The investment struggle: Is replacing gold with Bitcoin beneficial?

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ABSTRACT,
Cryptocurrencies are a new way of portfolio diversification. Bitcoin in particular has drawn attention by being speculated to be the 21st century gold. In this paper, reasons against and in favour of investing in Bitcoin in comparison to gold are discussed. For three different investment regions, a long only portfolio and a shorting allowed portfolio are constructed that are optimized by Sharpe Ratio, three portfolios are constructed that are benchmarked against 13%, 15% and 17% expected returns and are optimized by Sharpe Ratio where shorting is not allowed, three of the same portfolios are constructed where shorting is allowed and one portfolio is constructed where all asset weights are equal. All of these portfolios contain a gold index. This gold is then replaced by Bitcoin and the portfolios are evaluated by Sharpe Ratio, Omega Ratio, Sortino Ratio, Drawdown and Calmar Ratio. Furthermore, the Sharpe Ratio and Sortino Ratio are tested on their statistical significance.

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Keywords
Bitcoin, Gold, Risk-adjusted return, Portfolio construction, Gold replacement, Investment

1. INTRODUCTION

Investors such as pension funds and insurance companies who already have well-diversified portfolios are sometimes interested in improving the risk-return properties of their portfolios. These risk-return properties are often defined by a Sharpe Ratio, which "is designed to measure the expected return per unit of risk for a zero investment strategy".(Sharpe, 1994) New investments in these portfolios could change their Sharpe Ratios for the better or the worse. According to Markowitz's (1951) Modern Portfolio Theory, investors can do better by choosing a mix of low-risk and riskier investments than by going entirely with low-risk choices. This shows that additional diversification is key.

With the rise of a new asset classes come diversification possibilities. A recent new asset class is cryptocurrencies. According to Kuo Chuen et al. (2018), a sentiment-based cryptocurrency portfolio has an annualized Sharpe ratio of 8.21, which is significantly higher than the ten year Sharpe Ratio of the S&P 500 of 0.90 (Morningstar, n.d.). This means that a sentiment-based cryptocurrency portfolio outperforms the S&P 500 relative to the risk it has taken on. Of these cryptocurrencies, Bitcoin is both the first in existence and the biggest by market cap. (CoinMarketCap, n.d.)

Research as early as 1998 has suggested that gold can be seen as a safe haven for investors and a store of value. (Harmston, 1998) However, in recent years some prominent figures have argued in favour of Bitcoin as a replacement of gold. Jerome Powell, chair of the Federal Reserve, argued: "Almost no one uses bitcoin for payment, they use it more as an alternative to gold really. It's a store of value; it's a speculative store of value like gold" (Aure, 2019). Others like Citi Bank's managing director Tom Fitzpatrick have even argued in an independent report that Bitcoin is the digital gold of the 21st century. (Crypto Briefing, 2020)

Research from Henriques and Sadorsky (2018) on Bitcoin replacing gold in investment portfolios states that portfolios containing Bitcoin rank highest according to several risk-adjusted measures. However, it is also stated that further research is needed as data about and adoption of Bitcoin was limited. Currently four more years of data is available and according to the Chainalysis Team (2021), overall crypto adoption is up 881% over 2020 alone. This adoption is measured by on-chain cryptocurrency value received, on-chain retail value transferred and peer-to-peer exchange trade volume. The reason behind this increase in adoption is not certain, however has possibly been caused by a plethora of things, most notably; the increase in use cases, exponential price increases of certain cryptocurrencies, big investors coming into the crypto market and prominent figures advocating for crypto.

As the world of crypto is new in concept of research, relatively limited and sometimes out-dated research has been performed about the topic. This research can be seen as out-dated as the amount of data has in some cases doubled as time went by. The aim of this study is to find out whether Bitcoin could substitute gold in an already well-diversified portfolio in order to improve the risk-return characteristics of this portfolio. Using statistical analysis, this paper of this study will determine whether the replacement of gold with Bitcoin is a good decision at this moment in time.

This paper will answer the question whether Bitcoin can really replace gold in an already well-diversified portfolio. Furthermore the optimal portfolio weights will be calculated. These insights will be relevant to institutional investors such as insurance companies, pension funds and other types of investments funds. However, individuals with already well-diversified portfolios will also be able to gain knowledge about possible diversification from this paper. The insights of this paper will help settle the discussion whether Bitcoin is really on track to substitute gold and if Bitcoin is the '21st century gold'. The outcome will either prevent potential financial losses because of uneducated investments or stimulate potential financial gains by dictating the influences on risk-return properties of already well-diversified portfolios.

2. LITERATURE REVIEW

This section includes a literature review that will first discuss reasons why individuals might invest in Bitcoin rather than gold. The next section will contrarily discuss reasons why individuals might invest in gold rather than Bitcoin. After this, contradictory research in the field will be reviewed. Lastly, several researches about portfolio construction and their evaluation methods will be discussed.

2.1 The Bitcoin Standard

There are multiple reasons to invest in Bitcoin rather than Gold. Investing in gold will often come with costs like storage fees between 0.5-1.0% and handling costs of up to $12/kg. (Gold Republic, n.d.) Transportation of this gold can also be costly as it is heavy and should be handled with care, while the average transaction fee of Bitcoin is $1.29. (YCharts, n.d.) Bitcoin also does not cost anything to store or handle. Paper gold investments are available to counter these disadvantages, however, these investments do not offer physical ownership of gold, something that Bitcoin does. Bitcoin's low transaction costs are also beneficial as Bitcoin is divisible up to eight decimal places, called Satoshi's, making it a possible currency. Another reason would be the fact that gold can easily be counterfeited, while Bitcoin cannot due to cryptography. (Nakamoto, 2008) Both Bitcoin and gold have a finite supply. According to the U.S. Geological Survey (2022), roughly three-fourths of gold on Earth has already been mined, meaning there is about 57,000 metric tons to be mined. In case of a rise in gold's price, mining companies would be able to mine and distribute this gold, meaning that supply could go up when allowed by market conditions. Bitcoin's supply however cannot be tampered with as it is based on computer code. This begs the question on whether Bitcoin could really become the 21st century digital gold.

2.2 The Gold Standard

Gold on the other hand has its own benefits. Contrary to gold, Bitcoin is not legal to own all over the world. While El Salvador has made Bitcoin a legal tender (Trade, 2021), other countries have chosen to either ban certain cryptocurrencies or to ban the use of cryptocurrencies overall. (The Law Library of Congress, 2021) Furthermore, cryptocurrencies are debated to be haram, meaning Bitcoin cannot be used by the Muslim population. (Aims, n.d.) This is contradicted by research from Asif (2018), saying that only proof-of-stake[1] cryptocurrencies are haram, meaning Bitcoin, being a proof-of-work[2] cryptocurrency, is halal and can thus be traded by Muslims. This research on whether Bitcoin is halal or haram is partly based on Bitcoin's environmental impact. In absolute numbers, Bitcoin mining uses both less energy and produces less CO_2 than gold mining. (Badea & Mungiu- Pupăzan, 2021) However, mining one Bitcoin

[1] Proof-of-stake is a type of consensus mechanism used by blockchains to achieve distributed consensus by allowing miners to prove they have capital at risk by expending energy. (Ethereum Foundation, 2022)

[2] Proof-of-work is a decentralized consensus mechanism that requires miners of a certain network to expand effort solving mathematical puzzles to prevent exploitation. (Nakamoto, 2008)

consumes 23 times more energy than mining one Bitcoin worth of gold and emits almost 21 times more tonnes of CO_2. (Digiconomist, 2022) These legality and environmental reasons in combination with Bitcoin's short track record might, for some people, be reasons to choose gold over Bitcoin.

2.3 Contradictions

Current research on Bitcoin's ability to substitute gold contradicts one another. Research by Dyhrberg (2016) shows evidence that Bitcoin has clear hedging capabilities against the FTSE index and has less clear, but existent, hedging capabilities against the dollar. In this research, it is stated that Bitcoin can be used alongside gold to eliminate or minimize specific market risks. However, Bouri et al. (2017) contradicts this by stating that "Bitcoin is still lacking empirical evidence on its diversification, hedging and safe haven properties against other assets, in particular against major world equites, bonds, oil, gold, the general commodity index and the US dollar index." On the other hand, Henriques and Sadorsky (2018) have stated that Bitcoin can substitute gold in a portfolio in order to achieve a higher risk adjusted return. This shows that there are multiple sides to the story, which dictates a gap in the research and gives need for further research.

