Cryptocurrency investments - a statistical analysis of their effect on portfolio risk-return properties.

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ABSTRACT,
Interest in cryptocurrency assets among investors is rising. Known for being able to yield high returns in a short timeframe, prices of cryptocurrencies are often volatile. As such, assets in this class typically carry a lot of risk. However, cryptocurrencies may be useful as a diversification tool in traditional asset portfolios. In this study, the effects of adding cryptocurrency assets to already well-diversified portfolios are investigated through mean-variance spanning. A diversified benchmark portfolio is created containing ETFs of various asset classes. Subsequently, Bitcoin and Ethereum will be included in the portfolio to investigate the effects on risk-return properties. Sharpe Ratios are calculated for a portfolio with Bitcoin and Ethereum separately, and then for a portfolio including both assets. A regression analysis is performed in the same manner, with which a test statistic can be computed to determine if adding Bitcoin and Ethereum to the benchmark portfolio has any significant effects. The study concludes that cryptocurrencies can have a positive influence on risk-return trade-offs of diversified traditional asset portfolios. However, cryptocurrency allocation should be kept to a minimum to maintain low volatility levels. By allocating no more than four percent of their portfolio to cryptocurrency assets, investors can reduce risk while maintaining expected returns.

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Keywords
Sharpe Ratio, cryptocurrency investments, mean-variance spanning, multiple regression analysis, risk-return relationship, portfolio diversification.

1. INTRODUCTION: AN IMPORTANT DILEMMA INVESTORS ARE FACING: SHOULD CRYPTOCURRENCIES BE INCLUDED IN ALREADY WELL-DIVERSIFIED PORTFOLIOS?

An increasing number of investors are allocating cryptocurrency assets to their portfolios. (Klein et al., 2018, p. 105). Known for being able to yield high returns on a short-term basis, prices of cryptocurrencies are generally volatile, and therefore this asset class typically carries a lot of risk (Corbet et al., 2019, p. 183; Klein et al., 2018, p. 115). As a result, governments and investors worldwide are of the opinion that cryptocurrencies still too speculative to be considered a serious investment (Smith, 2019, pp. 156-157).

Bitcoin was launched in 2009 as the first cryptocurrency, which demonstrates how little time has passed since this asset class was introduced. As such, no clear frame of reference exists for how cryptocurrencies will behave on a long-term basis. Furthermore, the cryptocurrency space has been subjected to a variety of scams and other fraudulent operations in recent years (Kethineni & Cao, 2019, p. 329). Scammers have on multiple occasions managed to exploit the fact that the public does not yet fully understand cryptocurrency technology (Kethineni & Cao, 2019, p. 329; Foley et al., 2018, p. 2).

Additionally, many cryptocurrency investors are unfamiliar with investing, which may result in irresponsible decision-making, like investing too much capital in assets which are not fully understood (Kethineni & Cao, 2019, p. 336). Furthermore, a lack of experience may also make investors more prone to scams. Lastly, the technologies behind cryptocurrencies are complicated and can be difficult to understand. Because of this, many governments have not yet fully grasped their concept and uncertainties remain about the potential risks of this technology. For these reasons, regulators are generally cautious when making decisions relating to crypto assets (Luther, 2015, p. 391; Smith, 2019, pp. 156-157). This has led to cryptocurrency markets still being largely unregulated.

Generally, investors seek to minimise risk exposure. Taking this into account, a volatile asset class like cryptocurrencies seems undesirable to integrate in an investment portfolio. However, portfolio diversification is frequently used as a strategy to decrease risk exposure (Kajtazi & Moro, 2019, pp. 143-144; Lhabitant, 2017, pp. 1-2). By including a variety of asset types in a portfolio, investors will be less affected by the performance of a single asset, diminishing their exposure to unsystematic risk. This will cause the portfolio to be less volatile and as a result, improve its risk-return properties. This strategy is applied by investors of all kinds, like insurance companies and pension funds, but also retail investors (Lhabitant, 2017, pp. ix-xii). However, once a portfolio is already well-diversified, the inclusion of another asset class may not have a positive effect on the risk-return relationship of that portfolio. The portfolio could already be sufficiently diversified, and cryptocurrency assets may therefore not decrease risk levels any further. Furthermore, while returns of the investment portfolio may increase, the inherent volatility of cryptocurrencies may negatively affect risk levels, which worsens the risk-return properties of the portfolio. Likewise, if risk levels decrease but returns also decrease, there would be no improvement to the risk-return relationship either.

To summarise, the objective of this study is to determine whether the inclusion of cryptocurrency assets in diversified portfolios can increase their risk-return properties. This leads to the following research question:

"What is the effect of cryptocurrency investments on the risk level of already well-diversified portfolios?

The two currencies that will be analysed are Bitcoin and Ethereum. The reason for choosing these assets instead of different currencies is because Bitcoin and Ethereum are the most established and have the widest user bases (Huang et al., 2021, p. 678; Sabalionis et al., 2020, p. 103). As a result, prices are less volatile and because of how blockchain technology works, networks are more secure (Nakamoto, 2008, p. 3). Therefore, out of all cryptocurrencies, Bitcoin and Ethereum are considered the least speculative. Additionally, because Bitcoin and Ethereum are the most well-known, investors are more likely to add these currencies to their portfolio, so analysing them will add to the practical relevance of the research performed.

Two currencies will be analysed instead of one, because there is value in researching if risk levels vary between different cryptocurrencies, or if risk is even across the whole asset class. Especially because many types of cryptocurrencies exist, investors will find use in knowing if there are specific assets within this class they should invest in, or if Bitcoin and Ethereum will have the same effect on the risk-return relationship of their portfolio. Additionally, this study will demonstrate if the inclusion of multiple cryptocurrencies simultaneously will decrease portfolio risk levels even further because of potential additional diversification.

