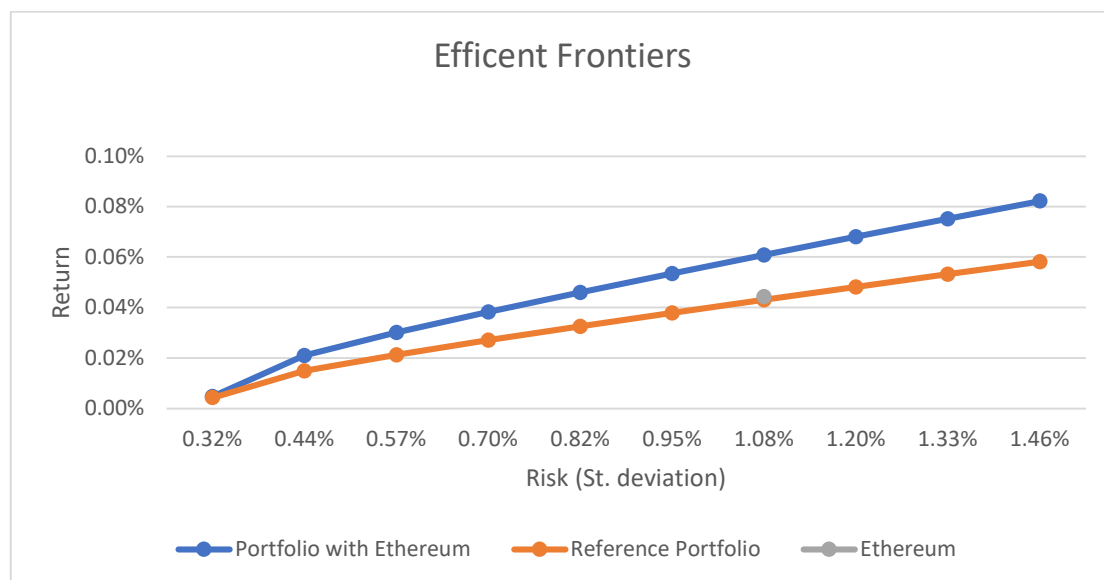
Figure 3, Efficient Frontiers before and after Ethereum addition

As compared to the previous portfolio, now Ethereum replaces Bitcoin in the portfolio and the new efficient frontier is presented in Figure 3. The new efficient frontier indicates higher efficiency because it shifts left and upwards, accepting the first hypothesis. In other words, the Ethereum portfolio is more efficient as compared to the traditional one. The results of the portfolio including Ethereum are presented in Table 6. Again, the incorporation of Ethereum enhances portfolio's expected return and Sharpe ratio. In general, the results follow the same pattern for the Sharpe ratio as compared to the Bitcoin portfolio. More specifically, the highest increase of the Sharpe ratio can be depicted in the naive portfolio (131%).

	1/N	MinVariance	MaxReturn	Tangency
Portfolio Expected Return	0.0371%	0.0048%	0.2688%	0.0822%
Portfolio StDev	0.9118%	0.3173%	6.5472%	1.4586%
Expected Sharpe Ratio	0.0388	0.0096	0.0408	0.0552
ETH	9.09%	0.18%	100.00%	16.01%
MSCI_WRLD	9.09%	-	-	20.50%
MSCI_EM	9.09%	-	-	-
BWX	9.09%	54.70%	-	-
USIG	9.09%	29.55%	-	11.36%
GSCI	9.09%	-	-	-
MSCI_RE	9.09%	-	-	-
MSCI_INFRA	9.09%	-	-	-
PE	9.09%	-	-	52.13%
MSCI_FRONTIER	9.09%	13.80%	-	-
HY	9.09%	1.77%	-	-

*ETH: Ethereum, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GS**CI: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 6, Portfolio results with Ethereum

For the rest of the strategies, the increase is smaller but, in all cases, the second hypothesis is confirmed, because Sharpe ratio increases after the addition of Ethereum. Ethereum's portfolio weights vary between the different portfolio strategies. There is a full investment to Ethereum in the maximum return portfolio (100%). On the contrary, there is a 0.18% allocation to Ethereum for the minimum variance portfolio, while there is a more balanced for the tangency portfolio (16.01%). The third hypothesis is also accepted because there is an increase in the Sharpe ratio for all four investment strategies, thus we have the same results for all investment strategies.

5.1.3 Tether

In this section, I analyze the addition of Tether (USDT) to the Reference portfolio. The efficient frontier of the portfolio including Tether in Figure 4 indicates less efficiency in the biggest part of it, around the minimum variance portfolio area, rejecting the first hypothesis, which refers to higher portfolio efficiency after incorporating cryptocurrencies. The results of Tether are completely different from the ones of Bitcoin and Ethereum and are summarized in Table 7.
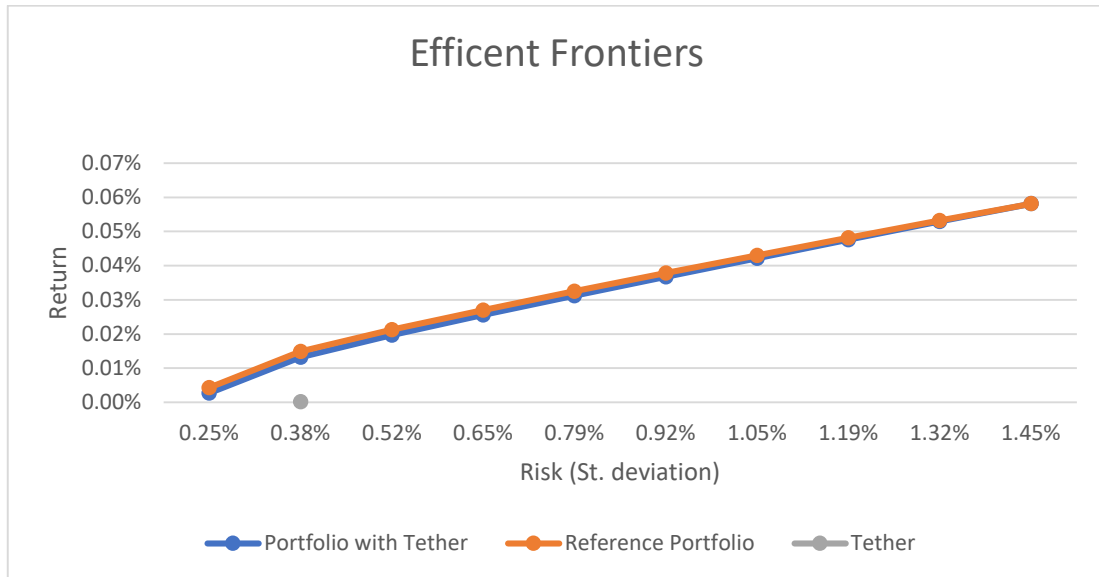
Figure 4, Efficient Frontiers before and after Tether addition

	1/N	MinVariance	MaxReturn	Tangency
Portfolio Expected Return	0.0127%	0.0028%	0.0582%	0.0582%
Portfolio StDev	0.6641%	0.2505%	1.4532%	1.4532%
Expected Sharpe Ratio	0.0165	0.0041	0.0388	0.0388
USDT	9.09%	37.99%	-	-
MSCI_WRLD	9.09%	-	-	-
MSCI_EM	9.09%	-	-	-
BWX	9.09%	34.70%	-	-
USIG	9.09%	17.93%	-	-
GSCI	9.09%	-	-	-
MSCI_RE	9.09%	-	-	-
MSCI_INFRA	9.09%	-	-	-
PE	9.09%	-	100.00%	100.00%
MSCI_FRONTIER	9.09%	8.72%	-	-
HY	9.09%	0.66%	-	-

*USDT: Tether, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GS**CI: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 7, Portfolio results with Tether

Tether decreases slightly the Sharpe ratio of the portfolio in the naive strategy and in the minimum variance strategy almost halves the Sharpe ratio, with the allocation to Tether accounting at 37.99%. Regarding the other two investment strategies, the results remain the same as compared to the Reference portfolio, without investing any capital in the cryptocurrency. This is the only case in this study, where there is not an investment to cryptocurrencies for the maximum return and tangency

portfolio in the full sample. The second hypothesis is rejected for Tether because in all cases Sharpe ratio decreases after the addition of the cryptocurrency. Also, the third hypothesis of robust results across all the Tether portfolios is accepted, because in all investment portfolios Sharpe ratio decreases.

5.1.4 Ripple

In this section, I analyze the addition of Ripple (XRP) to the Reference portfolio. The addition of Ripple to the portfolio affects the efficient frontier, moving it to the left, supporting the first hypothesis of portfolio efficiency. The diversification benefits of Ripple are dependent on the investment strategy and the results are summarized in Table 8. The incorporation of Ripple in the naive portfolio increases the Sharpe ratio by 53%, while in the minimum variance portfolio increases the Sharpe ratio by 16% with an allocation of 0.38% to Ripple.
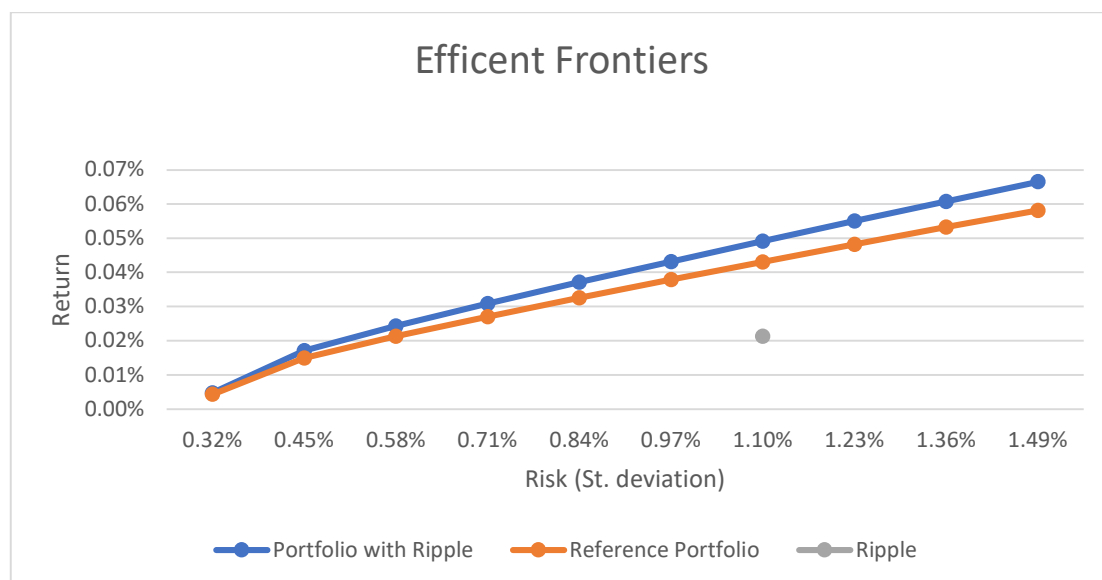
Figure 5, Efficient Frontiers before and after Ripple addition

Also, the Sharpe ratio of the tangency portfolio increases by 18% with an allocation of 7.86% to Ripple. However, the Sharpe ratio almost halves in the maximum return strategy with a full allocation to Ripple. All in all, the second hypothesis is confirmed for all the investment strategies, except for the maximum return. This is based on the fact that the Sharpe ratio decreases in the maximum return strategy, while on the other ones it increases. According to that, the third hypothesis is rejected due to opposite changes in the Sharpe ratio. As a result, results are not robust for the portfolio including Ripple.