2.4 Portfolio Construction

Markowitz's (1952) modern portfolio theory started a period in finance in which portfolio diversification became increasingly important. The theory shows a need for maximization of returns while minimizing risks. When building up a portfolio, increasing the number of assets in the portfolio decreases the amount of overall risk. (Statman, 1987) Historically, the focus of diversification was on shares, bonds, and derivatives, while more recently also taxes and leverage has been added to the mix. Even more recent, cryptocurrencies have been added to the diversification possibilities. (Kajtazi & Moro, 2018) A well-diversified portfolio will thus have to include multiple if not all of these asset classes. A problem with literature regarding well-diversified portfolios is the fact that opinions differ on what is considered effective diversification. (Zaimovic et al., 2021) Statman (1987) for example argues that a well-diversified portfolio can be achieved by including 30-40 stocks. Shawky and Smith (2005) on the other hand found that the optimal portfolio size can be obtained with 481 stocks and even goes as far as stating that any significant deviations from that number are suboptimal. Diversification in indexes of all above mentioned asset classes will thus be the best option when doing research on well-diversified portfolios. Overdiversification will not be a problem as monitoring costs and transaction costs are outside of the scope of this study. (Wang, 2010)

2.5 Evaluation Methods

Early research by Fama & MacBeth (1973) shows that there seems to be a positive trade-off between return and risk, meaning that when risk goes up, so does return. However, they also found that this relation is not linear. Gold has been proven to be a valuable asset for diversification with a small portion being able to significantly reduce overall portfolio risk, and early research has shown that it could also lead to higher returns. (Šoja, 2019) Research on Bitcoin has shown that it can increase both the expected return and the risk of a portfolio, with the return contribution outweighing the additional portfolio risks. (Eisl et al., 2015) It can thus be concluded that adding assets to a portfolio can both positively and negatively influence its risk and return.

Assessing these trade-offs between risk and return can be done by using models like the Sortino Ratio (Sortino & van der Meer, 1991), the Omega Ratio (Keating & Shadwick, 2002) and most notably the Sharpe Ratio (Sharpe, 1994). Each of these models has their own use.

The Sharpe Ratio is well known and is used by multiple alike researches. (Henriques & Sadorsky, 2018; Kajtazi & Moro, 2018; Ma et al., 2020) It subtracts a time-independent risk-free rate from the portfolio return which is then divided by the risk, which is measured as the standard deviation of the portfolios return. The popularity of the Sharpe Ratio is a consequence of its simplicity. This simplicity allows the Sharpe Ratio to be applied to any asset, which is one of its biggest benefits. However, its simplicity is also its biggest problem. As the Sharpe Ratio relies on standard deviation, it is based on the normal distribution curve. Inflated Sharpe Ratios could result from odd return distributions. This reliance on the standard deviation also penalizes large positive returns, as no difference is being made between positive and negative volatility. (Harding, n.d.) Because of both its simplicity and popularity, the Sharpe Ratio will be used as a performance measure in this study. The hypothesis that will be tested is formulated as:

H_0: There is no difference in Sharpe Ratio between the constructed gold portfolios and their corresponding Bitcoin portfolios.

H_a: The Sharpe Ratios of the corresponding Bitcoin portfolios will be higher than those of the constructed gold portfolios.

The Omega Ratio is a commonly used alternative for the Sharpe Ratio (Henriques & Sadorsky, 2018; Kajtazi & Moro, 2018). It uses information about data that the Sharpe Ratio disregards. The Omega Ratio measures the ratio of probability weighted gains to losses relative to a threshold value. (Keating & Shadwick, 2002) While the Sharpe Ratio only considers the first two moments of the return distribution, the mean and variance, the Omega Ratio includes information on the mean, variance, skewness, and kurtosis. As a result of this, the Omega Ratio is well-used for investments with non-normal distributions. The Omega Ratio will thus be used as a performance measure in addition to the Sharpe Ratio in order to eliminate one of the Sharpe Ratio's biggest shortcomings.

The Sortino Ratio is similar to the Sharpe Ratio. As previously mentioned, one of the biggest shortcomings of the Sharpe Ratio is its penalization of large positive returns. The Sortino Ratio is used to combat this shortcoming by using downside volatility instead of overall volatility. Like the Sharpe Ratio and Omega Ratio, it is commonly used. (Kajtazi & Moro, 2018; Platankis & Urquhart, 2020) The hypothesis that will be tested is formulated as:

H_0: There is no difference in Sortino Ratio between the constructed gold portfolios and their corresponding Bitcoin portfolios.

H_a: The Sortino Ratios of the corresponding Bitcoin portfolios will be higher than those of the constructed gold portfolios.

Bitcoin is known to have frequent big drawdowns. (Detzel et al., 2018; Smales, 2019) For this reason, it is important to measure the maximum drawdown of a portfolio containing Bitcoin in comparison to a portfolio containing gold. Drawdown relates to return and variability (Harding et al., n.d.) and is thus worth exploring as an alternative evaluation method. The Calmar Ratio (Young, 1991) can be used as a performance measure that takes into account the maximum drawdown. It allows investors to see how a portfolio performed over a specific time based on its risk-adjusted basis. The higher the Calmar Ratio, the better the portfolio is performing relative to its maximum drawdown.

3. DATA AND METHODOLOGY

3.1 Data

3.1.1 Asset selection

In order to eliminate differences between regions with accordance to investing, portfolios for three regions will be constructed. These regions will be the United Stated, Europe and China. The broad range of assets used by Kajtazi & Moro (2018) will be used as a base to make up these portfolios. The portfolios will include equities, fixed income, commodities, real estate, cash equivalents and currencies. Of these assets, which can be found in table 3.1 in the appendix, one will be a gold index. During the research, the gold index will first be included in the portfolios and will later be substituted by Bitcoin. As this research sets out to find out whether Bitcoin can replace gold in an already well-diversified portfolio, and not if Bitcoin is a better alternative for gold when constructing a portfolio, the weights used for Bitcoin will be those that gold gets from the portfolio optimization method below.

Following the approach of Henriques & Sadorsky (2018) and Kajtazi & Moro (2018), the frequency of data collection will be daily. Daily price data on the assets is retrieved from Yahoo Finance, SPGlobal and Bitcoinity. The daily data cover the period from 1 april 2016 to 29 april 2022. The starting data is chosen based on Bitcoin being illiquid during its early days.

Figure 3.1 in the appendix shows the time series plots of U.S. assets. The time plots show initial steady increases in price for SPBDUBIT with recent sideways trading like SPBDUSBT, DJCBP and USDOLLAR. Slow price increases by SPGSGC and DJUSRET are shown. SPTR100, SPTRSMCP and DJCIT on the other hand show bigger returns with SPTR100 and SPTRSMCP trading somewhat similarly, as expected with the 0.803 correlation efficient displayed in table 3.3A in the appendix. Lastly, BTCUSD shows exponential growth with recent downwards price action, resulting in short-term sideways trading.

Table 3.2A in the appendix shows the summary statistics for daily percent returns of the U.S. assets. The table shows a positive mean and median for every asset with SPTR100 and SPTRSMCP showing high returns, which are accompanied by relatively high standard deviations. It can also be seen that BTCUSD shows an even higher mean return and standard deviation. The table shows positive non-zero excess kurtosis for all assets. It also shows non-zero results for skewness. This means that the null-hypothesis of normality can be rejected and it can be assumed that the returns of the chosen U.S. assets are not normally distributed. (NIST, n.d.)

Table 3.3A in the appendix shows the correlation coefficients for daily percentage returns of U.S. assets. The table shows high correlations between SPTR100, SPTRSMCP and DJUSRET. Furthermore, it shows a high correlation between DJCBP and SPBDUSBT. Notably, it shows low correlations between BTCUSD and the rest of the assets.

Figure 3.2 in the appendix shows the time series plots of EU assets. The time plots show initial steady increases in price for both SPPEDSBI and SPEIGCBI with recent steep crashes. Slow price increases by SPGSGC, SPTR350E and SPVREUET are shown with SPTR350E and SPVREUET trading very similarly, as expected with the 0.991 correlation coefficient displayed in table 3.3B in the appendix. Furthermore, a steady downward trend is shown by SPEUFTR. Lastly, BTCEUR shows again exponential growth with recent downwards price action, resulting in short-term sideways trading.

Table 3.2B in the appendix shows the summary statistics for daily percent returns of the EU assets. The table shows a positive mean and median for every asset with BTCEUR showing both a high return and median. The table shows relatively high standard deviations for SPGSGC, SPTR350E, SPVREUT and DWEURST and an even higher standard deviation for BTCEUR. The table shows positive non-zero excess kurtosis for all assets. It also shows non-zero results for skewness. This means that the null-hypothesis of normality can be rejected and it can be assumed that the returns of the chosen EU assets are not normally distributed. (NIST, n.d.)

Table 3.3B in the appendix shows the correlation coefficients for daily percentage returns of the EU assets. The table shows high correlations between SPTR350E, SPVREUET and DWEURST. Notably, it shows low correlations between BTCEUR and the rest of the assets.

Figure 3.3 in the appendix shows the time series plots of CN assets. The time plots show steady increases in price for SPCGBI, SPCSBI and SPCCBI. Slow price increases are shown for SPGSGC. Somewhat bigger price increases are shown for CSP100TR and CSSP300R, with similar price patterns as expected with the high correlation of 0.983 as displayed in table 3.3B in the appendix. SPCAS1CT shows high volatility with an overall downwards trend. DWAPRST and USDOLLAR show more sideways price action with DWAPRST showing more volatility. DJCIT shows initial sideways price action with recent high returns. Lastly, BTCCNY shows again exponential growth with recent downwards price action, resulting in short-term sideways trading.

Table 3.2C in the appendix shows the summary statistics for daily percent returns of the CN assets. The table shows a positive mean and median for all assets, except for the return of SPCAS1CT. It can be seen that Bitcoin shows a relatively high mean, median and standard deviation. The table shows positive non-zero kurtosis for all assets. It also shows non-zero results for skewness. This means that the null-hypothesis of normality can be rejected and it can be assumed that the returns of the chosen CN assets are not normally distributed. (NIST, n.d.)