A hypothetical portfolio (benchmark portfolio hereafter) is created containing only traditional assets. During the analysis, Bitcoin and Ethereum will be added to this portfolio to investigate if there are any significant effects to its risk-return properties. A variety of mutual funds will be included, because in the U.S. these entities are legally obligated to report their holdings to the Security and Exchange Commission (SEC) on a quarterly basis, and therefore asset allocation data can easily be retrieved (Agarwal et al., 2015, p. 2734). A specific portfolio that could be focused on is the SPDR S&P 500 ETF Trust Fund (SPY). This fund is considered a household name among investors and has seen a high amount of trading volume over the course of its existence. For this reason, it would be interesting to investigate what effect cryptocurrencies have on the level of risk this portfolio carries. Additionally, it could be useful to include a fund focused on bonds in the analysis, as the SPY only contains stocks. The Vanguard Long-Term Bond Fund could be used because this ETF has a long track record and has been popular among investors for many years. Lastly, the SPDR Gold Shares (GLD) fund is included, which is a physically backed gold ETF (State Street Corporation, 2022a). In short, the benchmark portfolio contains stocks, bonds, and a commodity backed ETF, which provides a good amount of diversification.

The outcome of this research adds to the existing literature of cryptocurrency investment theory by introducing mean-variance spanning tests to two assets in this class. As many questions still exist about the validity of cryptocurrencies as an investment (Klein et al., 2018, pp. 105, 116), this research can serve as a framework for the level of risk these investments typically carry as well as the significance of their effect on already well-diversified portfolios. The results of these analyses can be used for further research on these topics.

Additionally, this study may be relevant on a practical level because insights obtained can be used by a wide variety of investors who want to improve the risk-return properties of their portfolios, whether these are large financial institutions like pension funds and insurance companies, or retail investors. Moreover, governments are interested in the properties of cryptocurrencies as an investment because once risk levels of this asset class are better understood, it will be easier to establish the necessary laws and regulations (Luther, 2015, pp. 407-409; Smith, 2019, pp. 156-157, 165-166).

To answer the research question, the current knowledge of cryptocurrency asset behaviour will first be discussed in the form of a literature review. Moving on to the third section, the literature review is extended to theoretical elements surrounding cryptocurrency technology and the potential effects of including cryptocurrencies in already well-diversified portfolios. Additionally, literature behind mean-variance spanning and Sharpe Ratios and their use cases for portfolio diversification will be discussed. In chapter four, the focus is on the research methodology, which includes the selection process and collection of data, as well as the analysis itself. Finally, the results of the analysis will be presented in chapter five, to which a conclusion will be formed in chapter six. Lastly, limitations of the study and applications for future research will be discussed.

2. THE BEHAVIOUR OF THE CRYPTOCURRENCY MARKET

To answer the question if cryptocurrencies should be included in already well-diversified portfolios, it is wise to investigate how they behave on a market level and why many investors and organizations consider these assets a speculative investment. In recent years, cryptocurrencies have spiked in popularity and an increasing number of investors are considering including this asset class in investment portfolios (Klein et al., 2018, p. 105). According to Fang et al. (2022, pp. 1-2), 85% of currently released cryptocurrency trading publications have appeared after 2017, demonstrating a growing demand for research in this field in recent years.

Many papers covering cryptocurrency markets discuss investor behaviour. For example, Özdemir (2022, pp. 30-31) found that the Covid pandemic has led to an increase in risk-taking behaviour by cryptocurrency investors. Not only were investments themselves riskier but investors also participated more in herding behaviour, which means decisions of other investors were often mimicked, suggesting insufficient portfolio diversification (Bouri et al., 2019, p. 220). These factors consequently led to an increase in the volatility of cryptocurrency assets. Bouri et al. (2019, p. 220) also argue that herding behaviour among crypto investors varies over time. However, there seems to be a positive correlation with uncertainty. Furthermore, the entrance of institutional investors may bring more rationality to cryptocurrency markets, which could decrease volatility of these assets (Bouri et al., 2019, p. 220).

Investors have previously argued that cryptocurrency assets can demonstrate bubble-like qualities. Literature associated with this topic indicates that both Bitcoin and Ethereum have indeed experienced bubble phases, most notably in 2013 and 2017 (Kyriazis et al., 2020, p. 9). Additionally, research shows that this is not exclusive to Bitcoin and Ethereum, as other cryptocurrencies have also undergone this scenario. Bubbles are formed because of overconfidence among investors, which could be a consequence of favourable recent returns. The question is consequently raised if this irrational behaviour and overoptimism from investors will persist, or if the bubble will eventually burst (Kyriazis et al., 2020, p. 9; Fry, 2018, p. 228). According to Bouri et al. (2019, p. 183), there is a high correlation between price movements in different cryptocurrencies. Explosive reactions in one cryptocurrency will often lead to explosive price movements in other cryptocurrencies. In these volatility spill overs, Bitcoin is often the first mover (Yi et al., 2018, p. 112).

Furthermore, research suggests that on average, volatility of cryptocurrency assets is higher than assets like stocks and bonds. When comparing price data for Bitcoin from the last seven years to price data for gold, treasury bonds, and the S&P 500, Bitcoin is clearly the more speculative asset (Doumenis et al., 2021, pp. 1, 13-14). As previously stated, volatility spill overs in the cryptocurrency space are not uncommon. While Bitcoin is the largest cryptocurrency in terms of market capitalization, it does not necessarily dominate the crypto market. Yi et al. (2018, pp. 112-113) argue that it is therefore wise to also invest in other cryptocurrencies besides Bitcoin. However, it is true that cryptocurrencies with a large market capitalization generally start volatility booms, which smaller capitalization currencies subsequently follow (Yi et al., 2018, pp. 112-113).

Government regulation is an important factor influencing the volatility of cryptocurrencies. Jalal et al. (2021, p. 13) argue that effective law and policy making may lead to a reduction in herding behaviour as well as volatility in the crypto space. However, effective regulation of cryptocurrency assets is a convoluted task, especially considering the quantity and geographic dispersion of cryptocurrency users, as well as the privacy centred protections imposed by the technology (Jalal et al., 2021, p. 10). Additionally, attempts to completely restrict access to cryptocurrencies will prove unsuccessful because of the digital nature of this technology. If services are restricted in certain countries, the network will develop elsewhere (Böhme, 2015, pp. 231-232).

All in all, cryptocurrency assets are considered highly speculative. For one because the asset class is still new and long-term price predictions are difficult to make, but also because volatility spill overs are frequent and herding behaviour among investors is highly prevalent. Furthermore, the importance of government regulation is heavily stressed in recent literature. However, the difficulty of effective implementation of laws and policies relating to cryptocurrencies is also recognized.