	1/N	MinVariance	MaxReturn	Tangency
Portfolio Expected Return	0.0276%	0.0047%	0.1643%	0.0665%
Portfolio StDev	1.0112%	0.3180%	8.4881%	1.4922%
Expected Sharpe Ratio	0.0256	0.0095	0.0192	0.0434
XRP	9.09%	0.38%	100.00%	7.86%
MSCI_WRLD	9.09%	-	-	-
MSCI_EM	9.09%	-	-	-
BWX	9.09%	59.95%	-	-
USIG	9.09%	26.61%	-	-
GSCI	9.09%	-	-	-
MSCI_RE	9.09%	1.49%	-	-
MSCI_INFRA	9.09%	-	-	-
PE	9.09%	-	-	92.14%
MSCI_FRONTIER	9.09%	10.88%	-	-
HY	9.09%	0.68%	-	-

*XRP: Ripple, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GSCI**: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 8, Portfolio results with Ripple

5.1.5 Litecoin

In this section, I analyze the addition of Litecoin (LTC) to the Reference portfolio and its efficient frontier is provided in Figure 6. The first hypothesis of portfolio efficiency after the incorporation of the cryptocurrency is confirmed by observing Figure 6, where there is a smaller move to the left as compared to the previous more efficient cryptocurrencies. Table 9 provides the results for the portfolio including Litecoin. Again, the strongest increase in the Sharpe ratio is observed in the naive portfolio (43%). In addition, there is a slight increase of the Sharpe ratio in the tangency portfolio (6%), with a 7.16% allocation to Litecoin. On the other hand, the Sharpe ratio decreases in half in the maximum return strategy with a 100% investment to Litecoin and for the minimum variance portfolio there is no allocation to the cryptocurrency and the results are identical to the Reference portfolio. As a result, the second hypothesis is confirmed only for the naive and the tangency portfolio, because only for these two portfolios Sharpe ratio increases. The results do not remain robust, because Sharpe ratio does not change for the minimum variance portfolio and decreases for the maximum return. Hereby, the third hypothesis is rejected, due to nonuniform results.

	1/N	MinVariance	MaxReturn	Tangency
Portfolio Expected Return	0.0260%	0.0043%	0.1468%	0.0645%
Portfolio StDev	1.0126%	0.3175%	7.1449%	1.5263%
Expected Sharpe Ratio	0.0240	0.0081	0.0203	0.0411
LTC	9.09%	-	100.00%	7.16%
MSCI_WRLD	9.09%	-	-	-
MSCI_EM	9.09%	-	-	-
BWX	9.09%	54.70%	-	-
USIG	9.09%	29.39%	-	-
GSCI	9.09%	-	-	-
MSCI_RE	9.09%	-	-	-
MSCI_INFRA	9.09%	-	-	-
PE	9.09%	-	-	92.84%
MSCI_FRONTIER	9.09%	14.15%	-	-
HY	9.09%	1.77%	-	-

*LTC: Litecoin, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GSCI**: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 9, Portfolio results with Litecoin
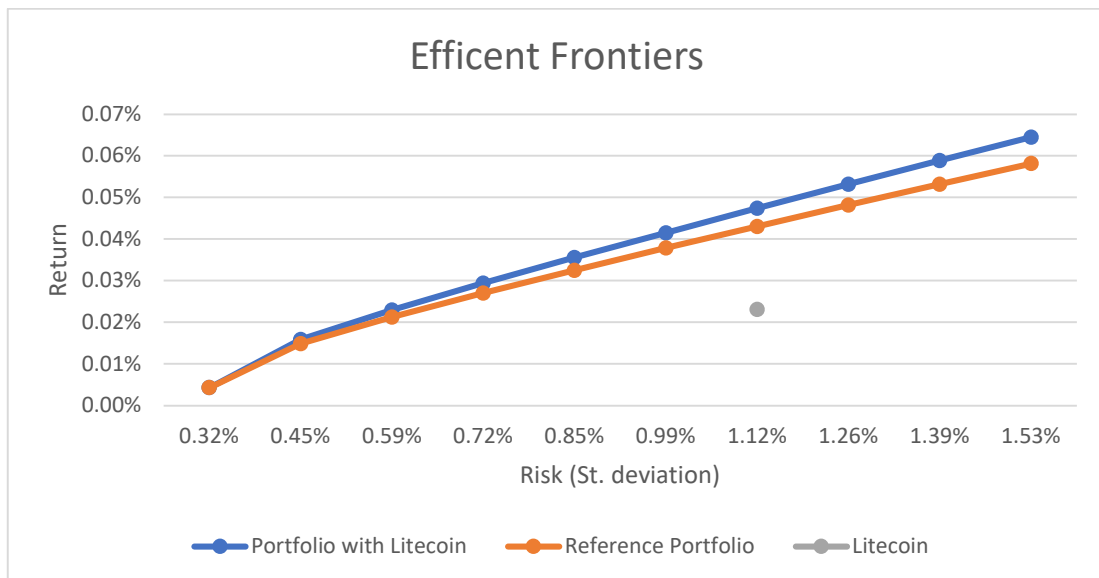
Figure 6, Efficient Frontiers before and after Litecoin addition

5.1.6 Cryptocurrency Index

In this section, I analyze the addition of the Cryptocurrency Index (CRIX) to the Reference Portfolio, which is used as a benchmark for the cryptocurrency market and the results are presented in Table 10. According to Figure 7, the addition of the Cryptocurrency Index to the portfolio results in a move of the efficient frontier to the left and upwards. This results in more portfolio efficiency, accepting the first

hypothesis. The naive portfolio including the Index has the biggest gain in the Sharpe ratio (89%) as compared to the other portfolio strategies. Also, the Sharpe ratio of the minimum variance portfolio increases by 14%, with a weak allocation of 0.10% to the Cryptocurrency Index.
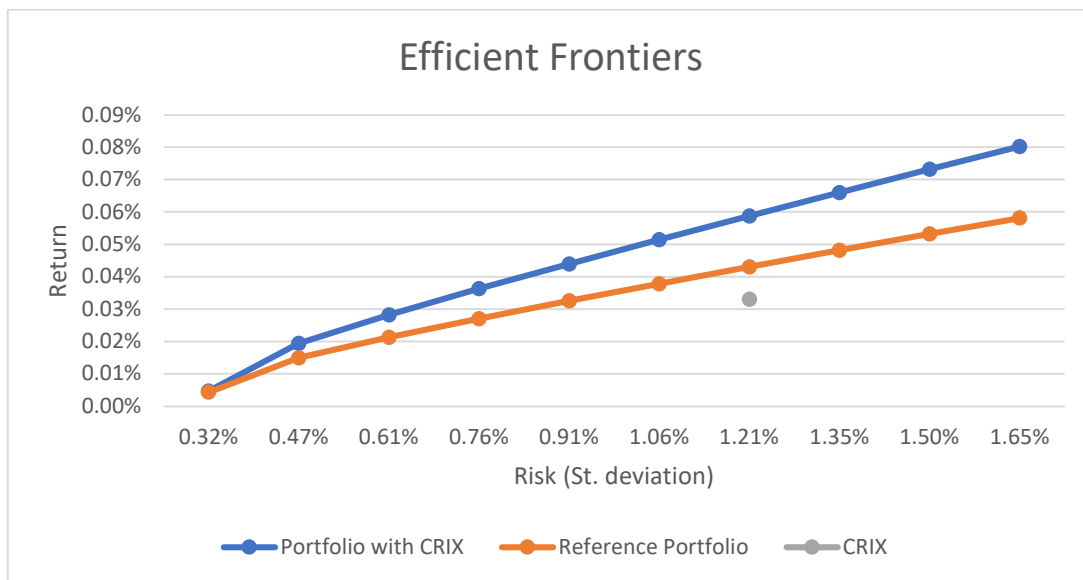
Figure 7, Efficient Frontiers before and after CRIX addition

	1/N	MinVariance	MaxReturn	Tangency
Portfolio Expected Return	0.0470%	0.0047%	0.3775%	0.0802%
Portfolio StDev	1.4293%	0.3172%	13.7608%	1.6497%
Expected Sharpe Ratio	0.0317	0.0093	0.0273	0.0476
CRIX	9.09%	0.10%	100.00%	6.93%
MSCI_WRLD	9.09%	-	-	0.08%
MSCI_EM	9.09%	-	-	-
BWX	9.09%	54.60%	-	-
USIG	9.09%	29.39%	-	0.08%
GSCI	9.09%	-	-	-
MSCI_RE	9.09%	-	-	-
MSCI_INFRA	9.09%	-	-	-
PE	9.09%	-	-	92.91%
MSCI_FRONTIER	9.09%	14.15%	-	-
HY	9.09%	1.77%	-	-

*CRIX: Cryptocurrency Index, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GS**CI: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 10, Portfolio results with CRIX

The effect is stronger for the tangency portfolio; there is an increase of 23% with an investment to the Index of 6.93%. The second hypothesis is accepted for all

investment strategies except the maximum return, because after the addition of the Index Sharpe ratio increases. However, the second hypothesis is rejected for the maximum return portfolio, because there is a decrease of the Sharpe ratio after a full investment to the benchmark index. The above-mentioned renders the results not robust in all the different investment strategies. Therefore, the third hypothesis is not confirmed for the portfolio including the Cryptocurrency Index.

5.1.7 Mixed Portfolio

In order to have a broader image of the cryptocurrency market, I incorporate all the examined cryptocurrencies in one portfolio and the efficient frontier is illustrated in Figure 8. Figure 8 indicates that the addition of the mixed portfolio improves the efficiency of the portfolio, by moving the efficient frontier upwards and to the left, confirming the first hypothesis. Interestingly, the second hypothesis is confirmed for all four investment strategies. That means that in all investment strategies the Sharpe ratio is higher after the incorporation of all the examined cryptocurrencies.
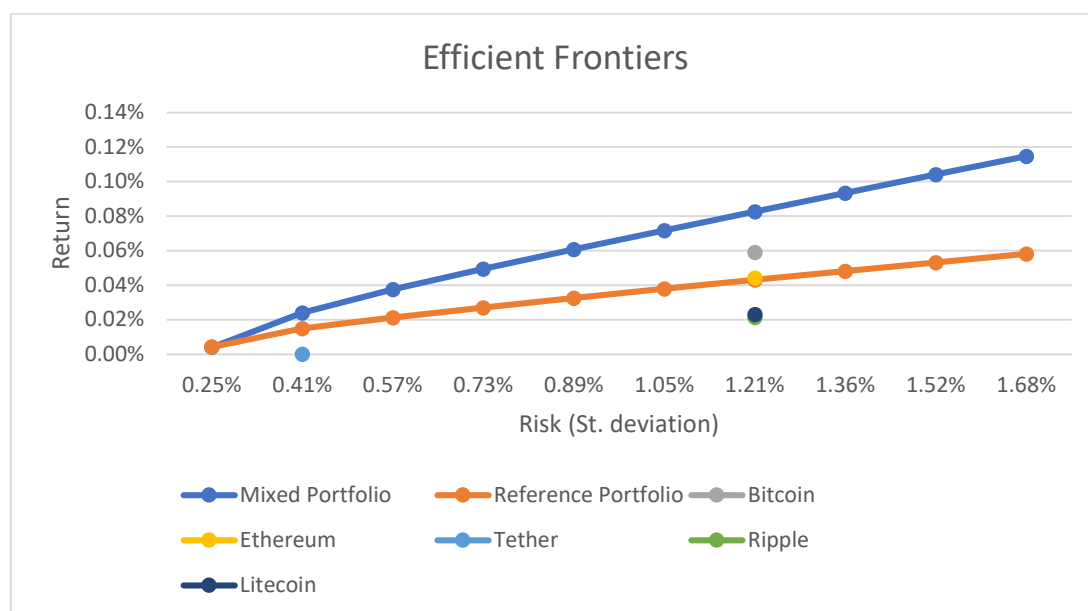
Figure 8, Efficient Frontiers before and after Mixed portfolio addition

In Table 11, the highest increase (197%) in the Sharpe ratio is observed in the naive portfolio. Also, a strong increase of 73% is noticed in the tangency portfolio with an allocation of 25.10% to Bitcoin, 4.90% to Ripple and 1.39% to Litecoin. The results have the same pattern for the maximum return portfolio, where a full allocation to Bitcoin and a higher Sharpe ratio are observed. In addition, the Sharpe ratio of the minimum variance portfolio increases by 16% with an investment of 37.98% in Tether and less than 1% in Bitcoin, Ethereum and Ripple in total. The results remain

robust after comparing all of the portfolios because in all cases Sharpe ratio increases. Taking into consideration the above, I accept the third hypothesis due to uniform results.