Table 3.3C in the appendix shows the correlation coefficients for daily percentage returns of CN assets. The table shows somewhat high correlations between SPCCBI and SPCSBI. Furthermore, it shows high correlations between CSSP300R, CS100TR and SPCAS1CT. Notably, it shows low correlations between BTCCNY and the rest of the assets, with the correlation of BTCCNY and SPCCBI standing out, nearing almost zero.

3.1.2 Benchmark selection

Following the approach of Henriques and Sadorsky (2018), an U.S. Treasury bill will be selected to benchmark as a risk-free asset. For this study, the current return of the 12-month U.S. Treasury bill is selected which makes 2% risk-free rate of return on an annual basis. The return of this U.S. Treasury bill will be used as a risk-free rate in the calculations of the Sharpe Ratio and Sortino Ratio. Furthermore, it will be used as the target return when calculating the Omega Ratio.

3.2 Methodology

3.2.1 Portfolio optimization

A total of nine different portfolios will be set up for each region in order to test the hypotheses. Three different kinds of constraints will be put on the portfolios following the techniques used by Kajtazi and Moro (2018). With the constraints of portfolio one and two, multiple different portfolios will be constructed using the following techniques. Using the modern portfolio theory by Markowitz (1952), optimal portfolios will be

constructed with the best possible risk-return ratio based on the Sharpe Ratio. Furthermore, three benchmark portfolios with annual target returns of 13%, 15% and 17% will be constructed following the approach of Henriques and Sadorsky (2018) optimized by Sharpe Ratio.

Portfolio 1: Long-Only Portfolio ($w_i \in \mathbb{R}+ : \sum w_i = 1$)

This portfolio does not allow investors to short assets and limits the weights of individual assets to 100%.

Portfolio 2: Shorting-Allowed Portfolio ($w_i \in \mathbb{R} : -1 \leq w_i \leq 1 : \sum w_i = 1$)

This portfolio does allow investors to short assets and does not place any weight-related constraints on individual assets.

Portfolio 3: Equal-Weights Portfolio ($w_i = 1\ N\ \forall\ i$)

This portfolio equally distributes the weights over the assets irrespective of their risk-return properties. Research by DeMiguel et al. (2009) shows that various optimisation methods, under which Markowitz's (1952) mean-variance optimisation procedure, do not outperform an 1/N portfolio consisting of the same assets in terms of Sharpe Ratio.

The expected return of assets is calculated as the annualized daily return, where the approach of Feibel (2003) of annualizing with 365 days is used. The expected return of asset i is calculated as:

$$E(r_i) = (1 + \frac{\sum r_i}{n})^{365} - 1$$

Where:

$E(r_i)$ = Expected return of asset i

r_i = Daily return of asset i

n = Number of observations

The expected return of the portfolio p is calculated as:

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

Where:

$E(r_p)$ = The expected return of the portfolio

W_i = Weight of asset i

Following the approach of Markowitz (1952), the variance of portfolio p is calculated as:

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

Where:

σ_p^2 = Variance of portfolio p

$w_{i,j}$ = weight of asset i,j

$r_{i,j}$ = return of asset i,j

The constructed portfolios will need matrix multiplication to determine the optimal asset weights in the portfolio. The expected return for the portfolio is calculated as:

$$E(r_p) = W^T R = [W_1 \dots W_j] \begin{bmatrix} E(r_1) \\ \vdots \\ E(r_j) \end{bmatrix}$$

Where:

W^T = Transposed weights matrix

R = Expected return matrix

The variance of the portfolio is calculated as:

$$\sigma_p^2 = W^T S(W)$$

Where:

S(W) = Multiplication matrix of standard deviations and weights

The standard deviation of the portfolio is calculated as:

$$\sigma_p = \sqrt{W^T S(W)} = \left[[W_1 \dots W_j] \begin{bmatrix} \sigma_{i1} & \cdots & \sigma_{1j} \\ \vdots & \ddots & \vdots \\ \sigma_{j1} & \cdots & \sigma_{ij} \end{bmatrix} \begin{bmatrix} W_i \\ \vdots \\ W_j \end{bmatrix} \right]^{\frac{1}{2}}$$

The optimal weights for assets in a portfolio are the ones that maximize the value of the Sharpe Ratio for the portfolio. For the portfolios that are benchmarked with annual returns, daily expected returns and standard deviations are annualized and used in combination with the maximization of Sharpe Ratio.

The Sharpe Ratio used here is calculated as:

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

Where:

S_p = Sharpe ratio of the portfolio

r_f = Return of risk-free asset

3.2.2 Evaluating portfolio performance

Evaluating the portfolio performance will be done using multiple different instruments that are related to risk-return ratio's. First, the average return earned in excess of the risk-return rate per unit of volatility or total risk, the Sharpe Ratio defined as:

$$\text{Sharpe Ratio} = \frac{R_p - R_f}{\sigma_p}$$

Where:

R_p = Portfolio return

, will be calculated using theory by Sharpe (1994). Second, the convex reformulated Omega Ratio (Kapsos et al., 2014) will be used, which represents the ratio between the average return and the average loss. A high Omega Ratio indicates a low probability of making extreme losses. The Omega Ratio is defined as:

$$\Omega(r, \tau) = \frac{E(r) - \tau}{E^+(\tau - r)} + 1$$

Where:

τ = Daily target return

$E^+(\tau - r)$ = Expected downside return

The Sortino Ratio (Sortino & van der Meer, 1991), which is much alike the Sharpe Ratio but focuses on downside volatility, will be used, which is defined as:

$$S = \frac{R_p - r_f}{\sigma_d}$$

Where:

R_p = Expected portfolio return

σ_d = Standard deviation of the downside

Equity curves will be constructed for all portfolios in order to provide a quick visual way of analysing the portfolio performances over time. These equity curves will follow a portfolio that starts with a value of 1000 in the local currency of the region of the portfolio. Of these equity curves, the maximum drawdown will be calculated, defined as:

$$MDD = \frac{(P - L)}{P}$$

Where:

P = Peak value before largest drop

L = Lowest value before new high established

Taking into account the MDD, the Calmar Ratio (Young, 1991) will be used as the last performance measure, defined as:

$$Calmar\ Ratio = \frac{Annualized(R_p)}{MDD_p}$$

3.2.3 Evaluating significance

The Sharpe Ratio and Sortino Ratio will be tested on their statistical significance. First, the rolling return, rolling risk and rolling downside risk are calculated. After, the rolling Shape Ratio and rolling Sortino Ratio are calculated. The standard error needed for the t-test will be calculated by the use of block bootstrapping. (Efron & Tibshirani, 1993) Following the approach of Berenson et al. (2018), there will be 5000 resamples with subsets of size n. n is the amount of datapoints gathered by calculating the rolling Sharpe Ratio and Sortino Ratio. For the U.S., EU and CN portfolios, this is 1156, 1158 and 1068 respectively.

The rolling return is calculated as:

$$Rolling\ return = \sum_{i=1}^{365} w_i r_i$$

The rolling risk is calculated as:

$$Rolling\ risk = \sigma_r \sqrt{365}$$

Where:

σ_r = Standard deviation of returns used in rolling return

The rolling downside risk is calculated as:

$$Rolling\ downsiderisk = \sigma_d \sqrt{365}$$

Where:

σ_d = Standard deviation of downside returns used in rolling return

The rolling Sharpe Ratio is calculated as:

$$Sharpe_r = \frac{(Rolling\ return - R_f)}{Rolling\ risk}$$

The rolling Sortino Ratio is calculated as:

$$Sortino_r = \frac{(Rolling\ return - R_f)}{Rolling\ downsiderisk}$$

The right sided t-test that will be performed will take the following form:

$$t = \frac{S_a - S_t}{\sigma_s / \sqrt{n_b}}$$

Where:

S_a = Annual Sharpe/Sortino Ratio of portfolio

S_t = Annual target Sharpe/Sortino Ratio

σ_s = Standard deviation of bootstrapped Sharpe/Sortino Ratio

n_b = Number of bootstraps

In this study, the annual Sharpe/Sortino Ratio of the portfolio will be the Sharpe/Sortino Ratio of the Bitcoin portfolio, and the annual target Sharpe/Sortino Ratio will be the Sharpe/Sortino Ratio of the corresponding gold portfolio.

The significance of the Sharpe Ratios and Sortino Ratios will be tested at the significance of alpha = 0.05.

4. RESULTS

4.1 Optimal Portfolio Weights

Table 4.1 in the appendix shows the optimal portfolio weights for U.S., EU and CN assets.

It can be seen that the U.S. portfolios have gold/Bitcoin weights that are in the range of 0.107-0.197, meaning no U.S. portfolio will contain less than 10.7% or more than 19.7% of gold/Bitcoin, which are somewhat like the CN portfolios. These CN portfolios range from 0-0.159, meaning no CN portfolio will contain less than 0% or more than 15.9% of gold/Bitcoin.

The EU portfolios have gold/Bitcoin weights that are in the range of 0.140-0.576, meaning no EU portfolio will contain less than 14.0% or more than 57.6% of gold/Bitcoin. Furthermore, it can be seen that there is no EU portfolio that is benchmarked by a 17% return and limited to only buying, optimized by Sharpe Ratio, as no such portfolio could be formed.