3. THEORETICAL FRAMEWORK

3.1 Cryptocurrency technology and its use cases: what makes a cryptocurrency unique?

Cryptocurrencies are a form of digital currency secured by cryptography. As a result, these assets are nearly impossible to duplicate and counterfeit (Böhme et al., 2015, pp. 216-217; Zheng et al., 2017, p. 558). Additionally, cryptocurrencies are built on blockchain technology and no central authority like bank or government system is needed to maintain the network (Böhme et al., 2015, p. 219). According to some, this technology could revolutionize the way transactions are performed in the future (Kethineni, 2019, pp. 325-326).

Bitcoin was the first cryptocurrency, and it was revolutionary at the time of its release in 2009. The objective of the technology was to achieve a digital currency system without the involvement of any central organization (Chen et al., 2019, p. 293; (Yi et al., 2018, p. 98). Participants in the network are anonymous and the Bitcoin system operates on a concept called Proof of Work, where decisions are made based on where the most CPU power is generated (Chen et al., 2019, p. 293; Nakamoto, 2008, p. 3). This structure provides the Bitcoin network with high security because an attacker could theoretically only hack the network by obtaining majority CPU power, which is not only discouraged because the currency would become worthless when hacked, but also nearly impossible to accomplish with the size the Bitcoin network has reached (Böhme et al., 2015, pp. 218-219).

After the success of Bitcoin, many other cryptocurrencies emerged, each with adaptations to the original concept to fulfil new use cases (Bouri et al., 2019, p. 217; Chen et al., 2019, p. 293). In recent years, cryptocurrency assets have increased in popularity and just a couple of years ago, the number of cryptocurrencies in circulation surpassed the 1000 mark (Yi et al., 2018, p. 98). For this reason, it is difficult to decide on a specific currency to invest in.

However, while the technology behind several projects may seem promising, most of these currencies do not really introduce any innovative developments and can be unsafe for investors because government supervision in the crypto space is still lacking (Bouri et al., 2019, p. 217; Chen, 2018, pp. 570-571). Moreover, the few currencies that do propose interesting use cases should be approached with caution, as fraudulent activities have been widely circulating the crypto space (Foley et al., 2018, pp. 38-39; Kethineni, 2019, pp. 329-331). One frequently encountered scam is the pump-and-dump scheme, where the creator of a cryptocurrency artificially inflates the price by making false promises and giving overly positive statements. Once enough capital has been raised, the project is abandoned leaving investors with a worthless asset. (Chen et al., 2019, pp. 293-294). Cryptocurrency assets are especially vulnerable to these types of practices because crypto markets are still largely unregulated (Bouri et al., 2019, p. 217; Chen et al., 2019, pp. 293-294).

For this reason, it can be risky to invest in a new cryptocurrency project. While the concept may sound promising on paper, often none of the proposed ideas have been realised yet and there is no guarantee that they ever will. Therefore, it is advised to invest in a cryptocurrency that has existed for at least a few years, as there is a significantly lower chance of investing in pump-and-dump schemes and ending up with a worthless asset. In short, an asset is generally less speculative when it has a longer track-record.

One cryptocurrency that has existed for multiple years is Ethereum. Ethereum took the fundamentals of Bitcoin and expanded the concept to allow developers to build applications on a decentralized software platform (Buterin, 2014, p. 34). Ethereum incorporates the same technologies as Bitcoin like blockchain and cryptography, but also integrates smart contracts (Buterin, 2014, p. 13). Smart contracts are a type of software running on the blockchain that executes a task when certain conditions are met (Buterin, 2014, p. 13; Luu et al., 2016, p. 254). This feature gives Ethereum many additional use cases over Bitcoin. Because Ethereum runs on blockchain and cryptography technology, applications developed on the software are decentralized, secure, and privacy oriented (Buterin, 2014, p. 13; Huang et al., 2021, pp. 679-680).

Furthermore, both Bitcoin and Ethereum currently operate on a Proof of Work system. With Proof of Work, decisions on the network are made based on where the most CPU power comes from. For this reason, the network becomes more secure based on its number of active users (Böhme et al., 2015, pp. 218-219; Gervais et al., 2016, p. 3). Bitcoin and Ethereum are first and second respectively in terms of market capitalization (Iqbal et al., 2021, p. 2), and are widely considered to be the most popular assets in their class. Additionally, both Bitcoin and Ethereum have been around for multiple years.

In conclusion, Bitcoin and Ethereum seem to be the most responsible investments in the crypto space. First, the fact that these assets were some of the first cryptocurrencies to emerge has given them a first mover advantage and long track-record. Additionally, their networks are considered more secure and less susceptible to scams partially because of their wide user bases (Böhme et al., 2015, pp. 218-219). For these reasons, Bitcoin and Ethereum will likely have more longevity than other cryptocurrencies and are generally considered to be the least speculative assets in the crypto space.

3.2 An overview of mean-variance spanning in science: using spanning tests and Sharpe Ratios to predict portfolio performance

As previously stated, mean-variance spanning will be used to evaluate the significance of the effect Bitcoin and Ethereum have on a traditional asset portfolio. In short, mean-variance spanning involves running an OLS regression analysis on a benchmark asset denoted with K (Brière et al., 2015, p. 8). A linear model is estimated to determine the significance of explanatory variables (Schmitz & Hoffman, 2020, pp. 11-12).

$$R_{Test} = \alpha + \beta R_{Benchmark} + \epsilon$$

In short, the goal of spanning is to determine whether adding certain variables to a model will have a significant effect on the behaviour of that model (Schmitz & Hoffman, 2020, p. 11). For this study, the test assets will consist of Bitcoin and Ethereum and the benchmark asset will be the diversified portfolio containing traditional assets.

A variety of spanning tests exist. These tests can often be used interchangeably; however, they may yield different results depending on the sample size. Especially when sample sizes are small, it is important to assess which test is the best fit for that specific type of research (Zhou & Kan, 2012, p. 146). Huberman and Kandel (1987, pp. 880-881) proposed a mean-variance spanning analysis using a likelihood ratio test. However, for this study a Wald Test will be used. The Likelihood Ratio Test and Wald Test are very similar in practice and will often come to the same conclusion. (Agresti, 2007, p. 12). However, one notable difference is that the Wald Test has the tendency to over-reject the null hypothesis when sample sizes are small, which may make it unsuitable for certain analyses (Brière et al., 2015, p. 9; Schmitz & Hoffman, 2020, p. 14). Despite this, the Wald Test is easier to use as it only requires the estimation of one model, while the Likelihood Ratio Test requires two models to be estimated. Because of its simplicity, The Wald Test can also be applied in a wider variety of situations than the Likelihood Ratio Test.