	1/N	MinVariance	MaxReturn	Tangency
Portfolio Expected Return	0.0660%	0.0041%	0.2706%	0.1147%
Portfolio StDev	1.2893%	0.2490%	5.0643%	1.6838%
Expected Sharpe Ratio	0.0499	0.0094	0.0531	0.0671
BTC	6.67%	0.29%	100.00%	25.10%
ETH	6.67%	0.21%	-	-
USDT	6.67%	37.98%	-	-
XRP	6.67%	0.14%	-	4.90%
LTC	6.67%	-	-	1.39%
MSCI_WRLD	6.67%	-	-	-
MSCI_EM	6.67%	-	-	17.20%
BWX	6.67%	33.70%	-	-
USIG	6.67%	17.33%	-	-
GSCI	6.67%	-	-	-
MSCI_RE	6.67%	-	-	-
MSCI_INFRA	6.67%	-	-	-
PE	6.67%	-	-	-
MSCI_FRONTIER	6.67%	7.81%	-	51.42%
HY	6.67%	2.55%	-	-

*BTC: Bitcoin, **ETH**: Ethereum, **USDT**: Tether, **XRP**: Ripple, **LTC**: Litecoin, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GS**CI: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 11, Portfolio results with Mixed Portfolio

5.1.8 Portfolio efficiency comparison

It is valuable for an investor to be able to compare the investment alternatives. So far, I presented the efficient frontiers one by one. In this section, I compare all the efficient frontiers that I have examined. The comparison is presented in Figure 9, where it is clear that the Mixed portfolio is the most efficient one. In addition, the portfolio including Bitcoin is the second most efficient one, indicating also a significant shift of the efficient frontier to the left and up. Regarding the rest of the portfolios, the shift is weaker, however a medium-size shift is observed for the portfolios including Ethereum and the Cryptocurrency Index.
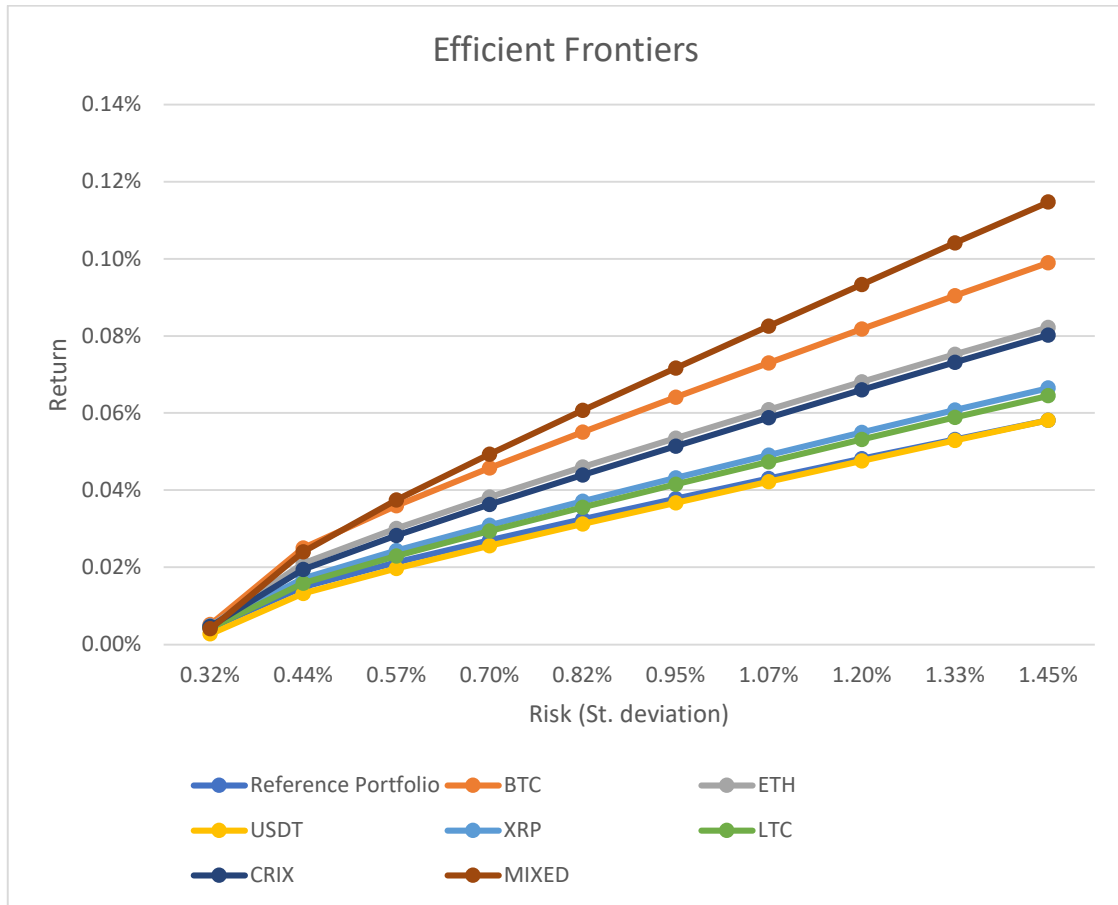
Figure 9, Comparison of the Efficient Frontiers including cryptocurrencies

5.1.9 Cryptocurrency performance

It is crucial to examine the returns of the cryptocurrencies to understand if they enhance portfolio performance too. An amount of one hundred is invested in each cryptocurrency on the 1st of August 2017, which is the start of the sample.
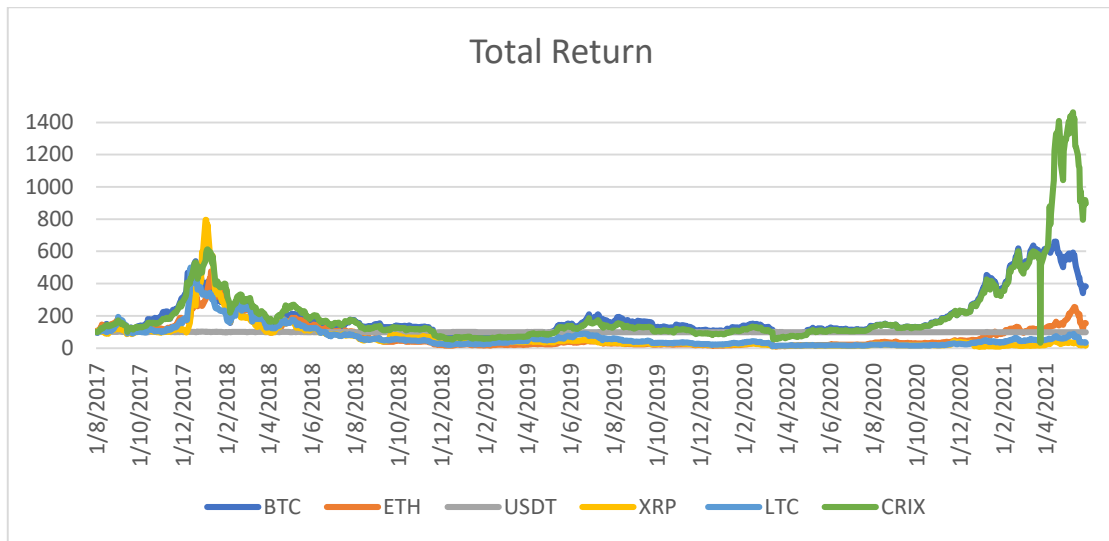
Figure 10, Total return index of cryptocurrencies

At the end of the examined period, some cryptocurrencies outperform. More specifically, the best performance is observed in Cryptocurrency Index (795.51%),

the second-best in Bitcoin (282.47%) and the third-best in Ethereum (53.35%). The rest of the cryptocurrencies underperform, resulting in capital under 100. According to Figure 10, there is another but lower performance outbreak at the start of 2018, where Ripple has the best performance (668.37%), while Cryptocurrency Index experiences the second-best performance (512.06%). The rest of the cryptocurrencies perform better in the above-mentioned period as compared to the end of the sample period.

5.1.10 Market capitalization

Figure 11 represents the cryptocurrency market capitalization during the examined period. The market capitalization of Bitcoin is the largest one, which has a starting point of € 38 billion and after sizeable increases after October 2020, reaches its maximum of almost € 1 trillion in mid of April 2021, and ends in € 580 billion. Ethereum's market capitalization is smaller, which has a starting point of € 18 billion and reaches its maximum at € 400 billion in mid of May 2021, and ends in € 261 billion.
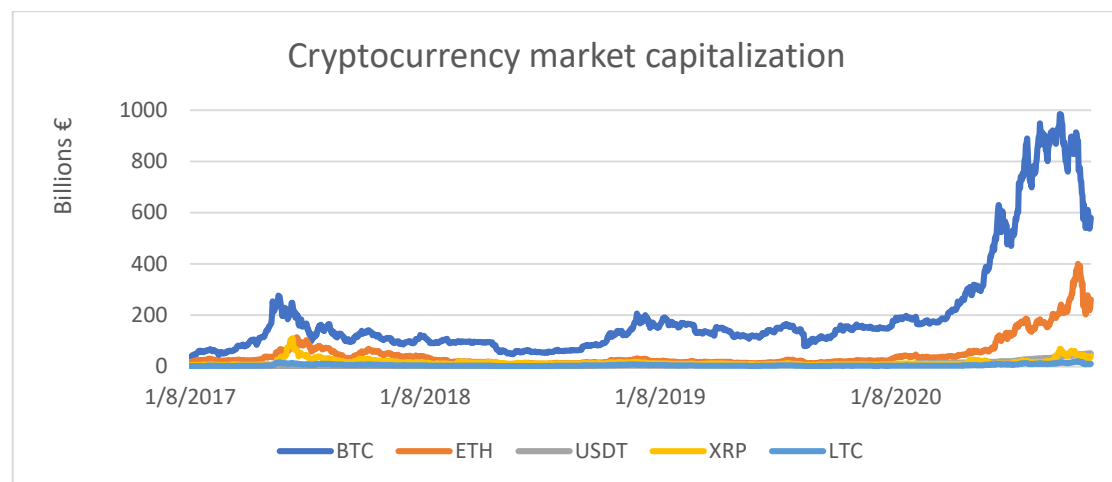
Figure 11, Market capitalization of the examined cryptocurrencies

The rest cryptocurrencies of the thesis do not experience a market capitalization higher than € 69 billion.