It can be seen that there is not one portfolio where gold is shorted, meaning there will be no shorting for Bitcoin. Furthermore, it can be seen that the CN portfolios have somewhat low gold/Bitcoin weights, U.S. portfolios have more average gold/Bitcoin weights, and EU portfolios have higher gold/Bitcoin rates, meaning that there was certainly a need for eliminating differences between regions.

4.2 Portfolio Comparison

4.2.1 U.S. portfolios

Table 4.2 contains the portfolio comparison of U.S. gold portfolios and Bitcoin portfolios. It can be seen that the mean return for each portfolio containing Bitcoin is higher than its corresponding gold portfolio. The standard deviations of these portfolios are also higher than their corresponding gold portfolios, which is expected as both BTCUSD's mean return and standard deviation are higher than SPGSGC's, as seen in table 3.2A in the appendix.

Table 4.2: Portfolio comparison of U.S. portfolios

Gold Portfolio									
	EW	ONS	NS-13	NS-15	NS-17	OWS	S-13	S-15	S-17
Mean Return	10,57%	9,38%	12,19%	14,05%	15,90%	16,92%	12,17%	14,07%	15,98%
Standard Deviation	9,01%	6,01%	8,33%	9,93%	11,57%	11,17%	7,79%	9,14%	10,49%
Sharpe Ratio	0,951	1,228	1,224	1,213	1,201	1,336	1,307	1,321	1,332
Sortino Ratio	0,063	0,084	0,082	0,081	0,079	0,091	0,091	0,091	0,091
Omega Ratio	1,141	1,170	1,168	1,165	1,161	1,171	1,171	1,171	1,171
Maximum Drawdown	17,30%	9,85%	14,07%	16,26%	18,54%	15,24%	10,39%	12,18%	14,12%
Calmar Ratio	0,611	0,952	0,866	0,864	0,857	1,110	1,172	1,155	1,132
Bitcoin Portfolio									
	EW	ONS	NS-13	NS-15	NS-17	OWS	S-13	S-15	S-17
Mean Return	27,00%	24,97%	34,38%	39,89%	45,18%	48,75%	32,82%	38,92%	45,40%
Standard Deviation	12,69%	10,35%	14,27%	16,54%	18,72%	19,15%	13,24%	15,54%	17,93%
Sharpe Ratio	1,970	2,220	2,269	2,290	2,307	2,442	2,327	2,375	2,421
Sortino Ratio	0,128	0,152	0,149	0,147	0,145	0,154	0,156	0,156	0,155
Omega Ratio	1,229	1,253	1,249	1,246	1,242	1,251	1,254	1,253	1,252
Maximum Drawdown	21,44%	14,67%	20,17%	23,12%	25,92%	26,75%	18,76%	21,98%	25,18%
Calmar Ratio	1,259	1,702	1,704	1,725	1,743	1,822	1,749	1,771	1,803

Abbriviations used for the portfolio names can be found in the legend of table 4.1 in the appendix

In table 4.2, it can also be seen that the Sharpe Ratios, Sortino Ratios and Omega Ratios are higher for every portfolio containing Bitcoin than its corresponding gold portfolio. The statistical comparison between the Sharpe Ratios and Sortino Ratios of the gold portfolios and their corresponding Bitcoin portfolios can be found in table 4.3. The information in this table can be used to reject the null hypothesis of the Sharpe Ratio for every portfolio. It can thus be concluded that the Bitcoin portfolios containing U.S. assets have significantly higher Sharpe Ratios than their corresponding gold portfolios. The information in this table can also be used to see that the null hypothesis of the Sortino Ratio can also be rejected for any portfolio. It can thus be concluded that the Bitcoin portfolios containing U.S. assets do

have significantly higher Sortino Ratios than their corresponding gold portfolios.

Table 4.3: Comparison of Sharpe Ratios and Sortino Ratios U.S. portfolios

Sharpe Ratio									
	EW	ONS	NS-13	NS-15	NS-17	OWS	S-13	S-15	S-17
Difference	1,018	0,992	1,046	1,077	1,106	1,106	1,020	1,054	1,089
p-value	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Sortino Ratio									
	EW	ONS	NS-13	NS-15	NS-17	OWS	S-13	S-15	S-17
Difference	0,065	0,068	0,067	0,066	0,065	0,064	0,065	0,065	0,064
p-value	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000

Abbriviations used for the portfolio names can be found in the legend of table 4.1 in the appendix

Figure 4.1 shows the equity curves for U.S. gold portfolios and figure 4.2 shows the equity curves for their corresponding Bitcoin portfolios. In table 4.2 it can be seen that for every portfolio containing Bitcoin, the maximum drawdown is bigger than its corresponding gold portfolio. As expected, the Bitcoin equity curves all have larger final values than their corresponding gold equity curves. Table 4.2 can also be used to see that every portfolio containing Bitcoin has a higher Calmar Ratio than its corresponding gold portfolio, indicating that the increase in drawdown was worth the trade-off, as it came with an even higher increase in mean return.

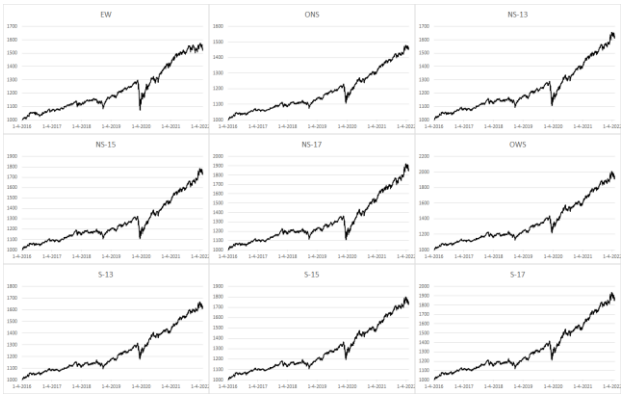

Figure 4.1: Equity curves U.S. gold portfolios

Figure 4.2: Equity curves U.S. Bitcoin portfolios

4.2.2 EU portfolios

Table 4.4 contains the portfolio comparison of EU gold portfolios and Bitcoin portfolios. It can be seen that the mean return for each portfolio containing Bitcoin is higher than its corresponding gold portfolio. The standard deviations of these portfolios are also higher than their corresponding gold portfolios, which is expected as both BTCEUR's mean return and standard deviation are higher than SPGSGC's, as seen in table 3.2B in the appendix.

Table 4.4: Portfolio comparison of EU portfolios

Gold Portfolio									
	EW	ONS	NS-13	NS-15	NS-17	OWS	S-13	S-15	S-17
Mean Return	6,23%	13,39%	12,15%	13,29%	-	30,34%	12,30%	14,21%	16,13%
Standard Deviation	9,24%	12,85%	11,67%	17,26%	-	26,49%	10,27%	11,82%	13,38%
Sharpe Ratio	0,458	0,886	0,870	0,654	-	1,070	1,002	1,033	1,056
Sortino Ratio	0,031	0,061	0,060	0,043	-	0,069	0,071	0,073	0,074
Omega Ratio	1,072	1,136	1,134	1,104	-	1,160	1,156	1,160	1,162
Maximum Drawdown	20,82%	23,15%	21,58%	32,14%	-	43,17%	17,09%	19,14%	21,14%
Calmar Ratio	0,299	0,578	0,563	0,413	-	0,703	0,719	0,743	0,763
Bitcoin Portfolio									
	EW	ONS	NS-13	NS-15	NS-17	OWS	S-13	S-15	S-17
Mean Return	26,39%	102,17%	91,08%	34,09%	-	242,16%	83,58%	100,67%	118,63%
Standard Deviation	14,94%	41,84%	38,06%	21,53%	-	81,69%	34,45%	40,18%	45,91%
Sharpe Ratio	1,632	2,394	2,341	1,491	-	2,940	2,368	2,456	2,540
Sortino Ratio	0,108	0,131	0,132	0,093	-	0,119	0,138	0,136	0,135
Omega Ratio	1,245	1,291	1,293	1,216	-	1,262	1,301	1,297	1,293
Maximum Drawdown	26,52%	58,71%	55,07%	37,05%	-	83,90%	51,21%	57,06%	62,03%
Calmar Ratio	0,995	1,740	1,654	0,920	-	2,886	1,632	1,764	1,912

Abbriviations used for the portfolio names can be found in the legend of table 4.1 in the appendix

In table 4.4, it can also be seen that the Sharpe Ratios, Sortino Ratios and Omega Ratios are higher for every portfolio containing Bitcoin than its corresponding gold portfolio. The statistical comparison between the Sharpe Ratios and Sortino Ratios of the gold portfolios and their corresponding Bitcoin portfolios can be found in table 4.5. The information in this table can be used to reject the null hypothesis of the Sharpe Ratio for every portfolio. It can thus be concluded that the Bitcoin portfolios containing EU assets have significantly higher Sharpe Ratios than their corresponding gold portfolios. The information in this table can also be used to see that the null hypothesis of the Sortino Ratio can also be rejected for any portfolio. It can thus be concluded that the Bitcoin portfolios containing EU assets do have significantly higher Sortino Ratios than their corresponding gold portfolios.