The necessary and sufficient conditions for spanning in terms of restrictions are (Scholtens & Spierdijk, 2010, p. 521; Zhou & Kan, 2012, p. 142):

$$H_0: \alpha = 0, \qquad \sum_{k=1}^{K} \beta_k = 1$$

Under the null hypothesis of spanning, a portfolio exists containing the K benchmark assets which has the same expected return as the test assets but a lower variance. In this case, the benchmark assets dominate the test assets. On the other hand, when the test assets span the benchmark assets, the null hypothesis is rejected. To explain, the null is accepted when the addition of cryptocurrency assets to the benchmark portfolio has no effect on the performance of the benchmark portfolio. Spanning is assessed using a Wald Test. The Wald Test has asymptotic properties and relies on a chi square distribution, and has the following formula (Brière et al., 2015, p. 9; Zhou & Kan, 2012, p. 146):

$$W = T\,(\lambda_1 + \lambda_2) \sim \chi_2^2$$

In this formula, λ_1 and λ_2 are calculated as follows (Brière et al., 2015, p. 9):

$$\lambda_1 = max_r \frac{1+\hat{\theta}_2^2(r)}{1+\hat{\theta}_1^2(r)} - 1, \qquad \lambda_2 = min_r \frac{1+\hat{\theta}_2^2(r)}{1+\hat{\theta}_1^2(r)} - 1$$

If the Wald Test demonstrates that the parameters for certain explanatory variables are close to zero, the variables can be removed from the model. However, if the Wald Test shows a high value, the explanatory variables have a significant effect on the performance of the model. In other words, Bitcoin and Ethereum will likely have a significant effect on the performance of the benchmark portfolio in this situation.

The risk-return relationship of a portfolio can be measured using the Sharpe Ratio. The Sharpe Ratio equals the expected return of a portfolio subtracted by the risk-free rate, divided by the standard deviation of the portfolio's excess return (also called the volatility of the portfolio) (Sharpe, 1994, p. 49). The formula for the Sharpe Ratio is as follows:

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

This formula allows investors to easily identify the profits resulting from risk taking behaviours, because the risk-free rate is subtracted from the portfolio's return (The risk-free rate is the return of a risk-free investment) (Bodnar & Zabolotskyy, 2016, p. 2). A portfolio with high returns is not necessarily desirable if it comes with an excess amount of additional risk. Therefore, a higher Sharpe Ratio is generally more desirable.

Portfolio managers have historically used this performance measure to make investment decisions, partially because of its simplicity and ease of use (Gatfaoui, 2015, p. 1; Hodoshima, 2018, p. 327). However, the Sharpe Ratio has been criticized in literature for having several limitations (Gatfaoui, 2015, pp. 3-4; Hodoshima, 2018, p. 327). For one, the formula uses the standard deviation of returns to express total portfolio risk. Therefore, the assumption is made that returns are normally distributed, which is often not true in practice (Gatfaoui, 2015, pp. 3-4, 15). Furthermore, Sharpe Ratios are sensitive to cherry-picking of data. Portfolio managers can lengthen the interval at which return data is measured. Short-term data generally has a higher standard deviation, so the apparent risk experienced by the portfolio will seem lower when lengthening the measurement interval because volatility will seem lower (Gatfaoui, 2015, p. 2). Another weakness of the Sharpe Ratio is that it is calculated based on several assumptions. For example, future returns are often estimated based on past returns. While these values will generally be very similar, there is not guarantee that past returns will predict the future performance of an asset.

3.3 Including cryptocurrency assets in already well-diversified portfolios: what are the potential effects?

While diversification is a widely utilised and proven to be effective strategy to diminish portfolio risk, the question remains if the addition of cryptocurrency assets will have positive effects if a sufficient level of portfolio diversification has already been reached. The inclusion of a wide variety of assets may improve risk-return properties of a portfolio, but effects will diminish in severity if the portfolio already contains multiple types of assets. Eventually, a portfolio will reach a satisfactory level of diversification at which point a further increase in asset variety will not positively influence its risk-return properties.

However, cryptocurrency assets may prove to be an exception to this rule. Evidence suggests that Bitcoin and other cryptocurrencies like Ethereum can effectively be used to further diversify portfolios, as these currencies demonstrate hedging properties against certain assets (Klein et al., 2018, p. 115; Bouri et al., 2017, pp. 196-197). Furthermore, studies have found there to be a positive correlation between Bitcoin and Ethereum price levels (Akbulaev et al., 2020, p. 46; Katsiampa et al., 2019, p. 74). This suggests that both assets could behave differently than those already present in well-diversified traditional portfolios. This could imply that the addition of Bitcoin and Ethereum can decrease risk-levels of these portfolios.

Based on these findings, a hypothesis can be formed about the likely effect of the inclusion of Bitcoin and Ethereum on the risk-return relationship of already well-diversified portfolios. As evidence has been found that cryptocurrencies behave differently compared to assets like stocks and commodities, and Bitcoin and Ethereum have demonstrated hedging properties in the past (Klein et al., 2018, p. 115; Bouri et al., 2017, pp. 196-197), the expectation for the outcome of this study is that the addition of cryptocurrency assets will lead to a decrease in the risk-levels of already well-diversified portfolios. To further support this hypothesis, an analysis will be performed in chapter four on the correlation between price levels of Bitcoin and Ethereum with price levels of regular assets.

4. RESEARCH METHODOLOGY: MEAN-VARIANCE SPANNING AND THE SHARPE RATIO

4.1 Sample selection and data collection methods: creating a benchmark portfolio

Before executing the statistical analysis for this study, a literature review was performed. First, literature about the behaviour of the cryptocurrency market was reviewed to understand what makes the cryptocurrency asset class unique and increasingly popular. Following this, theory behind cryptocurrency technologies was evaluated to better understand differences between individual cryptocurrencies and what implications this has for investment potential. Finally, literature covering mean-variance spanning was reviewed, and how Sharpe Ratios can be used to measure portfolio diversification and performance.