5.2 Analysis Covid-19

For this chapter, I examine the same portfolios divided into two time periods: before and during the pandemic. The first one named "Period 1" is the period from the 1st of August 2017 to the 10th of March 2020, which consists of 654 observations. The second one named "Period 2" is from the 11th of March 2020 to the 28th of May 2021, which consists of 308 observations. For both periods, I implement the same

methodology as in the previous section and present the portfolio results for each cryptocurrency. The purpose of this section is to compare the results between the two time periods and examine if the fourth hypothesis is accepted or not, which states that during the pandemic there is a higher increase of the Sharpe ratio

5.2.1 Bitcoin

The comparison results for Bitcoin before and during Covid-19 are presented in Table 12. All Sharpe ratios increase for all investment strategies and the biggest increase is observed in the tangency portfolio. More precisely, the Sharpe ratio increases from 0.0278 to 0.1616.

	1/N		MinVariance		MaxReturn		Tangency	
	Per. 1	Per. 2	Per.1	Per. 2	Per. 1	Per. 2	Period 1	Period 2
Portfolio Expected Return	0.0107%	0.0938%	0.0074%	0.0116%	0.1545%	0.5170%	0.0642%	0.1237%
Portfolio StDev	0.6998%	1.0357%	0.2225%	0.4312%	5.1431%	4.8920%	1.8719%	0.8911%
Expected Sharpe Ratio	-0.0020	0.1101	-0.0213	0.0738	0.0277	0.1098	0.0278	0.1616
BTC	9.09%	9.09%	0.23%	0.16%	100.00%	100.00%	36.37%	10.97%
MSCI_WRLD	9.09%	9.09%	0.37%		-	-	-	13.48%
MSCI_EM	9.09%	9.09%	-	-	-	-	-	-
BWX	9.09%	9.09%	39.51%	52.69%	-	-	44.82%	-
USIG	9.09%	9.09%	51.95%	20.40%	-	-	-	16.13%
GSCI	9.09%	9.09%	1.05%	-	-	-	-	0.24%
MSCI_RE	9.09%	9.09%	2.63%		-	-	18.81%	-
MSCI_INFRA	9.09%	9.09%	-	-	-	-	-	-
PE	9.09%	9.09%	0.40%	-	-	-	-	-
MSCI_FRONTIER	9.09%	9.09%	3.86%	22.65%	-	-	-	59.19%
HY	9.09%	9.09%	-	4.10%	-	-	-	-

*BTC: Bitcoin, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GSCI**: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 12, Portfolio results with Bitcoin before and during Covid-19

However, less allocation to Bitcoin is observed during the pandemic for two portfolios. More specific, the allocation to Bitcoin decreases from 36.37% to 10.97% for the tangency portfolio and there is a slight decrease for the minimum variance portfolio from 0.23% to 0.16%, which means that the fourth hypothesis is not accepted because there is a lower allocation to the cryptocurrency. For the other two portfolios, I can conclude that the investment to Bitcoin during the pandemic leads to a higher Sharpe ratio, validating the fourth hypothesis. This is based on the

fact there is higher Sharpe ratio during the pandemic with the same portfolio weight for Bitcoin.

5.2.3 Ethereum

The comparison results for Ethereum before and during Covid-19 are presented in Table 13. Sharpe ratio increases in all cases and the highest increase is observed at the tangency portfolio (0.1768 from 0.0028). Higher investment to Ethereum is noticed at the maximum return and the tangency portfolio from no investment to 100% and 9.9% respectively.

	1/N		MinVariance		MaxReturn		Tangency	
	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Portfolio Expected Return	-0.0040%	0.1246%	0.0070%	0.0110%	0.0147%	0.8555%	0.0144%	0.1510%
Portfolio StDev	0.7892%	1.1253%	0.2225%	0.4313%	0.9623%	6.6826%	0.8342%	0.9686%
Expected Sharpe Ratio	-0.0204	0.1287	-0.0229	0.0724	0.0027	0.1311	0.0028	0.1768
ETH	9.09%	9.09%	0.16%	-	-	100.00%	-	9.90%
MSCI_WRLD	9.09%	9.09%	0.11%	-	-	-	-	12.37%
MSCI_EM	9.09%	9.09%	-	-	-	-	-	-
BWX	9.09%	9.09%	39.17%	52.80%	-	-	-	-
USIG	9.09%	9.09%	52.23%	20.35%	-	-	-	18.15%
GSCI	9.09%	9.09%	1.16%	-	-	-	-	1.00%
MSCI_RE	9.09%	9.09%	2.51%	-	-	-	32.39%	-
MSCI_INFRA	9.09%	9.09%	-	-	-	-	-	-
PE	9.09%	9.09%	0.92%	-	100.00%	-	67.61%	-
MSCI_FRONTIER	9.09%	9.09%	3.74%	22.92%	-	-	-	58.57%
HY	9.09%	9.09%	-	3.93%	-	-	-	-

*ETH: Ethereum, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GS**CI: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 13, Portfolio results with Ethereum before and during Covid-19

On the other hand, the minimum variance portfolio does not have any weight to Ethereum during the pandemic, while before the pandemic the portfolio weight was 0.16%. I can conclude that the incorporation of Ethereum into the portfolio leads to a higher Sharpe ratio during the pandemic for all portfolios, except of the minimum variance portfolio, due to the lack of investment to Ethereum. Thus, the fourth hypothesis is accepted for all investment strategies, except the minimum variance strategy, because there is higher Sharpe ratio during the pandemic with the same or higher portfolio weight for Ethereum.

5.2.4 Tether

	1/N		MinVariance		MaxReturn		Tangency	
	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Portfolio Expected Return	-0.0033%	0.0468%	0.0058%	-0.0006%	0.0147%	0.1505%	0.0144%	0.0034%
Portfolio StDev	0.4934%	0.9280%	0.2041%	0.0841%	0.9623%	2.1513%	0.8342%	0.0938%
Expected Sharpe Ratio	-0.0313	0.0723	-0.0309	0.2335	0.0027	0.0794	0.0028	0.2526
USDT	9.09%	9.09%	16.77%	93.28%	-	-	-	91.82%
MSCI_WRLD	9.09%	9.09%	0.11%	0.55%	-	-	-	1.31%
MSCI_EM	9.09%	9.09%	-	-	-	-	-	-
BWX	9.09%	9.09%	31.71%	6.18%	-	-	-	3.70%
USIG	9.09%	9.09%	44.40%	-	-	-	-	-
GSCI	9.09%	9.09%	0.93%	-	-	-	-	-
MSCI_RE	9.09%	9.09%	2.01%	-	-	-	32.39%	-
MSCI_INFRA	9.09%	9.09%	-	-	-	-	-	-
PE	9.09%	9.09%	0.83%	-	100.00%	100.00%	67.61%	-
MSCI_FRONTIER	9.09%	9.09%	3.24%	-	-	-	-	3.18%
HY	9.09%	9.09%	-	-	-	-	-	-

*USDT: Tether, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GS**CI: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 14, Portfolio results with Tether before and during Covid-19

Table 14 summarizes the results for portfolios including Tether before and during the pandemic. The pattern for the Sharpe ratio remains the same and for all portfolios there is an increase and the highest one is detected at the minimum variance portfolio from -0.0309 to 0.2335. It is also important to note that the Sharpe Ratio of 0.2526 of the tangency portfolio is the highest one observed for portfolios with an individual cryptocurrency. Portfolios that include Tether experience big increase in the allocation to Tether. More specific, there is an increase from no investment to 91.82% allocation to Tether for the tangency portfolio and from 16.77% to 93.28% for the minimum variance portfolio. All of the portfolios that have investment weight to the cryptocurrency experience higher Sharpe ratio during the pandemic. Thus, hypothesis four is accepted for these portfolios and rejected for the maximum return due to lack of investment to the cryptocurrency.

5.2.5 Ripple

The comparison results for Ripple before and during Covid-19 are displayed in Table 15. In all investment portfolios Sharpe ratio increases and the highest one is

observed at the tangency portfolio from 0.0036 to 0.1405, where only for this portfolio there is a lower allocation to Ripple from 8.13% to 2.44%.

	1/N		MinVariance		MaxReturn		Tangency	
	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Portfolio Expected Return	-0.0006%	0.0876%	0.0070%	0.0128%	0.0301%	0.4493%	0.0157%	0.0807%
Portfolio StDev	0.8630%	1.2693%	0.2225%	0.4280%	7.7499%	9.8822%	0.9981%	0.7187%
Expected Sharpe Ratio	-0.0147	0.0850	-0.0229	0.0773	0.0023	0.0475	0.0036	0.1405
XRP	9.09%	9.09%	0.13%	0.54%	100.00%	100.00%	8.13%	2.44%
MSCI_WRLD	9.09%	9.09%	0.09%	-	-	-	-	3.47%
MSCI_EM	9.09%	9.09%		-	-	-	-	3.65%
BWX	9.09%	9.09%	39.22%	53.08%	-	-	-	5.73%
USIG	9.09%	9.09%	52.14%	19.94%	-	-	-	13.42%
GSCI	9.09%	9.09%	1.26%		-	-	-	2.45%
MSCI_RE	9.09%	9.09%	2.48%	-	-	-	32.43%	-
MSCI_INFRA	9.09%	9.09%		-	-	-	-	-
PE	9.09%	9.09%	0.87%	-	-	-	59.45%	-
MSCI_FRONTIER	9.09%	9.09%	3.81%	22.42%	-	-	-	68.84%
HY	9.09%	9.09%	-	4.03%	-	-	-	-

*XRP: Ripple, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GSCI**: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 15, Portfolio results with Ripple before and during Covid-19

A slight increase from 0.13% to 0.54% can be seen for the minimum variance portfolio, which achieves a Sharpe ratio of 0.0773. The allocation to the cryptocurrency remains the same for the maximum return portfolio, which experiences a higher Sharpe ratio of 0.0475 during the Covid-19 period. All portfolios except the tangency one have the same or higher allocation to the cryptocurrency and in the same time Sharpe ratio is higher during Period 2. Subsequently, the fourth hypothesis is accepted for these portfolios. The results do not support the fourth hypothesis for the tangency portfolio, due to lower allocation to Ripple.

5.2.6 Litecoin

Table 16 summarizes the results for portfolios with Litecoin before and during the pandemic. The highest increase in the Sharpe ratio is observed in the tangency portfolio, meanwhile there is an increase for the rest of portfolios too. The allocation to Litecoin decreases from 5.61% to 2.53% for the tangency portfolio, while it remains the same for the other ones. More specific, there is not any investment to

Litecoin for the minimum variance portfolio and there is full investment for the maximum return portfolio, which increases the Sharpe ratio from 0.0016 to 0.0577.

	1/N		MinVariance		MaxReturn		Tangency	
	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Portfolio Expected Return	-0.0013%	0.0840%	0.0070%	0.0110%	0.0230%	0.4097%	0.0149%	0.0883%
Portfolio StDev	0.8441%	1.2997%	0.2227%	0.4313%	6.9986%	7.4509%	0.9028%	0.7952%
Expected Sharpe Ratio	-0.0158	0.0802	-0.0230	0.0724	0.0016	0.0577	0.0031	0.1366
LTC	9.09%	9.09%	-	-	100.00%	100.00%	5.61%	2.53%
MSCI_WRLD	9.09%	9.09%	0.09%	-	-	-	-	-
MSCI_EM	9.09%	9.09%	-	-	-	-	-	2.43%
BWX	9.09%	9.09%	39.27%	52.80%	-	-	-	-
USIG	9.09%	9.09%	52.22%	20.35%	-	-	-	10.65%
GSCI	9.09%	9.09%	1.26%	-	-	-	-	2.18%
MSCI_RE	9.09%	9.09%	2.48%	-	-	-	32.72%	-
MSCI_INFRA	9.09%	9.09%	-	-	-	-	-	-
PE	9.09%	9.09%	0.87%	-	-	-	61.67%	-
MSCI_FRONTIER	9.09%	9.09%	3.81%	22.92%	-	-	-	82.21%
HY	9.09%	9.09%	-	3.93%	-	-	-	-

LTC: Litecoin, MSCI_WRLD: MSCI International World Price Index, MSCI_EM: MSCI Emerging Markets Price Index, BWX: SPDR Bbg Barclays International Treasury Bond ETF, USIG: iShares Broad USD Investment Grade Corporate Bond ETF, GSCI: iShares S&P GSCI Commodity-Indexed Trust ETF, MSCI_RE: MSCI International World Real Estate Price Index, MSCI_INFRA: MSCI All Country World Transportation Infrastructure Industry Price Index, PE: S&P Listed Private Equity Index, MSCI_FRONTIER: MSCI Frontier Markets Price Index, HY: iShares iBoxx $ High Yield Corporate Bond ETF

Table 16, Portfolio results with Litecoin before and during Covid-19

The combination of equal allocation to Litecoin and higher Sharpe ratio during the pandemic, results in higher portfolio efficiency during the pandemic. For this reason, I accept the hypothesis four for the naïve and the maximum return portfolio, because there is higher Sharpe ratio during Period 2 with the same weights 9.09% and 100% respectively.