Table 4.5: Comparison of Sharpe Ratios and Sortino Ratios EU portfolios

Sharpe Ratio									
	EW	ONS	NS-13	NS-15	NS-17	OWS	S-13	S-15	S-17
Difference	1,174	1,508	1,471	0,837	-	1,870	1,365	1,422	1,484
p-value	0,000	0,000	0,000	0,000	-	0,000	0,000	0,000	0,000
Sortino Ratio									
	EW	ONS	NS-13	NS-15	NS-17	OWS	S-13	S-15	S-17
Difference	0,077	0,070	0,072	0,050	-	0,050	0,067	0,063	0,060
p-value	0,000	0,000	0,000	0,000	-	0,000	0,000	0,000	0,000

Abbriviations used for the portfolio names can be found in the legend of table 4.1 in the appendix

Figure 4.3 shows the equity curves for EU gold portfolios and figure 4.4 shows the equity curves for their corresponding Bitcoin portfolios. In table 4.4 it can be seen that for every portfolio containing Bitcoin, the maximum drawdown is bigger than its corresponding gold portfolio. As expected, the Bitcoin equity curves have all larger final values than their corresponding gold equity curves. Table 4.4 can also be used to see that every portfolio containing Bitcoin has a higher Calmar Ratio than its corresponding gold portfolio, indicating that the increase in drawdown was worth the trade-off, as it came with an even higher increase in mean return.

Figure 4.3: Equity curves EU gold portfolios

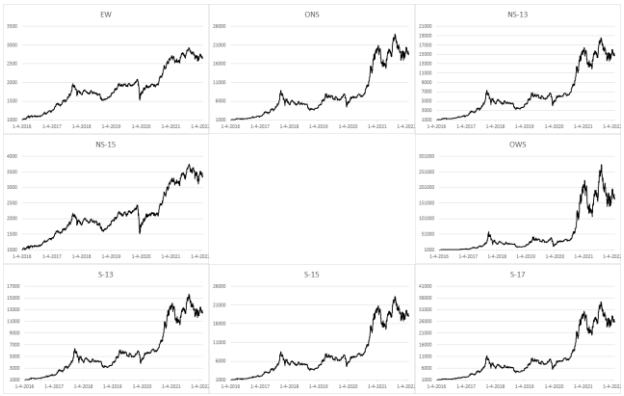

Figure 4.4: Equity curves EU Bitcoin portfolios

4.2.3 CN portfolios

Table 4.6 contains the portfolio comparison of CN gold portfolios and Bitcoin portfolios. It can be seen that the mean return for each portfolio containing Bitcoin is higher than its corresponding gold portfolio, expect for ONS as this portfolio does not contain gold/Bitcoin. Furthermore, there is only a small increase in mean return in the OWS portfolio. The standard deviations of these portfolios are also higher than their corresponding gold portfolios, which is expected as both BTCCNY's mean return and standard deviation are higher than SPGSGC's, as seen in table 3.2C in the appendix. Once again, the standard deviation for ONS stays the same. Furthermore, the increases in standard deviation are far more subtle than in the other regions.

Table 4.6: Portfolio comparison of CN portfolios

Gold Portfolio									
	EW	ONS	NS-13	NS-15	NS-17	OWS	S-13	S-15	S-17
Mean Return	8,15%	5,64%	12,41%	14,23%	16,03%	10,74%	10,74%	13,00%	16,92%
Standard Deviation	8,24%	2,64%	7,96%	9,92%	11,91%	3,40%	3,40%	4,18%	6,42%
Sharpe Ratio	0,746	1,381	1,308	1,233	1,178	2,570	2,570	2,631	2,326
Sortino	0,052	0,103	0,090	0,084	0,079	0,192	0,198	0,196	0,170
Omega	1,099	1,174	1,163	1,154	1,147	1,290	1,290	1,288	1,256
Maximum Drawdown	10,92%	4,01%	11,77%	15,13%	18,39%	5,54%	4,58%	4,33%	6,06%
Calmar Ratio	0,746	1,406	1,054	0,940	0,871	1,938	2,345	3,002	2,792
Bitcoin Portfolio									
	EW	ONS	NS-13	NS-15	NS-17	OWS	S-13	S-15	S-17
Mean Return	24,82%	5,64%	30,20%	37,56%	45,17%	11,37%	16,76%	21,56%	26,50%
Standard Deviation	12,39%	2,64%	12,40%	15,68%	18,98%	3,41%	4,59%	6,18%	7,98%
Sharpe Ratio	1,843	1,381	2,275	2,268	2,274	2,749	3,214	3,162	3,069
Sortino Ratio	0,128	0,103	0,156	0,151	0,146	0,207	0,246	0,237	0,224
Omega Ratio	1,211	1,174	1,250	1,243	1,237	1,306	1,337	1,328	1,316
Maximum Drawdown	17,67%	4,01%	15,01%	19,39%	23,59%	5,10%	4,06%	5,49%	7,81%
Calmar Ratio	1,405	1,406	2,012	1,937	1,915	2,229	4,128	3,927	3,393

Abbriviations used for the portfolio names can be found in the legend of table 4.1 in the appendix

In table 4.6 it can also be seen that the Sharpe Ratios, Sortino Ratios and Omega Ratios are higher for every portfolio containing Bitcoin than its corresponding gold portfolio, except for again the ONS portfolio. The statistical comparison between the Sharpe Ratios and Sortino Ratios of the gold portfolios and their corresponding Bitcoin portfolios can be found in table 4.7. The information in this table can be used to reject the null hypothesis of the Sharpe Ratio for every portfolio, except for the ONS portfolio. It can thus be concluded that the Bitcoin portfolios containing CN assets have significantly higher Sharpe Ratios than their corresponding gold portfolios, except for the ONS portfolio. The information in this table can also be used to see that the null hypothesis of the Sortino Ratio can also be rejected for all portfolios. It can thus be concluded that the Bitcoin portfolios containing CN assets do have significantly higher Sortino Ratios than their corresponding gold portfolios for all portfolios, except the ONS portfolio.

Table 4.7: Comparison of Sharpe Ratios and Sortino Ratios CN portfolios

Sharpe Ratio									
	EW	ONS	NS-13	NS-15	NS-17	OWS	S-13	S-15	S-17
Difference	1,097	0,000	0,967	1,035	1,096	0,179	0,644	0,531	0,743
p-value	0,000	1	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Sortino Ratio									
	EW	ONS	NS-13	NS-15	NS-17	OWS	S-13	S-15	S-17
Difference	0,076	0,000	0,066	0,067	0,068	0,015	0,048	0,041	0,055
p-value	0,000	1	0,000	0,000	0,000	0,000	0,000	0,000	0,000

Abbriviations used for the portfolio names can be found in the legend of table 4.1 in the appendix

Figure 4.5 shows the equity curves for CN gold portfolios and figure 4.6 shows the equity curves for their corresponding Bitcoin portfolios. In table 4.6 it can be seen that for every portfolio containing Bitcoin, the maximum drawdown is bigger than its corresponding gold portfolio, except for the ONS, OWS and S-13 portfolios. As expected, the Bitcoin equity curves all have larger final values than their corresponding gold equity curves, except for the ONS portfolio which does not contain gold/Bitcoin and thus does not change. Table 4.6 can also be used to see that for every portfolio containing Bitcoin has a higher Calmar Ratio than its corresponding gold portfolio, indicating that the increase in drawdown was worth the trade-off, as it came with an even higher increase in mean return. While the OWS and S-13 portfolio had no increase in drawdown, their Calmar Ratio still increased. The ONS portfolio had, as expected, no change in Calmar Ratio.

Figure 4.5: Equity curves CN gold portfolios

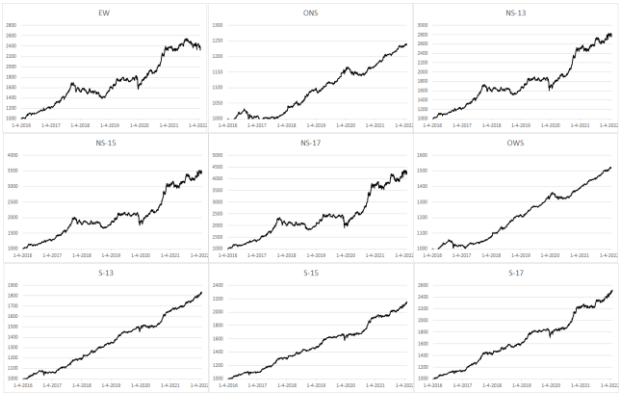

Figure 4.6: Equity curves CN Bitcoin portfolios

5. CONCLUSION

Bitcoin can be seen as an exciting new investment opportunity that is available to everyone. Prominent figures have spoken about Bitcoin being the 21st century gold and research has even gone as far as stating that it could possibly replace gold in an investment portfolio. Research on this topic is limited by Bitcoin's limited data and adoption. However, with recent increased adoption and interesting new price data, research on

Bitcoin's ability to replace gold is more relevant than ever. Bitcoin's advantages include its easy and cheap transportation, storage and transactions. But also its impossibility of being counterfeited and its limited supply to market. On the other hand, Bitcoin is being limited by law, religion and its negative impact on the environment. Contradictions have been found in previous research on Bitcoin's ability to replace gold in investment portfolios.