In this part of the study, price data for Bitcoin and Ethereum is collected from online databases and subsequently analysed in statistical programs. A regression analysis is performed of these cryptocurrency assets on a benchmark portfolio containing traditional assets, after which mean-variance spanning is used to determine if adding Bitcoin and Ethereum to this portfolio has a significant effect on its performance. This analysis will be executed three times. Two times to test Bitcoin and Ethereum separately against the benchmark portfolio and one last time to test both assets simultaneously. Furthermore, the risk-return properties of the benchmark portfolio will be calculated before the addition of any cryptocurrency assets. After calculating these data, Bitcoin and Ethereum will be included to form a hypothetical portfolio. The risk-return properties of this hypothetical portfolio will subsequently be analysed to determine if the addition of Bitcoin and Ethereum has improved its performance. To be more specific, the Sharpe Ratio of the portfolio will be calculated before and after the inclusion of cryptocurrencies, after which a conclusion can be formed about the effect of the addition of cryptocurrency assets on the risk-return relationship of the benchmark portfolio.

Because cryptocurrency prices have thus far been observed to follow a four-year cycle, it is likely best to retrieve return data from a period of at least four years to obtain the most accurate estimation of Bitcoin and Ethereum's future price performance (Meynkhard, 2019, pp. 83-84). Historical price data for all assets is retrieved from Yahoo Finance, with which portfolio volatility and expected returns can subsequently be calculated to obtain a hypothetical Sharpe Ratio.

To ensure validity of results, the benchmark portfolio for this analysis must be well-diversified, and as such, contain a variety of assets. Instead of picking individual stocks, several funds are selected. By combining different types of funds, a well-diversified portfolio containing multiple asset classes can be created. Exchange traded funds (ETFs) are a type of fund that can be traded on stock exchanges like regular stocks. Asset allocation data for these funds is public because ETFs in the U.S. are required by the SEC to disclose their holdings on a quarterly basis (Agarwal et al., 2015, p. 2734). Because of this, statistical analyses can easily be performed as the necessary data is available to the public.

Three ETFs are chosen for the benchmark portfolio. First is the SPDR S&P 500 ETF Trust Fund (SPY). The SPY launched in 1993 and was the first fund to be traded on a U.S. stock exchange (State Street Corporation, 2022b). It has since become a household name among investors, reflected by its high amounts of trading volume. The assets contained in this ETF are all stocks, making it a single asset class fund. However, the stocks have been picked from a wide variety of sectors. The technology sector makes up the largest part of the SPY's holdings, followed by the healthcare and financial sectors (State Street Corporation, 2022b). All in all, the SPY contains around 370 billion dollars' worth of assets (State Street Corporation, 2022b).

Additionally, a fund focused on bonds is included in the benchmark portfolio. Combining stocks and bonds in a portfolio is a widely used strategy for portfolio diversification, because stocks and bonds often have an inverse relationship, where the value of each tends to move in opposite directions. In other words, stocks and bonds usually have a negative correlation and bonds can be used as a hedging mechanism against stocks losing value and vice versa (Ma et al., 2021, p. 1, 6). Because of this, the addition of bonds to the hypothetical portfolio will likely have a positive effect on portfolio diversification and benefit its risk return properties. The Vanguard Long-Term Bond ETF (BLV) is picked to incorporate bonds in the hypothetical portfolio. The BLV is primarily focused on long-term bonds, with most holdings having a term to maturity of at least 15 years (The Vanguard Group, Inc., 2022). Almost 50% of assets contained in the fund are government grade bonds, with the other half primarily consisting of high-grade bonds (BBB rating or higher) (The Vanguard Group, Inc., 2022).

The last ETF included in the benchmark portfolio is the SPDR Gold Shares (GLD) fund. GLD is traded worldwide and was first launched on the New York Stock Exchange in 2004. It is the largest gold-backed ETF in the world (State Street Corporation, 2022a). Including GLD adds another asset class to our portfolio, which will make it more diversified. Additionally, Bitcoin has often been compared to gold as an asset, so it will be interesting to see how the two assets compare during the analysis.

4.2 The paradox of choice: selecting the right currencies for investment analysis

Currently, there are more than 2000 different cryptocurrencies in circulation (White et al., 2020, p. 1). However, the choice was made to focus only on Bitcoin and Ethereum for this study, because these are by far the most established projects in the cryptocurrency space (Huang et al., 2021, p. 678; Sabalionis et al., 2020, p. 103). As such, these assets have the widest user bases, which also leads to a safer network because of how the technology behind cryptocurrencies works (Nakamoto, 2008, p. 3; Huang et al., 2021, pp. 679-681). Furthermore, Bitcoin and Ethereum are among the longest running assets in the cryptocurrency space, which makes them less likely to suddenly lose a large portion of their value (Huang et al., 2021, p. 678; Sabalionis et al., 2020, p. 103). Therefore, they are less speculative on an investment level compared to other cryptocurrencies. Additionally, because Bitcoin and Ethereum are popular, investors are more likely to include them in their portfolio than other assets in their class. For this reason, analysing Bitcoin and Ethereum specifically will add to the practical relevance of this study.

The choice was made to analyse two assets instead of only one, because there may be value in determining if risk levels vary between cryptocurrencies or if all assets in this class behave similarly. If Bitcoin and Ethereum do not have identical behaviours, portfolio risk-return properties will be affected differently depending on which of the two is included. This is especially relevant because the number of different cryptocurrencies in circulation is large (White et al., 2020, p. 1; Yi et al., 2018, p. 98), which may cause investors to feel overwhelmed when entering cryptocurrency markets. Additionally, correlation with traditional assets may be different for each of these cryptocurrencies, which can cause investors to prefer one over the other as a diversification mechanism. Furthermore, no more than two cryptocurrency assets will be studied, because this may make analyses unnecessarily complicated without any added research value. For example, many cryptocurrency assets have been created only very recently and are therefore very speculative (Corbet et al., 2019, pp. 182-183). Bitcoin and Ethereum are widely considered to be the most established and least risky assets of their type. Both have wide user bases and a large amount of community support (Huang et al., 2021, p. 678; Sabalionis et al., 2020, p. 103). Additionally, most investors diversifying their portfolios with cryptocurrency assets will likely choose either Bitcoin or Ethereum. Therefore, the analysis of additional cryptocurrencies will only complicate this study without adding to its practical relevance.