5.2.7 Cryptocurrency Index

The results for the benchmark for the cryptocurrency market follow the same pattern as the individual cryptocurrencies and more details are presented in Table 17. In all portfolios, Sharpe ratio increases and the biggest increase is observed at the tangency portfolio from 0.0233 to 0.1374, while the allocation to the Cryptocurrency Index shrinks from 48.53% to 0.82%. Regarding the maximum return portfolio, there is a full investment to the index during the pandemic, achieving a Sharpe ratio of 0.0398, while before the pandemic all funds are invested to the private equity index resulting in a 0.0027 Sharpe ratio.

	1/N		MinVariance		MaxReturn		Tangency	
	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Portfolio Expected Return	0.0085%	0.0840%	0.0073%	0.0116%	0.0147%	0.9030%	0.0696%	0.0849%
Portfolio StDev	0.7019%	1.2997%	0.2224%	0.4310%	0.9623%	23.1838%	2.4709%	0.7656%
Expected Sharpe Ratio	-0.0052	0.0802	-0.0216	0.0739	0.0027	0.0398	0.0233	0.1374
CRIX	9.09%	9.09%	0.23%	0.07%	-	100.00%	48.53%	0.82%
MSCI_WRLD	9.09%	9.09%	0.02%	-	-	-	-	3.87%
MSCI_EM	9.09%	9.09%		-	-	-	-	2.24%
BWX	9.09%	9.09%	39.13%	52.73%	-	-	35.55%	-
USIG	9.09%	9.09%	52.27%	20.35%	-	-	-	13.42%
GSCI	9.09%	9.09%	1.14%		-	-	-	1.98%
MSCI_RE	9.09%	9.09%	2.42%	-	-	-	15.92%	-
MSCI_INFRA	9.09%	9.09%		-	-	-	-	-
PE	9.09%	9.09%	1.03%	-	100.00%	-	-	-
MSCI_FRONTIER	9.09%	9.09%	3.75%	22.92%	-	-	-	77.67%
HY	9.09%	9.09%	-	3.93%	-	-	-	-

*CRIX: Cryptocurrency Index, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GSCI**: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 17, Portfolio results with Cryptocurrency Index before and during Covid-19

The index weights decrease slightly from 0.23% to 0.07% for the minimum variance portfolio, but as mentioned before the Sharpe ratio increases to 0.0739. The fourth hypothesis is confirmed for the naive and the maximum return portfolio. For the first one, the Sharpe ratio increases with 9.09% stable allocation to the Index and for the second one the Sharpe ratio increases with 100% stable allocation to the Index during the pandemic.

5.2.8 Mixed portfolio

The results of the portfolio containing all the cryptocurrencies of the study are presented in Table 18. This portfolio experiences strong increases in the Sharpe ratio for each investment strategy, resulting in higher Sharpe ratios during the pandemic and the highest one is observed at the tangency portfolio, which is 0.2896. For this portfolio, there is a total allocation to cryptocurrencies of 36.91% before the pandemic and during the pandemic increases to 93.83%. In more detail, the allocation to Bitcoin from 35.72% goes to zero and the allocation to Tether follows the opposite movement from zero to 92.8%. For the rest of the cryptocurrencies, the changes are less than 1.09% either increasing or decreasing.

	1/N		MinVariance		MaxReturn		Tangency	
	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Portfolio Expected Return	0.0109%	0.1831%	0.0061%	-0.0004%	0.1545%	0.8555%	0.0635%	0.0092%
Portfolio StDev	1.2244%	1.4123%	0.2029%	0.0912%	5.1431%	6.6826%	1.8439%	0.1018%
Expected Sharpe Ratio	-0.0010	0.1440	-0.0295	0.2177	0.0277	0.1311	0.0279	0.2896
BTC	6.67%	6.67%	0.16%	-	100.00%		35.72%	-
ETH	6.67%	6.67%	0.23%	0.08%	-	100.00%	-	0.66%
USDT	6.67%	6.67%	17.16%	90.63%	-	-	-	92.80%
XRP	6.67%	6.67%	0.05%	-	-	-	1.19%	0.10%
LTC	6.67%	6.67%	-	0.05%	-	-	-	0.26%
MSCI_WRLD	6.67%	6.67%	0.02%	-	-	-	-	1.44%
MSCI_EM	6.67%	6.67%	-	-	-	-	-	-
BWX	6.67%	6.67%	32.31%	5.35%	-	-	44.25%	3.35%
USIG	6.67%	6.67%	43.17%	-	-	-	-	-
GSCI	6.67%	6.67%	0.74%	-	-	-	-	-
MSCI_RE	6.67%	6.67%	2.54%	-	-	-	18.83%	-
MSCI_INFRA	6.67%	6.67%	-	-	-	-	-	-
PE	6.67%	6.67%	0.42%	-	-	-	-	-
MSCI_FRONTIER	6.67%	6.67%	3.20%	-	-	-	-	1.38%
HY	6.67%	6.67%	-	3.88%	-	-	-	-

*BTC: Bitcoin, **ETH**: Ethereum, **USDT**: Tether, **XRP**: Ripple, **LTC**: Litecoin, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GSCI**: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table 18, Mixed Portfolio results before and during Covid-19

Regarding the minimum variance portfolio, the total allocation to cryptocurrencies is 17.6% before Covid-19 and increases to 90.76% during the Covid-19 period. The biggest change is for Tether, which increases from 17.16% to 90.63%. For the rest of the cryptocurrencies, the changes are less than 0.16%. The maximum return portfolio experiences more straightforward changes, wherefrom full investment to Bitcoin before the pandemic shifts to full investment to Ethereum during the pandemic, resulting in a Sharpe ratio of 0.1311 from 0.0277. The mixed portfolio is the only portfolio of the study where the fourth hypothesis of higher Sharpe ratio during the pandemic is confirmed for all the examined investment strategies, because of the same or higher allocation to the cryptocurrencies during Period 2.

5.3 Summary
In this section, I provide summary tables in order to compare the addition of each cryptocurrency, sorted by investment strategy and based on the full sample.

	Reference Portfolio	Bitcoin Portfolio	Ethereum Portfolio	Tether Portfolio	Ripple Portfolio	Litecoin Portfolio	CRIX Portfolio	Mixed Portfolio
Portfolio Expected Return	0.0140%	0.0373%	0.0371%	0.0127%	0.0276%	0.0260%	0.0470%	0.0660%
Portfolio StDev	0.7288%	0.8228%	0.9118%	0.6641%	1.0112%	1.0126%	1.4293%	1.2893%
Expected Sharpe Ratio	0.0168	0.0432	0.0388	0.0165	0.0256	0.0240	0.0317	0.0499
MSCI_WRLD	10.00%	9.09%	9.09%	9.09%	9.09%	9.09%	9.09%	6.67%
MSCI_EM	10.00%	9.09%	9.09%	9.09%	9.09%	9.09%	9.09%	6.67%
BWX	10.00%	9.09%	9.09%	9.09%	9.09%	9.09%	9.09%	6.67%
USIG	10.00%	9.09%	9.09%	9.09%	9.09%	9.09%	9.09%	6.67%
GSCI	10.00%	9.09%	9.09%	9.09%	9.09%	9.09%	9.09%	6.67%
MSCI_RE	10.00%	9.09%	9.09%	9.09%	9.09%	9.09%	9.09%	6.67%
MSCI_INFRA	10.00%	9.09%	9.09%	9.09%	9.09%	9.09%	9.09%	6.67%
PE	10.00%	9.09%	9.09%	9.09%	9.09%	9.09%	9.09%	6.67%
MSCI_FRONTIER	10.00%	9.09%	9.09%	9.09%	9.09%	9.09%	9.09%	6.67%
HY	10.00%	9.09%	9.09%	9.09%	9.09%	9.09%	9.09%	6.67%
BTC	-	9.09%	-	-	-	-	-	6.67%
ETH	-	-	9.09%	-	-	-	-	6.67%
USDT	-	-	-	9.09%	-	-	-	6.67%
XRP	-	-	-	-	9.09%	-	-	6.67%
LTC	-	-	-	-	-	9.09%	-	6.67%
CRIX	-	-	-	-	-	-	9.09%	-
∑wι	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

BTC: Bitcoin, ETH: Ethereum, USDT: Tether, XRP: Ripple, LTC: Litecoin, CRIX: Cryptocurrency Index, MSCI_WRLD: MSCI International World Price Index, MSCI_EM: MSCI Emerging Markets Price Index, BWX: SPDR Bbg Barclays International Treasury Bond ETF, USIG: iShares Broad USD Investment Grade Corporate Bond ETF, GSCI: iShares S&P GSCI Commodity-Indexed Trust ETF, MSCI_RE: MSCI International World Real Estate Price Index, MSCI_INFRA: MSCI All Country World Transportation Infrastructure Industry Price Index, PE: S&P Listed Private Equity Index, MSCI_FRONTIER: MSCI Frontier Markets Price Index, HY: iShares iBoxx $ High Yield Corporate Bond ETF

Table 19, Summary Table for the naive investment strategy

Table 19 includes the weights, portfolio's expected return and standard deviation and Sharpe ratio for the naive investment strategy. In all cases except one, Sharpe ratio increases significantly after the addition of each cryptocurrency in the Reference Portfolio. The highest increase is observed in the Mixed portfolio, where the Sharpe ratio grows from 0.0168 to 0.0499. The only exemption is the Tether Portfolio, where the Sharpe ratio declines slightly to 0.0165. As a result, hypothesis 2, which mentions that Sharpe ratio increases after the addition of a cryptocurrency in the portfolio is accepted for all portfolios except the one including Tether.

Table 20 demonstrates the summary results for the minimum variance strategy. The same pattern is observed as in the naive strategy and in all cases except one, Sharpe ratio increases significantly after the addition of each cryptocurrency in the Reference Portfolio. The greatest increase is observed in the Bitcoin Portfolio, which is from 0.0081 to 0.0109. Tether portfolio is the exemption, where the Sharpe ratio lessens to 0.0041. In the same logic as before, hypothesis 2 is accepted for all

portfolios excluding the one including Tether, because Sharpe Ratio increases after adding cryptocurrencies.