In this study, portfolios are constructed for three different investment regions in order to eliminate differences between the regions. A broad range of assets is used to make up these portfolios, including: equities, fixed income, commodities, real estate, cash equivalents and currencies. Of these assets, one is a gold index, which will be substituted by Bitcoin in order to see the differences in portfolio performance. For each region, nine different portfolios are constructed; a long only portfolio and a shorting allowed portfolio that are optimized by Sharpe Ratio, three portfolios that are benchmarked against 13%, 15% and 17% expected returns and are optimized by Sharpe Ratio where shorting is not allowed, three of the same portfolios but with shorting allowed and one portfolio where all asset weights are equal. These portfolios are evaluated by Sharpe Ratio, Omega Ratio, Sortino Ratio, Drawdown and Calmar Ratio. The Sharpe Ratio and Sortino Ratio are tested on their statistical significance by the use of block bootstrapping.

In this conclusion, the ONS portfolio of the CN region is left out as it does not contain gold/Bitcoin. The portfolios constructed resulted in a broad range of weights for gold/Bitcoin in the portfolios. The CN gold weights ranged from 0-0.159, the U.S. gold weights ranged from 0.107-0.197 and the EU gold weights ranged from 0.140-0.576, indicating a clear need for specific portfolios for different regions. In all regions, every portfolio's Sharpe Ratio and Sortino Ratio benefited significantly from substituting gold with Bitcoin. It can thus be stated that the Bitcoin portfolios have better risk-adjusted performances and operate efficiently as they do not take on unnecessary risk that is not being rewarded with higher returns. In all regions every portfolio's Omega Ratio benefited from substituting gold with Bitcoin. This means that the Bitcoin portfolios have lower probabilities of making extreme losses. Almost every portfolio in all the regions experienced an increase in maximum drawdown with the substitution of gold. However, these increased maximum drawdowns always came with a bigger increase in mean return, as every portfolio in all regions experienced an increase in Calmar Ratio, even when no increase in drawdown was experienced. These increased Omega Ratios and Calmar Ratios have not been proven on statistical significance. From the results it can be concluded that already well-diversified portfolios from these three regions would benefit from substituting gold with Bitcoin.

While it can be concluded that substituting gold with Bitcoin is beneficial, it might not be the way to go for all investors. With its extreme price fluctuations, negative environmental impact and regulatory problems, Bitcoin might be out of the scope for some risk-averse or green investors. For others, Bitcoin is worth exploring as a substitution for gold in their already well-diversified portfolios.

6. LIMITATIONS AND FUTURE RESEARCH

While gathering the data about the individual assets, it became clear that there are different trading days in the different regions. For this reason, some of the data had to be cleaned up in order to get the same array of dates for each region. While this is not a big problem as average returns were calculated, it does leave out some of the datapoints and should thus be mentioned.

Some of the individual assets that were used were only available in certain currencies. For this reason, some of the daily price points had to be calculated in the local currency with the use of exchange rates.

Previous studies have explored the possibilities of significance testing for the Sharpe Ratio and Sortino Ratio. For the Omega Ratio and Calmar Ratio this was not the case and thus the conclusion of the study is limited for these ratios. If research on significance testing of these ratios is introduced, further future research is needed in order to test this.

As stated by multiple researches on the topic (Henriques & Sadorsky, 2018; Kajtazi & Moro, 2018) the data on Bitcoin is still limited. When compared to gold, Bitcoin is still in its infancy stages. Furthermore, with the extreme volatility of Bitcoin, outcome of such researches can change quickly. During this research the price of Bitcoin has fallen remarkably. Including this could have possibly changed the outcome of the study. With the limitation of data, and especially with recent volatility, future research is encouraged as results might change over time.

7. ACKNOWLEDGEMENTS

I would like to thank Dr. X. Huang for being my first supervisor after my initial first supervisor was not available much. Dr. X. Huang has provided me with clear feedback and instructions that have helped me to increase the quality of this paper. Furthermore, I would like to thank Prof. Dr. L. Spierdijk for her timely help with finding a new first supervisor.

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9. APPENDIX

Table 3.1 – Asset Classes Included in the Analysis, based on Kajtazi and Moro (2018)

	Name	*Ticker/ Abbreviation*	*Asset Class*
United States	S&P U.S. Treasury Bill Index	SPBDUBIT	Money Market
	S&P U.S. Treasury Bond Index	SPBDUSBT	Fixed-Income
	Dow Jones Equal Weight U.S. Issued Corporate Bond Index	DJCBP	Fixed-Income
	S&P GSCI Gold/Bitcoin	SPGSGC/BTCUSD	Gold index/Bitcoin
	S&P 100	SPTR100	Equity (large cap)
	S&P 600	SPTRSMCP	Equity (small cap)
	Dow Jones Commodity Index	DJCIT	Commodities
	DOW JONES U.S. REAL ESTATE INDEX	DJUSRET	Real Estate
	Dow Jones FXCM Dollar Index	USDOLLAR	Currency
Europe	S&P Pan-Europe Developed Sovereign Bond Index	SPPEDSBI	Fixed-Income
	S&P Eurozone Investment Grade Corporate Bond Index	SPEIGCBI	Fixed-Income
	S&P GSCI Gold/Bitcoin	SPGSGC/BTCEUR	Gold index/Bitcoin
	S&P EUROPE 350	SPTR350E	Equity
	S&P GIVI EUROPE	SPVREUET	Commodities
	Dow Jones Europe Select Real Estate Securities Index	DWEURST	Real Estate
	S&P EURO Futures Index Spot	SPEUFTR	Currency
China	S&P China Government Bill Index	SPCGBI	Money Market
	S&P China Sovereign Bond Index	SPCSBI	Fixed-income
	S&P China Corporate Bond Index	SPCCBI	Fixed-income
	S&P GSCI Gold/Bitcoin	SPGSGC/BTCCNY	Gold index/Bitcoin
	S&P China A 100 Index	CSP100TR	Equity (large cap)
	S&P China A 300 Index	CSSP300R	Equity (mid cap)
	S&P China A Smallcap 1000 Index	SPCAS1CT	Equity (small cap)
	Dow Jones Commodity Index	DJCIT	Commodities
	Dow Jones Asia/Pacific Select Real Estate Securities Index	DWAPRST	Real Estate
	Dow Jones FXCM Dollar Index	USDOLLAR	Currency

Table 3.2: Summary statistics for daily percent returns

Table 3.2A: U.S. assets

	SPBDUBIT	*SPBDUSBT*	*DJCBP*	*SPGSGC*	*SPTR100*	*SPTRSMCP*	*DJCIT*	*DJUSRET*	*USDOLLAR*	*BTCUSD*
Mean	0,000	0,000	0,000	0,000	0,001	0,001	0,000	0,000	0,000	0,004
Standard Error	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,001
Median	0,000	0,000	0,000	0,000	0,001	0,001	0,001	0,001	0,000	0,003
Standard Deviation	0,000	0,002	0,004	0,009	0,012	0,015	0,010	0,013	0,003	0,041
Kurtosis	12,118	6,927	15,416	5,409	17,863	11,806	7,007	28,515	2,673	3,518
Skewness	1,859	0,104	-0,977	-0,146	-0,566	-0,753	-0,791	-1,657	0,298	0,296
Minimum	0,000	-0,017	-0,036	-0,050	-0,116	-0,133	-0,081	-0,174	-0,011	-0,202
Maximum	0,001	0,018	0,029	0,058	0,102	0,090	0,043	0,087	0,018	0,199

Table 3.2B: EU assets

	SPPEDSBI	*SPEIGCBI*	*SPGSGC*	*SPTR350E*	*SPVREUET*	*DWEURST*	*SPEUFTR*	*BTCEUR*
Mean	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,004
Standard Error	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,001
Median	0,000	0,000	0,000	0,001	0,001	0,000	0,000	0,002
Standard Deviation	0,003	0,001	0,009	0,011	0,010	0,013	0,004	0,040
Kurtosis	4,701	24,929	6,149	16,831	21,396	14,782	0,943	4,099
Skewness	-0,075	-1,991	0,272	-1,231	-1,519	-1,024	-0,097	0,389
Minimum	-0,015	-0,019	-0,051	-0,115	-0,116	-0,127	-0,017	-0,188
Maximum	0,017	0,009	0,078	0,085	0,083	0,093	0,021	0,203

Table 3.2C: CN assets

	SPCGBI	*SPCSBI*	*SPCCBI*	*SPGSGC*	*CSP100TR*	*CSSP300R*	*SPCAS1CT*	*DJCIT*	*DWAPRST*	*USDOLLAR*	*BTCCNY*
Mean	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,004
Standard Error	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,001
Median	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,002
Standard Deviation	0,000	0,001	0,000	0,009	0,012	0,012	0,015	0,010	0,010	0,004	0,049
Kurtosis	6,450	6,154	14,196	5,760	3,765	3,934	3,738	6,565	32,546	2,929	5,580
Skewness	0,062	-0,555	-0,902	-0,141	-0,232	-0,335	-0,765	-0,643	-0,497	0,398	0,194
Minimum	-0,001	-0,013	-0,005	-0,051	-0,075	-0,078	-0,087	-0,078	-0,112	-0,020	-0,365
Maximum	0,001	0,006	0,003	0,056	0,076	0,070	0,060	0,055	0,098	0,024	0,253

Daily data from 1 april 2016 to 29 april 2022 (1520, 1522 and 432 observations respectively). Data is provided in basis points. Abriviations can be found in table 3.1 in the appendix.