Furthermore, cryptocurrency assets are known to be highly correlated with each other on a price level (Akbulaev et al., 2020, p. 46; Katsiampa et al., 2019, p. 74). Therefore, including multiple cryptocurrencies will likely not have any added benefits for portfolio diversification. Adding Bitcoin or Ethereum will likely have a similar effect on portfolio performance as other cryptocurrencies. The only difference being that Bitcoin and Ethereum are considered far less speculative investments because of their long track record relatively speaking (Huang et al., 2021, p. 678; Sabalionis et al., 2020, p. 103).

4.3 Asset analysis: descriptive statistics and correlation

Table 1 shows descriptive statistics for all assets included in the analysis. The most notable observation is the difference in variance between Bitcoin & Ethereum and traditional assets, with Ethereum being the most volatile and BLV the least volatile. Weekly price data is used over a 5-year period, which brings our sample size to 260 for each asset.

Table 1: Descriptive Statistics of all assets present in the portfolio.

	BTC	ETH	SPY	BLV	GLD
Observations	262	262	262	262	262
Mean	1.62%	1.88%	0.27%	0.04%	0.15%
Median	1.57%	0.82%	0.50%	0.26%	0.23%
Std. Deviation	11.46%	14.98%	2.64%	1.82%	1.90%
Variance	131.26%	224.44%	6.97%	3.32%	3.59%
Minimum	−33.49%	−41.34%	−15.05%	−8.98%	−9.06%
Maximum	41.48%	65.12%	12.09%	12.96%	8.66%
Skewness	.15	.50	−.72	.31	−.18
Kurtosis	1.00	2.15	8.00	13.03	3.63

Despite the large amount of risk carried by cryptocurrency assets, portfolio volatility can still decrease after adding Bitcoin and Ethereum. If correlation of returns is low for the cryptocurrency assets and traditional assets in the benchmark portfolio, volatility could still be reduced through diversification. However, correlation between the traditional assets should also be measured. If there is a high positive correlation between SPY and BLV price data, including both ETFs in the portfolio will likely not lead to a well-diversified portfolio. On the other hand, if correlation is negative, the funds can be used to hedge against each other's losses. In other words, correlation between SPY and BLV should ideally be low, to ensure an added diversification benefit and better portfolio risk-return properties.

To calculate the correlation of asset returns, the retrieved data should preferably be of a long timeframe because the analysis will be more accurate if more data is collected. However, Ethereum is the newest asset included in the hypothetical portfolio as it was only launched in 2015. As such, data used will not precede 2015, because price data for Ethereum does not exist beyond this timeframe (Corbet et al., 2018, p. 83). Additionally, the first stage of an asset's existence is often paired with extreme volatility and speculative behaviour among investors. As such, this price data likely does not provide an accurate sample for future Ethereum returns. Therefore, correlations are calculated using return data from a five-year period (2017-2022). Furthermore, because stock markets are closed on weekends and certain holidays, it seemed illogical to compare daily return data, as cryptocurrency exchanges are opened on every day of the year. Therefore, weekly price data was obtained for both cryptocurrencies and ETFs.

Table 2: Correlations for all assets included in the hypothetical portfolio over a five-year period.

	BTC	ETH	SPY	BLV	GLD
BTC	1	.735	.170	.050	.141
ETH		1	.217	.078	.171
SPY			1	.285	.247
BLV				1	.450
GLD					1

As can be seen in table 2, Bitcoin and Ethereum seem to have a slight positive correlation with BLV at around 5 to 7%. Correlation with SPY and GLD is also positive though still weak. Bitcoin seems to be slightly less correlated with traditional assets than Ethereum, suggesting it may be a better option for portfolio diversification than its counterpart. As expected, this data gives the indication that cryptocurrencies are not highly correlated with stocks, bonds, or gold. However, they do seem to lean slightly more towards stocks than the other traditional asset classes. This validates our hypothesis that the addition of Bitcoin and Ethereum to the benchmark portfolio will likely reduce risk levels, which will improve the Sharpe Ratio along with portfolio performance. However, correlation is not explicitly negative either, so a definitive conclusion remains unclear.

Furthermore, Bitcoin and Ethereum seem to be highly positively correlated with each other as expected. This implies that adding both cryptocurrencies to the benchmark portfolio together may lead to an increase in volatility, which is undesirable. However, correlation is not perfect, and it may be interesting to investigate if both assets have a different effect on portfolio risk-return properties.

4.4 Research design: analysis of return data over a five-year period through use of spanning tests and the Sharpe Ratio

The basis for this research is formed by obtaining historical price data for two types of cryptocurrencies from online databases. Consequently, mean-variance spanning will be used to determine if the addition of these cryptocurrencies to the benchmark portfolio will have a positive effect on its risk-return properties. Mean-variance spanning tests can measure if adding explanatory variables to a model has a significant impact on the behaviour of this model (Schmitz & Hoffman, 2020, pp. 11-12). If the spanning test concludes that the explanatory variables are insignificant, that means the inclusion of Bitcoin and Ethereum does not add anything of significance to the benchmark portfolio. To summarise, if the test statistic has an insignificant value, we can conclude that cryptocurrencies can be left out of the benchmark portfolio without any significant loss to its overall performance.

Several mean-variance spanning tests exist, although they are all quite similar (Zhou & Kan, 2012, p. 146). The Wald Test will be used for this study because of its simplicity and ease of use. For one, the Wald Test only requires estimating one model, while the likelihood ratio test requires an estimation of two models. Furthermore, different spanning tests will often come to the same conclusion, especially when sample sizes are large. Only when a sample is small does it become more relevant which type of test is used for analysis. One weakness of the Wald Test seems to be a tendency to over-reject the null hypothesis with small sample sizes (Brière et al., 2015, p. 9; Schmitz & Hoffman, 2020, p. 14). However, weekly price data over a 5-year period was collected for this study, bringing the sample size to 260 for each asset.