	Reference Portfolio	Bitcoin Portfolio	Ethereum Portfolio	Tether Portfolio	Ripple Portfolio	Litecoin Portfolio	CRIX Portfolio	Mixed Portfolio
Portfolio Expected Return	0.0043%	0.0052%	0.0048%	0.0028%	0.0047%	0.0043%	0.0047%	0.0041%
Portfolio StDev	0.3175%	0.3171%	0.3173%	0.2505%	0.3180%	0.3175%	0.3172%	0.2490%
Expected Sharpe Ratio	0.0081	0.0109	0.0096	0.0041	0.0095	0.0081	0.0093	0.0094
MSCI_WRLD	-	-	-	-	-	-	-	-
MSCI_EM	-	-	-	-	-	-	-	-
BWX	54.70%	54.58%	54.70%	34.70%	59.95%	54.70%	54.60%	33.70%
USIG	29.39%	29.51%	29.55%	17.93%	26.61%	29.39%	29.39%	17.33%
GSCI	-	-	-	-	-	-	-	-
MSCI_RE	-	-	-	-	1.49%	-	-	-
MSCI_INFRA	-	-	-	-	-	-	-	-
PE	-	-	-	-	-	-	-	-
MSCI_FRONTIER	14.15%	13.79%	13.80%	8.72%	10.88%	14.15%	14.15%	7.81%
HY	1.77%	1.77%	1.77%	0.66%	0.68%	1.77%	1.77%	2.55%
BTC	-	0.34%	-	-	-	-	-	0.29%
ETH	-	-	0.18%	-	-	-	-	0.21%
USDT	-	-	-	37.99%	-	-	-	37.98%
XRP	-	-	-	-	0.38%	-	-	0.14%
LTC	-	-	-	-	-	-	-	-
CRIX	-	-	-	-	-	-	0.10%	-
∑wₗ	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

BTC: Bitcoin, ETH: Ethereum, USDT: Tether, XRP: Ripple, LTC: Litecoin, CRIX: Cryptocurrency Index, MSCI_WRLD: MSCI International World Price Index, MSCI_EM: MSCI Emerging Markets Price Index, BWX: SPDR Bbg Barclays International Treasury Bond ETF, USIG: iShares Broad USD Investment Grade Corporate Bond ETF, GSCI: iShares S&P GSCI Commodity-Indexed Trust ETF, MSCI_RE: MSCI International World Real Estate Price Index, MSCI_INFRA: MSCI All Country World Transportation Infrastructure Industry Price Index, PE: S&P Listed Private Equity Index, MSCI_FRONTIER: MSCI Frontier Markets Price Index, HY: iShares iBoxx $ High Yield Corporate Bond ETF

Table 20, Summary Table for the minimum variance investment strategy

Table 21 provides the summary results for the maximum return strategy, where they follow a different pattern. The Sharpe ratio increases only after the addition of Bitcoin or Ethereum. The Mixed portfolio delivers the same results as the Ethereum portfolio because the optimal allocation is 100% to Bitcoin. The greatest increase is observed in the Bitcoin portfolio, where there is an increase from 0.0388 to 0.0531. Taking into consideration the above-mentioned results, hypothesis 2 is accepted only for the Bitcoin, Ethereum and Mixed portfolios, because only in these portfolios Sharpe ratio increases. Table 22 reports the summary results for the tangency portfolio strategy. In all portfolios including the one with Tether, the Sharpe ratio increases. The most sizeable one is detected in the Mixed portfolio, where the Sharpe ratio increases from 0.0388 to 0.0671. The Sharpe ratio of the Tether portfolio increases marginally. Only in this investment strategy, hypothesis 2 is accepted for all cryptocurrencies.

	Reference Portfolio	Bitcoin Portfolio	Ethereum Portfolio	Tether Portfolio	Ripple Portfolio	Litecoin Portfolio	CRIX Portfolio	Mixed Portfolio
Portfolio Expected Return	0.0582%	0.2706%	0.2688%	0.0582%	0.1643%	0.1468%	0.3775%	0.2706%
Portfolio StDev	1.4532%	5.0643%	6.5472%	1.4532%	8.4881%	7.1449%	13.7608%	5.0643%
Expected Sharpe Ratio	0.0388	0.0531	0.0408	0.0388	0.0192	0.0203	0.0273	0.0531
MSCI_WRLD	-	-	-	-	-	-	-	-
MSCI_EM	-	-	-	-	-	-	-	-
BWX	-	-	-	-	-	-	-	-
USIG	-	-	-	-	-	-	-	-
GSCI	-	-	-	-	-	-	-	-
MSCI_RE	-	-	-	-	-	-	-	-
MSCI_INFRA	-	-	-	-	-	-	-	-
PE	100.00%	-	-	100.00%	-	-	-	-
MSCI_FRONTIER	-	-	-	-	-	-	-	-
HY	-	-	-	-	-	-	-	-
BTC	-	100.00%	-	-	-	-	-	100.00%
ETH	-	-	100.00%	-	-	-	-	-
USDT	-	-	-	-	-	-	-	-
XRP	-	-	-	-	100.00%	-	-	-
LTC	-	-	-	-	-	100.00%	-	-
CRIX	-	-	-	-	-	-	100.00%	-
∑wₗ	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

BTC: Bitcoin, ETH: Ethereum, USDT: Tether, XRP: Ripple, LTC: Litecoin, CRIX: Cryptocurrency Index, MSCI_WRLD: MSCI International World Price Index, MSCI_EM: MSCI Emerging Markets Price Index, BWX: SPDR Bbg Barclays International Treasury Bond ETF, USIG: iShares Broad USD Investment Grade Corporate Bond ETF, GSCI: iShares S&P GSCI Commodity-Indexed Trust ETF, MSCI_RE: MSCI International World Real Estate Price Index, MSCI_INFRA: MSCI All Country World Transportation Infrastructure Industry Price Index, PE: S&P Listed Private Equity Index, MSCI_FRONTIER: MSCI Frontier Markets Price Index, HY: iShares iBoxx $ High Yield Corporate Bond ETF

Table 21, Summary Table for the maximum return investment strategy

	Reference Portfolio	Bitcoin Portfolio	Ethereum Portfolio	Tether Portfolio	Ripple Portfolio	Litecoin Portfolio	CRIX Portfolio	Mixed Portfolio
Portfolio Expected Return	0.0582%	0.0990%	0.0822%	0.0582%	0.0665%	0.0645%	0.0802%	0.1147%
Portfolio StDev	1.4532%	1.4995%	1.4586%	1.4532%	1.4922%	1.5263%	1.6497%	1.6838%
Expected Sharpe Ratio	0.0388	0.0649	0.0552	0.0388	0.0434	0.0411	0.0476	0.0671
MSCI_WRLD	-	23.64%	20.50%	-	-	-	0.08%	-
MSCI_EM	-	-	-	-	-	-	-	17.20%
BWX	-	-	-	-	-	-	-	-
USIG	-	10.98%	11.36%	-	-	-	0.08%	-
GSCI	-	-	-	-	-	-	-	-
MSCI_RE	-	-	-	-	-	-	-	-
MSCI_INFRA	-	-	-	-	-	-	-	-
PE	100.00%	41.42%	52.13%	100.00%	92.14%	92.84%	92.91%	-
MSCI_FRONTIER	-	-	-	-	-	-	-	51.42%
HY	-	-	-	-	-	-	-	-
BTC	-	23.96%	-	-	-	-	-	25.10%
ETH	-	-	16.01%	-	-	-	-	-
USDT	-	-	-	-	-	-	-	-
XRP	-	-	-	-	7.86%	-	-	4.90%
LTC	-	-	-	-	-	7.16%	-	1.39%
CRIX	-	-	-	-	-	-	6.93%	-
∑wₗ	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

BTC: Bitcoin, ETH: Ethereum, USDT: Tether, XRP: Ripple, LTC: Litecoin, CRIX: Cryptocurrency Index, MSCI_WRLD: MSCI International World Price Index, MSCI_EM: MSCI Emerging Markets Price Index, BWX: SPDR Bbg Barclays International Treasury Bond ETF, USIG: iShares Broad USD Investment Grade Corporate Bond ETF, GSCI: iShares S&P GSCI Commodity-Indexed Trust ETF, MSCI_RE: MSCI International World Real Estate Price Index, MSCI_INFRA: MSCI All Country World Transportation Infrastructure Industry Price Index, PE: S&P Listed Private Equity Index, MSCI_FRONTIER: MSCI Frontier Markets Price Index, HY: iShares iBoxx $ High Yield Corporate Bond ETF

Table 22, Summary Table for the tangency portfolio investment strategy

Table 23 summarizes the Sharpe ratio across all portfolios and investment strategies. The aim of this table is to help the reader to understand if the results remain robust when an investor selects a different investment strategy, which is the third hypothesis.

	1/N	MinVariance	MaxReturn	Tangency
Reference Portfolio	0.0168	0.0081	0.0388	0.0388
BTC Portfolio	0.0432	0.0109	0.0531	0.0649
ETH Portfolio	0.0388	0.0096	0.0408	0.0552
USDT Portfolio	0.0165	0.0041	0.0388	0.0388
XRP Portfolio	0.0256	0.0095	0.0192	0.0434
LTC Portfolio	0.0240	0.0081	0.0203	0.0411
CRIX Portfolio	0.0317	0.0093	0.0273	0.0476
Mixed Portfolio	0.0499	0.0094	0.0531	0.0671

*BTC: Bitcoin, **ETH**: Ethereum, **USDT**: Tether, **XRP**: Ripple, **LTC**: Litecoin, **CRIX**: Cryptocurrency Index*

Table 23, Summary Table for the Sharpe ratio

As mentioned before, the Bitcoin, Ethereum and Mixed portfolios provide robust results when changing the investment strategy, because in all cases, the Sharpe ratio increases after the addition of each cryptocurrency. As a result, I accept the third hypothesis for the above-mentioned portfolios. However, the addition of Tether results in a lower Sharpe ratio with the exemption of the tangency portfolio, where it increases marginally. Regarding the Ripple, Litecoin and CRIX portfolios a decrease in the Sharpe ratio is observed when an investor selects the maximum return strategy. Thus, for these portfolios, I reject the third hypothesis.

6. Conclusion

The development of cryptocurrencies and the adoption of Blockchain technology contributed to financial innovations over the last two decades. The attention on cryptocurrencies has increased due to the considerable returns and a lot of people, mainly the younger ones, find these assets attractive for investment. Nevertheless, cryptocurrencies receive awareness from institutional investors, regulators and governments also. Cryptocurrencies are a very controversial discussion point for the finance industry and the stakeholders involved. This undiscovered market is still in an early stage not only from the investing perspective but also from the research one. Thus, this thesis answers the below research question:

Does the incorporation of cryptocurrencies into an investor's portfolio offer any diversification benefits? Also, can we observe any different results in the Covid-19 period?

The goal of this research is to better understand how cryptocurrencies behave in comparison to other asset classes and how an investor may make his portfolio more efficient. Therefore, this thesis investigates if the incorporation of cryptocurrencies into a portfolio can offer any diversification benefits in the recent sample period 2017-2021. In addition, it examines if there are any different results during the pandemic, which influences the financial markets also. After constructing the efficient frontiers for the portfolios including cryptocurrencies, I partially confirm the first hypothesis except for the Tether portfolio. In more detail, the first hypothesis mentions that in terms of the efficient frontier framework, the traditional portfolio with cryptocurrency is more efficient. With regards on which cryptocurrency should an investor choose to increase the portfolio efficiency; the answer is the Mixed portfolio. The efficient frontier of the Mixed portfolio is steeper and more to the left than any other efficient frontier of the study. Hypothesis two evaluates the portfolios by using the Sharpe ratio and supports that the incorporation of cryptocurrencies into the Reference portfolio, induces a higher Sharpe ratio. This hypothesis is rejected because the portfolios are sensitive to the investment strategy and the selection of cryptocurrency. Furthermore, the Sharpe ratio of the Mixed portfolio is greater than any other one of the portfolios including an individual cryptocurrency in most of the cases. This study includes different investment

strategies to verify that the results remain the same among these strategies, which is the third hypothesis. However, the above is not observed in the examined portfolios, thus the third hypothesis is rejected. Finally, the pandemic affects in the examined portfolios and, concerning the fourth hypothesis, the increase of the Sharpe ratio is higher during the pandemic sample. However, at the same time, lower allocation to cryptocurrencies is observed depending on the investment strategy. Thus, the fourth hypothesis is accepted only partially. In order to have a clear picture regarding the acceptance of the four hypotheses, Table 24 summarizes for which crypto coin or index each hypothesis is accepted or not.