Table 3.3: Correlation coefficients for daily percent returns

Table 3.3A: U.S. assets

	SPBDUBIT	*SPBDUSBT*	*DJCBP*	*SPGSGC*	*SPTR100*	*SPTRSMCP*	*DJCIT*	*DJUSRET*	*USDOLLAR*	*BTCUSD*
SPBDUBIT	1									
SPBDUSBIT	0,285*	1								
DJCBP	0,138*	0,726*	1							
SPGSGC	0,088*	0,286*	0,252*	1						
SPTR100	-0,137*	-0,349*	0,017	0,000	1					
SPTRSMCP	-0,153*	-0,373*	-0,024	-0,003	0,803*	1				
DJCIT	-0,098*	-0,171*	0,020	0,285*	0,303*	0,337*	1			
DJUSRET	-0,069*	-0,144*	0,200*	0,085*	0,723*	0,722*	0,230*	1		
USDOLLAR	-0,077*	-0,193*	-0,281*	-0,363*	-0,108*	-0,124*	-0,206*	-0,150*	1	
BTCUSD	-0,061**	-0,017	0,024	0,094*	0,076*	0,080*	0,106*	0,050**	-0,083*	1

Table 3.3B: EU assets

	SPPEDSBI	*SPEIGCBI*	*SPGSGC*	*SPTR350E*	*SPVREUET*	*DWEURST*	*SPEUFTR*	*BTCEUR*
SPPEDSBI	1							
SPEIGCBI	0,723*	1						
SPGSGC	0,301*	0,223*	1					
SPTR350E	-0,080*	0,083*	-0,090*	1				
SPVREUET	-0,060**	0,106*	-0,072*	0,991*	1			
DWEURST	0,088*	0,222*	0,042	0,697*	0,725*	1		
SPEUFTR	0,008	0,006	0,350*	-0,036	-0,027	0,209*	1	
BTCEUR	0,050**	0,074*	0,096*	0,141*	0,144*	0,129*	0,048	1

Table 3.3C: CN assets

	SPCGBI	*SPCSBI*	*SPCCBI*	*SPGSGC*	*CSP100TR*	*CSSP300R*	*SPCAS1CT*	*DJCIT*	*DWAPRST*	*USDOLLAR*	*BTCCNY*
SPCGBI	1										
SPCSBI	0,228*	1									
SPCCBI	0,290*	0,584*	1								
SPGSGC	0,042	0,064**	0,062**	1							
CSP100TR	0,027	-0,061**	-0,047	-0,009	1						
CSSP300R	0,032	-0,059**	-0,044	-0,009	0,983*	1					
SPCAS1CT	0,043	-0,058**	-0,028	0,014	0,641*	0,756*	1				
DJCIT	-0,033	-0,012	-0,010	0,234*	0,158*	0,168*	0,163*	1			
DWAPRST	0,012	0,002	0,037	0,205*	0,235*	0,229*	0,153*	0,157*	1		
USDOLLAR	-0,022	0,040	0,052	-0,161*	-0,248*	-0,241*	-0,162*	-0,059**	-0,210*	1	
BTCCNY	0,009	-0,013	0,000	0,085*	-0,015	-0,004	0,034	0,078*	0,023	-0,010	1

Pearson correlation coefficient. * Denotes significance at 0.01 level (2-tailed). ** Denotes significance at 0.05 level (2-tailed).
Abbreviations can be found in table 3.1 in the appendix