By using the Wald Test, it can be measured if the test assets span the benchmark portfolio. First, the benchmark portfolio will be tested against Bitcoin and Ethereum separately, after which both cryptocurrencies are combined in the test portfolio and measured against the benchmark portfolio. As previously discussed, a benchmark portfolio was created containing stock, bond, and commodity ETFs. A regression model is estimated for Bitcoin and Ethereum against this portfolio. The Test statistic can consequently be determined to reach a conclusion about the effects of the inclusion of Bitcoin and Ethereum in the benchmark portfolio on its risk-return properties.

Subsequently, Sharpe Ratios are calculated. First, Different weights are allocated to the assets included in the benchmark portfolio. Expected portfolio returns are then calculated by multiplying the expected returns of the assets by their allocated weights. Volatility is determined using the covariances of the assets and their allocated weights in the portfolio. Using this method, we can establish the returns and volatility levels of this portfolio for different weights of the included assets. For example, a minimum risk portfolio can be calculated by modifying the weights of the included assets so that volatility is minimised. Additionally, the optimal portfolio can be determined by calculating the Sharpe Ratio. The optimal portfolio is that which maximises the Sharpe Ratio. In other words, the portfolio with the best expected return-to-volatility ratio will have the highest Sharpe Ratio because it will likely have the best risk-return properties.

By calculating expected return and volatility values of a portfolio for different asset allocations, the mean-variance efficient frontier of that portfolio can be established. The capital allocation line can subsequently be determined by drawing a line from a hypothetical risk-free asset to the optimal portfolio. A risk-free asset has a volatility of 0%. For the expected returns of the risk-free asset, the 5-year treasury rate was used as a benchmark, which is 3,61% at the time of writing. The capital allocation line is useful because it provides a clear visualisation of portfolio risk-return properties, which allows for easy comparison of portfolios. The steeper the capital allocation line, the better the trade-off between risk and return for that portfolio.

This process of calculating expected return and volatility values for different asset allocations will be repeated for three other hypothetical portfolios. One portfolio will contain both Bitcoin and Ethereum. Furthermore, the other portfolios contain only BTC and ETH respectively. A mean-variance efficient frontier and capital allocation line will be created for these portfolios, which allows for straightforward comparison. As a result, it is easy to identify the effects of adding Bitcoin and/or Ethereum to the benchmark portfolio.

5. RESULTS

5.1 Spanning tests: the significance of cryptocurrency assets in the benchmark portfolio

Table 3: Regression statistics for the minimum variance portfolio.

Test Assets	Slope	Standard Error	Wald Statistic
BTC & ETH	1.272	.190	6.69
BTC	1.063	.111	9.58
ETH	1.277	.144	8.87

As can be seen in table 3, the benchmark portfolio was tested against three test portfolios. All test assets seem to significantly span the assets in the benchmark portfolio, because the Wald Statistic is quite high in all three instances. This means that all test assets have a significant effect on the performance of the benchmark portfolio, suggesting that the addition of cryptocurrency assets to already well-diversified portfolios may increase risk-return properties. Especially Bitcoin seems to have a significant effect on the minimum variance benchmark portfolio, as can be seen in table 3.

Table 4: Regression statistics for the optimal portfolio.

Test Assets	Slope	Standard Error	Wald Statistic
BTC & ETH	1.131	.112	10.10
BTC	1.022	.089	11.48
ETH	1.177	.113	10.42

Table four shows the same data, but in this instance the regression analysis was performed on optimal portfolios. That is, the portfolios with asset allocations that maximise expected returns and minimise volatility. In other words, these portfolios maximise the Sharpe Ratio. For this analysis, the Wald Test comes to the same conclusion, which is to reject the null hypothesis because the test assets significantly span the assets in the benchmark portfolio.

5.2 Sharpe Ratios: do cryptocurrencies improve risk-return properties of already well-diversified portfolios?

Figure 1 shows the mean-variance efficient frontier and capital allocation line for the benchmark portfolio. This portfolio contains only the SPY, BLV, and GLD ETFs. The optimal asset allocation instance of this portfolio has an expected return 9,53% with a 5-year volatility of 25,74%. The risk of this portfolio can be minimised to 24,48%, however this will also decrease expected returns to 8,97%.

Subtracting the 5-year risk-free rate of 3,61% from the expected return and dividing by the volatility gives us a Sharpe Ratio of 0,2301, which is visualised in figure 1 using the capital allocation line.

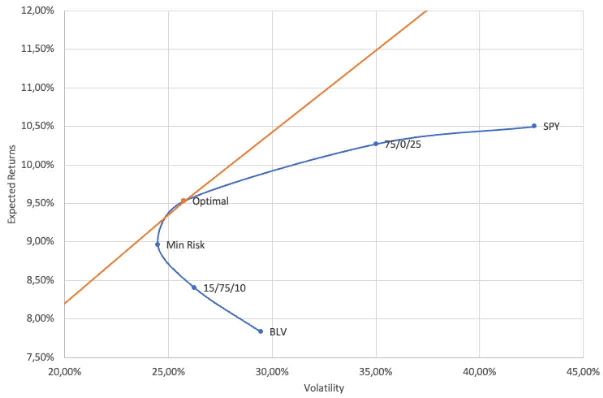

Figure 1: Mean-variance efficient frontier with capital allocation line of the benchmark portfolio.

Besides the benchmark portfolio, three other hypothetical portfolios were created, but with the addition of Bitcoin or Ethereum, or both simultaneously. The mean-variance efficient frontier and capital allocation line were also created for these portfolios, like in figure 1. However, results are difficult to compare between four different figures. Instead, it may be more intuitive to display all efficient frontiers in one single image to identify the differences between all portfolios more easily. This can be observed in appendix A. It immediately becomes apparent that the slope in the mean-variance efficient frontier for the benchmark portfolio is less extreme. In other words, for every unit of risk taken, the benchmark portfolio provides investors with less expected returns than the portfolios that include cryptocurrency assets.

Furthermore, in appendix B we can see the capital allocation line for all portfolios. Like in appendix A, the capital allocation line is much steeper for cryptocurrency portfolios than it is for the benchmark portfolio. Because the capital allocation line is just a visual representation of the Sharpe Ratio of the optimal portfolio, it is to be expected that the Sharpe Ratio for a portfolio with cryptocurrencies will generally be much higher. This implies that Bitcoin and Ethereum have better risk-return trade-offs than traditional assets and including cryptocurrencies in an already well-diversified portfolio will likely lead to an improvement in its risk-return properties.