Crypto coin or index	Hypothesis 1	Hypothesis 2	Hypothesis 3	Hypothesis 4
Bitcoin (BTC)	Accept	Accept	Accept	Reject
Ethereum (ETH)	Accept	Accept	Accept	Accept
Tether (USDT)	Reject	Reject	Accept	Reject
Ripple (XRP)	Accept	Reject	Reject	Reject
Litecoin (LTC)	Accept	Reject	Reject	Reject
CRIX	Accept	Reject	Reject	Reject

Table 24,Summary Table hypothesis acceptance/rejection per crypto coin or index

This thesis contributes to the literature by including cryptocurrencies other than and including Bitcoin in an already diversified portfolio. Nevertheless, the existing literature covers mainly analyses including Bitcoin. The results of the Bitcoin portfolio are supported in terms that the addition of Bitcoin to an optimal portfolio increases portfolio performance by several articles such as the Wu & Pandey (2014), Brière et al. (2015), Eisl et al. (2015), Guesmi et al. (2018) and Kajtazi and Moro (2019). Also, Bouri et al. (2016) defend that Bitcoin is not a powerful hedge but it can be used as a diversifier in their study, which includes equity, bonds, commodities and cash. The more complete approach of Trimborn et al. (2017) validates the results regarding Bitcoin, Ripple and Litecoin portfolios. However, the above study includes only equities from three countries. Anyfantaki et al. (2018) use a similar dataset regarding cryptocurrencies as compared to this thesis, using Bitcoin, Ethereum, Ripple and Litecoin, however, they include only U.S. equity and bonds. They conclude

that in the in-sample tests there are investment opportunities due to the augmentation of cryptocurrencies and in the out-of-sample analysis there are some diversification benefits after adding these cryptocurrencies to a traditional portfolio. In addition, Chuen et al. (2018) conclude that since the correlations between cryptocurrencies and traditional assets are constantly low and the average return of most cryptocurrencies is greater, the CRIX can be a viable alternative to help diversify a portfolio.

The results of this thesis contradict with some of the papers of the existing literature. For example, Chen et al. (2021) support that the investment to cryptocurrency leads to lower Sharpe ratios. However, their portfolios include only cryptocurrency and not traditional assets. Also, Goodell & Goutte (2021) support that Tether is a better diversifier during the pandemic, as compared to the rest of the examined cryptocurrencies of their work such as Bitcoin and Ethereum, due to the negative correlation with the equity indices used in their research. Although, the thesis results suggest stronger negative correlation for Ethereum and Bitcoin with the MSCI International World Price Index as compared to Tether during the Covid-19 sample. However, the thesis results conform with the ones of their paper for the rest of the equity indexes used in this thesis.

There are various limitations in the thesis that may have an impact on the study's findings. To begin, portfolios were built without accounting for transaction costs associated with asset purchases. Dividends paid to shareholders were not counted as part of total returns, which is a further restriction of the study. As a result, future research could take into account the above limitations and take into consideration more cryptocurrencies with growing popularity. Finally, more advanced portfolio design approaches, such as the Black-Litterman model, might be employed to assess cryptocurrencies' diversification benefits.

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Appendix

	N	Mean	Median	St. Deviation	Kurtosis	Skewness	Minimum	Maximum
BTC	654	0.00154	0.00040	0.05143	4.06125	-0.27229	-0.26829	0.24987
ETH	654	-0.00008	-0.00047	0.06469	4.32268	-0.53501	-0.34521	0.26837
USDT	654	0.00000	0.00000	0.00488	10.35621	-0.00571	-0.02617	0.03457
XRP	654	0.00030	-0.00119	0.07750	14.49686	1.90060	-0.41981	0.61832
LTC	654	0.00023	-0.00266	0.06999	9.66849	1.30125	-0.30795	0.52766
CRIX	654	0.00130	0.00088	0.05078	4.57795	-0.52474	-0.30901	0.22027
MSCI_WRLD	654	0.00013	0.00072	0.00907	16.58769	-1.87888	-0.08864	0.04282
MSCI_EM	654	-0.00009	0.00038	0.00963	8.13476	-1.30917	-0.07975	0.03217
BWX	654	0.00012	0.00004	0.00286	1.13255	0.20634	-0.00876	0.01290
USIG	654	0.00006	0.00019	0.00257	14.74059	-1.83092	-0.02324	0.00965
GSCI	654	-0.00030	0.00071	0.01224	20.06340	-1.83953	-0.12875	0.06558
MSCI_RE	654	0.00014	0.00067	0.00825	15.60719	-1.72638	-0.07773	0.04178
MSCI_INFRA	654	-0.00028	0.00033	0.00749	13.65125	-2.01569	-0.07070	0.01680
PE	654	0.00015	0.00087	0.00962	22.46702	-2.60519	-0.10332	0.03594
MSCI_FRONTIER	654	-0.00026	0.00015	0.00738	132.60289	-7.93258	-0.12689	0.02144
HY	654	-0.00004	0.00017	0.00570	18.32880	-1.57619	-0.05824	0.03002

BTC: Bitcoin, ETH: Ethereum, USDT: Tether, XRP: Ripple, LTC: Litecoin, CRIX: Cryptocurrency Index, MSCI_WRLD: MSCI International World Price Index, MSCI_EM: MSCI Emerging Markets Price Index, BWX: SPDR Bbg Barclays International Treasury Bond ETF, USIG: iShares Broad USD Investment Grade Corporate Bond ETF, GSCI: iShares S&P GSCI Commodity-Indexed Trust ETF, MSCI_RE: MSCI International World Real Estate Price Index, MSCI_INFRA: MSCI All Country World Transportation Infrastructure Industry Price Index, PE: S&P Listed Private Equity Index, MSCI_FRONTIER: MSCI Frontier Markets Price Index, HY: iShares iBoxx $ High Yield Corporate Bond ETF

Table A.1, Period 1 descriptive statistics

	N	Mean	Median	St. Deviation	Kurtosis	Skewness	Minimum	Maximum
BTC	308	0.00517	0.00609	0.04892	6.63239	-0.88323	-0.31595	0.16104
ETH	308	0.00856	0.00808	0.06683	7.79715	-1.01339	-0.42357	0.26957
USDT	308	0.00000	0.00000	0.00092	18.58030	-1.18940	-0.00744	0.00506
XRP	308	0.00449	0.00299	0.09882	11.12310	0.29323	-0.54102	0.58632
LTC	308	0.00410	0.00605	0.07451	10.93625	-1.69065	-0.48678	0.23728
CRIX	308	0.00903	0.00808	0.23184	134.41668	-0.51685	-2.81084	2.74772
MSCI_WRLD	308	0.00096	0.00117	0.01567	14.95096	-1.21302	-0.10671	0.07792
MSCI_EM	308	0.00087	0.00124	0.01312	6.69607	-1.04708	-0.07414	0.04959
BWX	308	-0.00020	-0.00008	0.00563	31.87048	-0.51246	-0.04700	0.04623
USIG	308	0.00008	0.00017	0.00756	19.88097	-0.05001	-0.04406	0.05043
GSCI	308	0.00087	0.00240	0.01774	7.00250	-1.29785	-0.10984	0.05643
MSCI_RE	308	0.00013	0.00047	0.01784	19.45918	-2.06668	-0.15018	0.07359
MSCI_INFRA	308	0.00013	-0.00002	0.01841	15.15357	-1.50890	-0.12543	0.07582
PE	308	0.00150	0.00211	0.02151	12.93694	-1.01012	-0.13720	0.12043
MSCI_FRONTIER	308	0.00089	0.00181	0.00836	19.36873	-2.62808	-0.07160	0.02357
HY	308	0.00087	0.00124	0.01312	6.69607	-1.04708	-0.07414	0.04959

BTC: Bitcoin, ETH: Ethereum, USDT: Tether, XRP: Ripple, LTC: Litecoin, CRIX: Cryptocurrency Index, MSCI_WRLD: MSCI International World Price Index, MSCI_EM: MSCI Emerging Markets Price Index, BWX: SPDR Bbg Barclays International Treasury Bond ETF, USIG: iShares Broad USD Investment Grade Corporate Bond ETF, GSCI: iShares S&P GSCI Commodity-Indexed Trust ETF, MSCI_RE: MSCI International World Real Estate Price Index, MSCI_INFRA: MSCI All Country World Transportation Infrastructure Industry Price Index, PE: S&P Listed Private Equity Index, MSCI_FRONTIER: MSCI Frontier Markets Price Index, HY: iShares iBoxx $ High Yield Corporate Bond ETF

Table A.2, Period 2 descriptive statistics

	BTC	ETH	USDT	XRP	LTC	CRIX	MSCI_WRLD	MSCI_EM	BWX	USIG	GSCI	MSCI_RE	MSCI_INFRA	PE	MSCI_FRONTIER	HY
BTC	1															
ETH	0.7019	1														
USDT	-0.1071	-0.1391	1													
XRP	0.0360	0.1089	0.0303	1												
LTC	0.1991	0.2446	-0.0558	0.1645	1											
CRIX	0.6699	0.5991	-0.1280	0.1948	0.2336	1										
MSCI_WRLD	0.0339	0.0255	0.0213	0.0081	0.0937	0.0739	1									
MSCI_EM	0.0384	0.0719	0.0407	0.0398	0.1088	0.0382	0.6999	1								
BWX	-0.0685	-0.0471	0.0318	-0.0477	0.0614	-0.0412	0.1839	0.1710	1							
USIG	0.0113	-0.0093	0.0051	0.0031	0.0281	-0.0198	-0.0483	-0.0085	0.4509	1						
GSCI	0.0922	0.0995	0.0217	0.0050	0.0594	0.1081	0.4738	0.4049	0.0242	0.0093	1					
MSCI_RE	-0.0060	-0.0188	-0.0053	0.0083	0.0627	0.0390	0.7341	0.5168	0.3828	0.1574	0.3050	1				
MSCI_INFRA	0.0658	0.0636	0.0176	0.0055	0.1137	0.0885	0.6555	0.7339	0.2379	0.1059	0.3337	0.6001	1			
PE	0.1131	0.1051	0.0062	0.0291	0.0804	0.0952	0.8373	0.6492	0.0782	0.0112	0.4655	0.5780	0.6165	1		
MSCI_FRONTIER	0.0890	0.0653	-0.0006	0.0173	0.0684	0.0824	0.4038	0.4353	0.0005	0.1714	0.3742	0.2929	0.3953	0.4495	1	
HY	-0.0380	-0.0656	0.0291	-0.0489	0.0530	-0.0083	0.8075	0.5619	0.4457	0.0673	0.3715	0.6978	0.5442	0.6246	0.2877	1

*BTC: Bitcoin, **ETH**: Ethereum, **USDT**: Tether, **XRP**: Ripple, **LTC**: Litecoin, **CRIX**: Cryptocurrency Index, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GS**CI: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table A.3, Period 1 correlation table