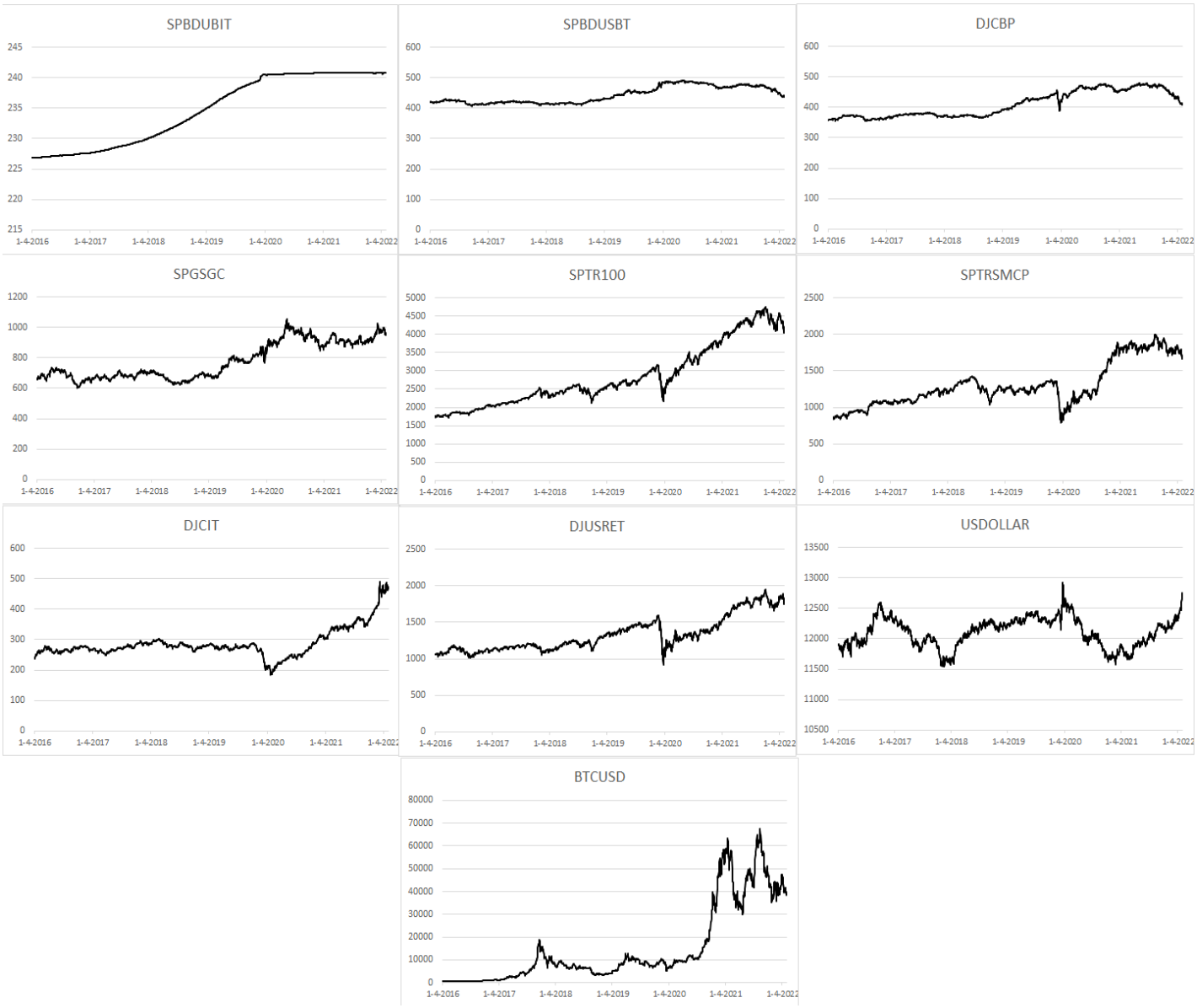

Figure 3.1: Time series plots of U.S. assets

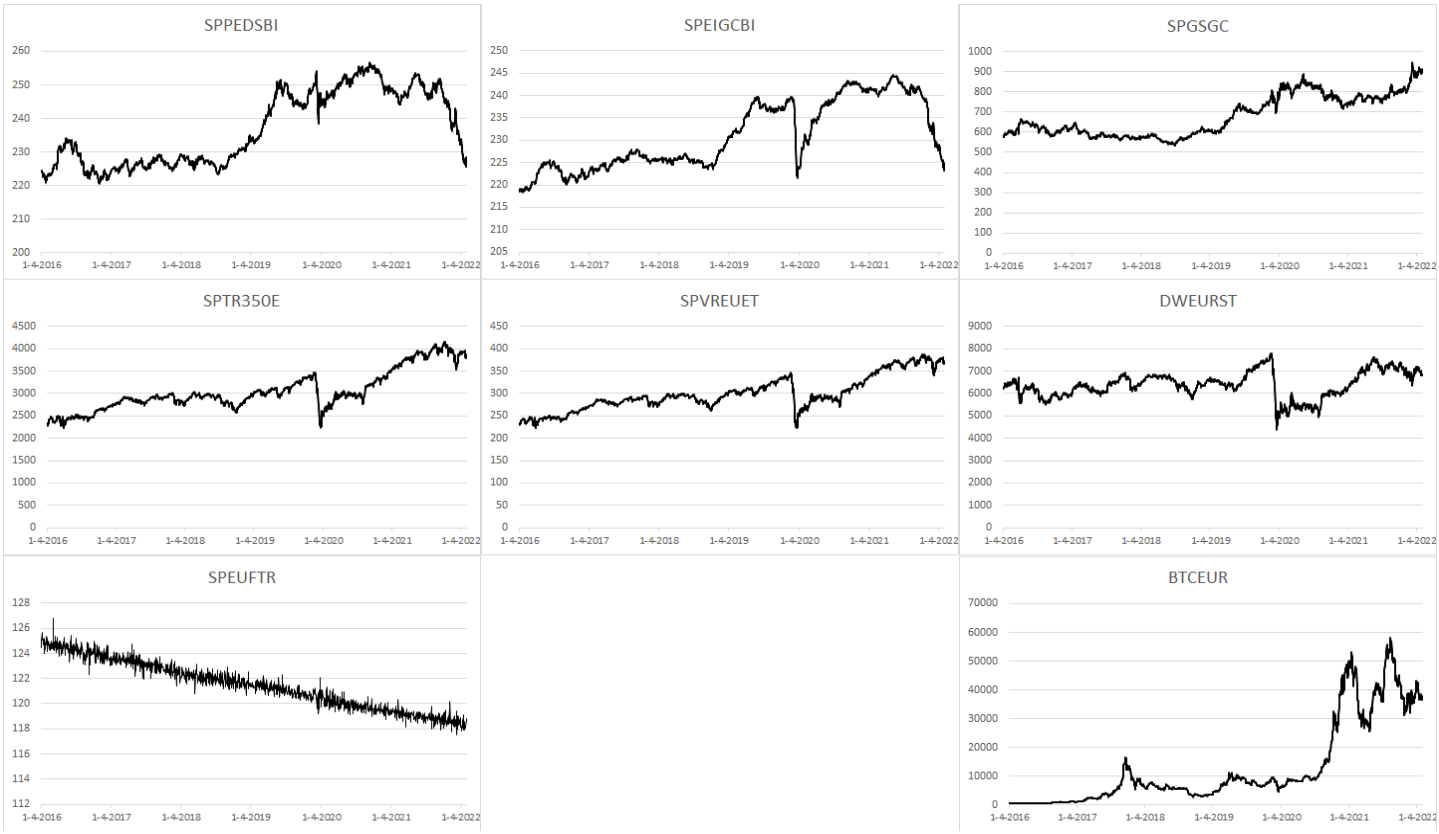

Figure 3.2: Time series plots of EU assets

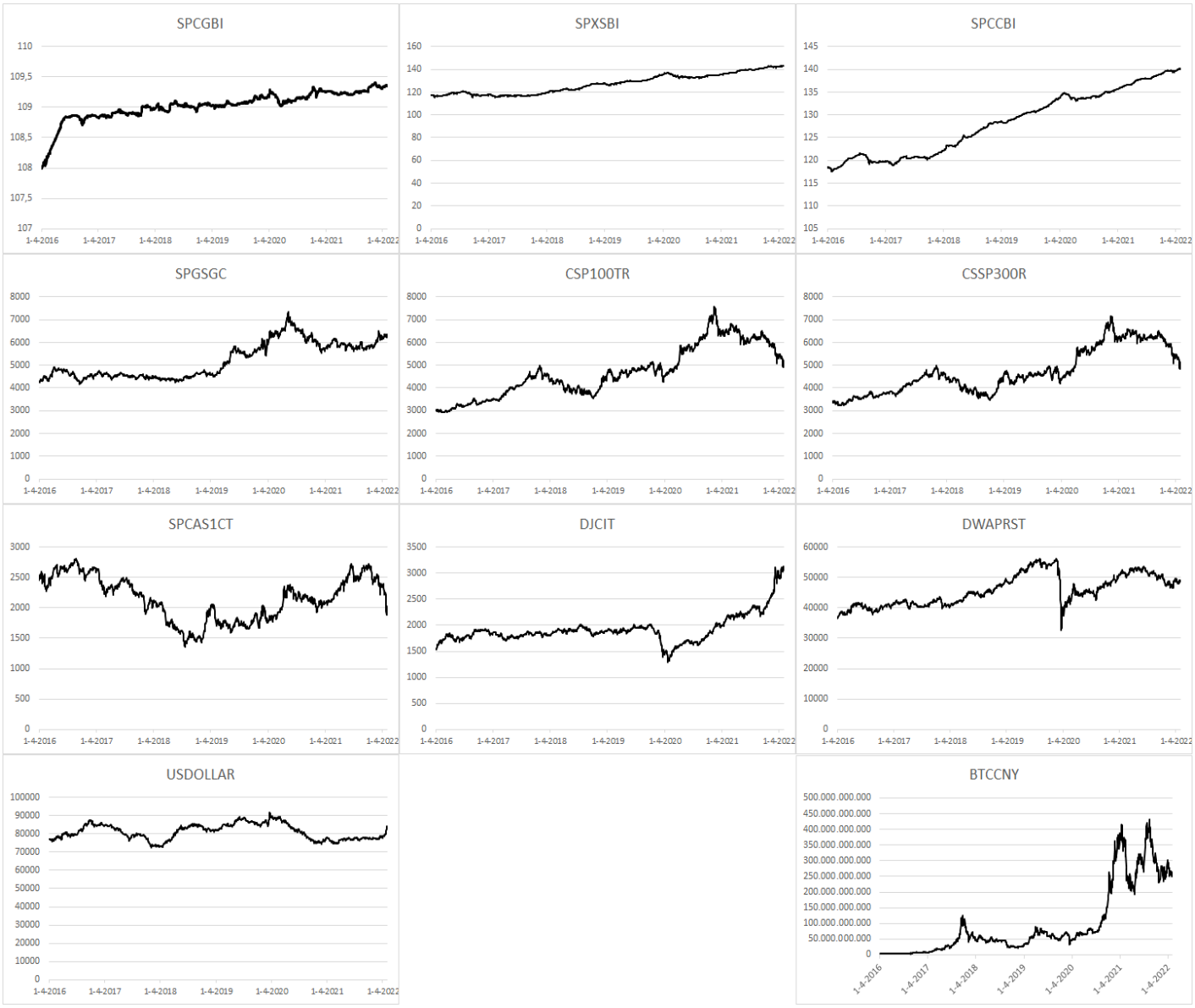

Figure 3.3: Time series plots of CN assets

Table 4.1: Optimal portfolio weights

Table 4.1A: U.S. assets

	SPBDUBIT	*SPBDUSBT*	*DJCBP*	*SPGSGC/BTCUSD*	*SPTR100*	*SPTRSMCP*	*DJCIT*	*DJUSRET*	*USDOLLAR*
EW	0,111	0,111	0,111	0,111	0,111	0,111	0,111	0,111	0,111
ONS	0	0,146	0,051	0,107	0,186	0	0,159	0	0,352
NS-13	0	0	0,079	0,146	0,250	0	0,214	0	0,312
NS-15	0	0	0,034	0,166	0,300	0	0,253	0	0,246
NS-17	0	0	0	0,184	0,350	0	0,293	0	0,173
OWS	-1	0,290	0,202	0,197	0,513	-0,079	0,297	-0,130	0,710
S-13	-0,578	0,330	0,119	0,136	0,353	-0,047	0,208	-0,090	0,569
S-15	-0,853	0,388	0,139	0,160	0,415	-0,056	0,244	-0,106	0,668
S-17	-1	0,357	0,175	0,185	0,479	-0,070	0,280	-0,122	0,716

Table 4.1B: EU assets

	SPPEDSBI	*SPEIGCBI*	*SPGSGC/BTCEUR*	*SPTR350E*	*SPVREUET*	*DWEURST*	*SPEUFTR*
EW	0,143	0,143	0,143	0,143	0,143	0,143	0,143
ONS	0	0	0,520	0,480	0	0	0
NS-13	0	0,096	0,473	0,431	0	0	0
NS-15	0	0	0,140	0,860	0	0	0
NS-17	-	-	-	-	-	-	-
OWS	-0,517	0,351	1	1	0,303	-0,235	-0,598
S-13	-0,340	0,805	0,431	0,485	0,043	-0,235	-0,189
S-15	-0,378	0,776	0,504	0,560	0,046	-0,265	-0,242
S-17	-0,415	0,747	0,576	0,634	0,049	-0,295	-0,295

Table 4.1C: CN assets

	SPCGBI	*SPCSBI*	*SPCCBI*	*SPGSGC/BTCCNY*	*CSP100TR*	*CSSP300R*	*SPCAS1CT*	*DJCIT*	*DWAPRST*	*USDOLLAR*
EW	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100
ONS	0	0,952	0	0	0,017	0	0	0,022	0,001	0,007
NS-13	0	0,432	0	0,103	0,154	0	0	0,311	0	0
NS-15	0	0,286	0	0,131	0,192	0	0	0,391	0	0
NS-17	0	0,141	0	0,159	0,230	0	0	0,470	0	0
OWS	-1	1	0,908	0,004	0,234	-0,228	0,019	0,035	0,002	0,026
S-13	-1	1	0,824	0,022	0,485	-0,455	0,012	0,090	0,001	0,021
S-15	-1	1	0,752	0,038	0,700	-0,650	0,006	0,137	0,000	0,018
S-17	-1	1	0,679	0,054	0,916	-0,846	-0,001	0,184	-0,002	0,014

Summary statistics on optimal portfolio weights Equal weights (EW), Optimized portfolio with (OWS) and without (ONS) shorting allowed and optimal portfolio's calculated for targets returns of 13%, 15% and 17% with (S-13, S-15, S-17) and without (NS-13, NS-15, NS-17) shorting allowed