	BTC	ETH	USDT	XRP	LTC	CRIX	MSCI_WRLD	MSCI_EM	BWX	USIG	GSCI	MSCI_RE	MSCI_INFRA	PE	MSCI_FRONTIER	HY
BTC	1															
ETH	0.8142	1														
USDT	0.0221	-0.0215	1													
XRP	0.0690	0.1247	0.0561	1												
LTC	0.0637	0.0707	-0.1437	-0.0616	1											
CRIX	0.2351	0.2196	-0.0377	-0.0186	0.0494	1										
MSCI_WRLD	-0.1220	-0.0899	-0.0778	-0.0285	0.3413	-0.0365	1									
MSCI_EM	0.1313	0.1771	0.0517	-0.0228	0.1938	0.0598	0.6334	1								
BWX	0.0292	0.0591	-0.2650	-0.1159	0.0561	-0.0287	0.0758	0.1173	1							
USIG	-0.0895	-0.0922	0.0998	-0.0142	0.1916	-0.0323	0.3252	0.2413	0.1768	1						
GSCI	0.0578	0.0333	0.0369	0.0156	0.1826	0.1061	0.4503	0.3202	0.1263	0.1954	1					
MSCI_RE	-0.0511	-0.0513	0.0507	-0.0389	0.2327	-0.0113	0.8765	0.6140	0.0394	0.3465	0.3727	1				
MSCI_INFRA	0.1314	0.1473	0.0276	-0.0363	0.1888	0.0181	0.6296	0.7203	0.0844	0.2744	0.3328	0.6855	1			
PE	-0.0271	0.0020	-0.0172	-0.0345	0.2899	-0.0277	0.8590	0.6417	0.1889	0.3689	0.4432	0.8263	0.7054	1		
MSCI_FRONTIER	0.2136	0.1755	0.1483	0.0181	0.1726	0.0478	0.4477	0.5391	0.0052	0.1230	0.3651	0.4795	0.5465	0.5089	1	
HY	-0.1359	-0.1223	0.0173	-0.0309	0.1913	-0.0781	0.8017	0.4956	0.1354	0.4279	0.3452	0.8120	0.5134	0.7158	0.2826	1

*BTC: Bitcoin, **ETH**: Ethereum, **USDT**: Tether, **XRP**: Ripple, **LTC**: Litecoin, **CRIX**: Cryptocurrency Index, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GS**CI: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table A.4, Period 2 correlation table

	BTC	ETH	USDT	XRP	LTC	CRIX	MSCI_WRLD	MSCI_EM	BWX	USIG	GSCI	MSCI_RE	MSCI_INFRA	PE	MSCI_FRONTIER	HY
BTC	0.002565															
ETH	0.002444	0.004287														
USDT	-0.000018	-0.000030	0.000016													
XRP	0.000207	0.000642	0.000009	0.007205												
LTC	0.000564	0.000872	-0.000016	0.000465	0.005105											
CRIX	0.002047	0.002439	-0.000024	0.000392	0.000843	0.018936										
MSCI_WR	-0.000018	-0.000010	0.000000	-0.000010	0.000168	-0.000018	0.000134									
MSCI_EM	0.000041	0.000082	0.000001	0.000012	0.000111	0.000072	0.000083	0.000118								
BWX	-0.000005	0.000001	0.000000	-0.000028	0.000016	-0.000017	0.000005	0.000006	0.000016							
USIG	-0.000010	-0.000016	0.000000	-0.000003	0.000038	-0.000020	0.000012	0.000008	0.000005	0.000023						
GSCI	0.000056	0.000068	0.000001	0.000013	0.000113	0.000187	0.000076	0.000056	0.000005	0.000009	0.000203					
MSCI_RE	-0.000016	-0.000026	0.000000	-0.000018	0.000123	-0.000004	0.000116	0.000074	-0.000007	0.000017	0.000059	0.000148				
MSCI_INF	0.000055	0.000080	0.000001	-0.000019	0.000124	0.000048	0.000088	0.000092	0.000006	0.000014	0.000056	0.000097	0.000146			
PE	0.000030	0.000048	0.000000	-0.000007	0.000186	-0.000010	0.000141	0.000099	0.000019	0.000019	0.000092	0.000132	0.000120	0.000211		
MSCI_FRO	0.000052	0.000055	0.000000	0.000013	0.000059	0.000053	0.000037	0.000040	0.000000	0.000005	0.000041	0.000035	0.000042	0.000051	0.000060	
HY	-0.000028	-0.000041	0.000001	-0.000024	0.000057	-0.000056	0.000066	0.000041	0.000007	0.000010	0.000036	0.000066	0.000044	0.000070	0.000015	0.000051

*BTC: Bitcoin, **ETH**: Ethereum, **USDT**: Tether, **XRP**: Ripple, **LTC**: Litecoin, **CRIX**: Cryptocurrency Index, **MSCI_WRLD**: MSCI International World Price Index, **MSCI_EM**: MSCI Emerging Markets Price Index, **BWX**: SPDR Bbg Barclays International Treasury Bond ETF, **USIG**: iShares Broad USD Investment Grade Corporate Bond ETF, **GS**CI: iShares S&P GSCI Commodity-Indexed Trust ETF, **MSCI_RE**: MSCI International World Real Estate Price Index, **MSCI_INFRA**: MSCI All Country World Transportation Infrastructure Industry Price Index, **PE**: S&P Listed Private Equity Index, **MSCI_FRONTIER**: MSCI Frontier Markets Price Index, **HY**: iShares iBoxx $ High Yield Corporate Bond ETF*

Table A.5, Full sample covariance matrix

	BTC	ETH	USDT	XRP	LTC	CRIX	MSCI_WRLD	MSCI_EM	BWX	USIG	GSCI	MSCI_RE	MSCI_INFRA	PE	MSCI_FRONTIER	HY
BTC	**0.002645**															
ETH	0.002335	**0.004185**														
USDT	-0.000027	-0.000044	**0.000024**													
XRP	0.000143	0.000546	0.000011	**0.006006**												
LTC	0.000717	0.001108	-0.000019	0.000892	**0.004898**											
CRIX	0.001750	0.001968	-0.000032	0.000767	0.000830	**0.002579**										
MSCI_WRLD	0.000016	0.000015	0.000001	0.000006	0.000059	0.000034	**0.000082**									
MSCI_EM	0.000019	0.000045	0.000002	0.000030	0.000073	0.000019	0.000061	**0.000093**								
BWX	-0.000010	-0.000009	0.000000	-0.000011	0.000012	-0.000006	0.000005	0.000005	**0.000008**							
USIG	0.000001	-0.000002	0.000000	0.000001	0.000005	-0.000003	-0.000001	0.000000	0.000003	**0.000007**						
GSCI	0.000058	0.000079	0.000001	0.000005	0.000051	0.000067	0.000053	0.000048	0.000001	0.000000	**0.000150**					
MSCI_RE	-0.000003	-0.000010	0.000000	0.000005	0.000036	0.000016	0.000055	0.000041	-0.000009	0.000003	0.000031	**0.000068**				
MSCI_INFRA	0.000025	0.000031	0.000001	0.000003	0.000060	0.000034	0.000045	0.000053	0.000005	0.000002	0.000031	0.000037	**0.000056**			
PE	0.000056	0.000065	0.000000	0.000022	0.000054	0.000047	0.000073	0.000060	0.000002	0.000000	0.000055	0.000046	0.000044	**0.000093**		
MSCI_FRONTIER	0.000034	0.000031	0.000000	0.000010	0.000035	0.000031	0.000027	0.000031	0.000000	0.000003	0.000034	0.000018	0.000022	0.000032	**0.000054**	
HY	-0.000011	-0.000024	0.000001	-0.000022	0.000021	-0.000002	0.000042	0.000031	0.000007	0.000001	0.000026	0.000033	0.000023	0.000034	0.000012	**0.000033**

BTC: Bitcoin, ETH: Ethereum, USDT: Tether, XRP: Ripple, LTC: Litecoin, CRIX: Cryptocurrency Index, MSCI_WRLD: MSCI International World Price Index, MSCI_EM: MSCI Emerging Markets Price Index, BWX: SPDR Bbg Barclays International Treasury Bond ETF, USIG: iShares Broad USD Investment Grade Corporate Bond ETF, GSCI: iShares S&P GSCI Commodity-Indexed Trust ETF, MSCI_RE: MSCI International World Real Estate Price Index, MSCI_INFRA: MSCI All Country World Transportation Infrastructure Industry Price Index, PE: S&P Listed Private Equity Index, MSCI_FRONTIER: MSCI Frontier Markets Price Index, HY: iShares iBoxx $ High Yield Corporate Bond ETF

Table A.6, Period 1 covariance matrix

	BTC	ETH	USDT	XRP	LTC	CRIX	MSCI_WRLD	MSCI_EM	BWX	USIG	GSCI	MSCI_RE	MSCI_INFRA	PE	MSCI_FRONTIER	HY
BTC	**0.002393**															
ETH	0.002662	**0.004466**														
USDT	0.000001	-0.000001	**0.000001**													
XRP	0.000334	0.000823	0.000005	**0.009766**												
LTC	0.000232	0.000352	-0.000010	-0.000453	**0.005552**											
CRIX	0.002667	0.003403	-0.000008	-0.000427	0.000854	**0.053749**										
MSCI_WRLD	-0.000093	-0.000094	-0.000001	-0.000044	0.000398	-0.000132	**0.000245**									
MSCI_EM	0.000084	0.000155	0.000001	-0.000030	0.000189	0.000182	0.000130	**0.000172**								
BWX	0.000008	0.000022	-0.000001	-0.000064	0.000024	-0.000037	0.000007	0.000009	**0.000032**							
USIG	-0.000033	-0.000047	0.000001	-0.000011	0.000108	-0.000057	0.000039	0.000024	0.000008	**0.000057**						
GSCI	0.000050	0.000039	0.000001	0.000027	0.000241	0.000437	0.000125	0.000075	0.000013	0.000026	**0.000315**					
MSCI_RE	-0.000045	-0.000061	0.000000	-0.000069	0.000309	-0.000047	0.000245	0.000144	-0.000004	0.000047	0.000118	**0.000318**				
MSCI_INFRA	0.000118	0.000181	0.000000	-0.000066	0.000259	0.000077	0.000182	0.000174	0.000009	0.000038	0.000109	0.000225	**0.000339**			
PE	-0.000029	0.000003	0.000000	-0.000073	0.000465	-0.000138	0.000290	0.000181	0.000023	0.000060	0.000169	0.000317	0.000279	**0.000463**		
MSCI_FRONTIER	0.000087	0.000098	0.000001	0.000015	0.000108	0.000093	0.000059	0.000059	0.000000	0.000008	0.000054	0.000071	0.000084	0.000092	**0.000070**	
HY	-0.000063	-0.000077	0.000000	-0.000029	0.000134	-0.000171	0.000118	0.000061	0.000007	0.000031	0.000058	0.000137	0.000089	0.000145	0.000022	**0.000089**

BTC: Bitcoin, ETH: Ethereum, USDT: Tether, XRP: Ripple, LTC: Litecoin, CRIX: Cryptocurrency Index, MSCI_WRLD: MSCI International World Price Index, MSCI_EM: MSCI Emerging Markets Price Index, BWX: SPDR Bbg Barclays International Treasury Bond ETF, USIG: iShares Broad USD Investment Grade Corporate Bond ETF, GSCI: iShares S&P GSCI Commodity-Indexed Trust ETF, MSCI_RE: MSCI International World Real Estate Price Index, MSCI_INFRA: MSCI All Country World Transportation Infrastructure Industry Price Index, PE: S&P Listed Private Equity Index, MSCI_FRONTIER: MSCI Frontier Markets Price Index, HY: iShares iBoxx $ High Yield Corporate Bond ETF

Table A.7, Period 2 covariance matrix