As previously discussed, the benchmark portfolio with optimal weights has an expected return of 9,53% and a 5-year volatility of 25,74%. However, the portfolios containing cryptocurrencies have much higher expected returns for each unit of volatility, as can be observed in appendix B. Furthermore, table 5 demonstrates that the inclusion of both Bitcoin and Ethereum simultaneously will lead to a Sharpe Ratio of 0,4353, which is significantly higher than the Sharpe Ratio of the benchmark portfolio. Even so, it is quite evident that volatility drastically increases once cryptocurrency assets are added to the benchmark portfolio. As can be seen in table 5, volatility more than doubles when both Bitcoin and Ethereum are included in the benchmark portfolio. This will cause risk levels of the portfolio to rise. As previously stated, cryptocurrencies tend to provide investors with more expected returns for every unit of risk taken than regular assets. However, the risk-return relationship is not the only factor that should be considered. Once volatility levels of a portfolio exceed a certain level, many investors will lose interest, even if a portfolio comes with large additional returns for every unit of risk taken. Most rational investors do not want to be exposed to volatility levels present in cryptocurrency assets.

Table 5: Optimal performance with and without BTC and ETH.

	No Crypto	BTC Only	ETH Only	BTC & ETH
Volatility	25.74%	45.45%	55.89%	55.15%
Sharpe Ratio	.2301	.3975	.4245	.4352

5.3 Reducing portfolio risk with cryptocurrency investments

In table 6, we can see the optimal portfolios (the portfolios with the highest Sharpe Ratio) below a certain volatility threshold. As expected, allocation to crypto currencies decreases as volatility thresholds decrease. When a threshold of 25% is considered, allocation to cryptocurrencies falls below 3%, with only 0,09% of the portfolio being allocated to Ethereum.

Table 6: Optimal performance with volatility thresholds.

	50%	40%	30%	25%
Sharpe Ratio	.4346	.4268	.3844	.2780
% BTC	8.73%	6.75%	4.39%	2.44%
% ETH	12.05%	8.28%	3.79%	0.09%

In the end, the objective of portfolio diversification is to decrease risk. Unfortunately, this is not an inherent quality of cryptocurrency assets. On the contrary, cryptocurrencies are widely known to be highly volatile, and as such high in risk (Corbet et al., 2019, p. 183; Klein et al., 2018, p. 115). While correlation of Bitcoin and Ethereum with the traditional assets in the benchmark portfolio seems to be low, it appears to not be enough to offset the high amounts of volatility inherent to Bitcoin and Ethereum prices. However, as shown in table 6, when only a small percentage of the portfolio is allocated to cryptocurrency assets, volatility can be kept to a minimum while simultaneously increasing the Sharpe Ratio.

As previously discussed, the optimal benchmark portfolio has an expected return of 9,53% with a volatility of 25,74%. This portfolio has a Sharpe Ratio of 0,2301. As can be seen in table 6, volatility can be decreased to 25% while still increasing expected returns and in turn the Sharpe Ratio. If we want to keep volatility identical to the optimal benchmark portfolio (25,74%), we can increase returns to 11,58% by allocating 2,86% and 0,92% of the portfolio to Bitcoin and Ethereum respectively, which increases the Sharpe Ratio to 0,3097.

To summarise, risk levels of already well-diversified portfolios can be reduced through the addition of Bitcoin and Ethereum. If only a small percentage of the portfolio is allocated to Bitcoin or Ethereum, volatility will decrease while expected returns will rise. If more than 4% of the portfolio is allocated to cryptocurrency assets, volatility will drastically increase. The Sharpe Ratio is almost always higher when cryptocurrencies are included in the benchmark portfolio, because cryptocurrencies have a much better risk-return ratio than traditional assets. Despite this, volatility of the portfolio will be too high for most rational investors when a large portion of the portfolio is allocated to cryptocurrencies. Therefore, cryptocurrency investments should be kept to small percentages in diversified portfolios.

6. DISCUSSION AND CONCLUSION

6.1 Portfolio diversification with cryptocurrency assets: key findings

Answering the research question can provide an insight in how cryptocurrency assets affect traditional asset portfolios. While previous studies have found evidence of the diversification potential of cryptocurrency assets, the asset class is also known to carry a high amount of volatility. The main objective of portfolio diversification is to reduce risk, which may not be a realistic objective with volatile assets like Bitcoin and Ethereum. To investigate this, the following research question was created:

"What is the effect of cryptocurrency investments on the risk level of already well-diversified portfolios?"

In this study, mean-variance spanning was used to determine if adding Bitcoin and Ethereum to a well-diversified benchmark portfolio has any significant effects on the performance of that portfolio. As can be seen in table 3 and table 4, the Wald Test statistic determines that adding the test variables to our benchmark portfolio has a significant effect for both optimal and minimum variance portfolios. In other words, adding cryptocurrencies to an already well-diversified traditional asset portfolio will likely have a positive effect on its risk-return properties. Additionally, spanning tests were executed for Bitcoin and Ethereum separately. These Wald Test statistics are also significant, suggesting that adding either Bitcoin or Ethereum separately will positively impact the risk-return properties of the benchmark portfolio as well. To summarise, the findings of the analysis imply that both Bitcoin and Ethereum significantly span the assets in the benchmark portfolio, which suggests that portfolios which include either one or both cryptocurrencies will have a superior risk-return relationship to portfolios without Bitcoin or Ethereum.

Furthermore, optimal asset allocations were determined for portfolios with and without cryptocurrencies. As shown in table 5, Sharpe Ratios drastically increase when cryptocurrency assets are added to the benchmark portfolio. Including both Bitcoin and Ethereum seems to have the strongest effect on diversification as the risk-return properties are the most favourable for this portfolio. This is also visualised in appendix B using capital allocation lines. However, while risk-return trade-offs are more favourable for portfolios which include cryptocurrencies, volatility seems to drastically increase when Bitcoin or Ethereum is included in the benchmark portfolio. This is contrary to the basic principles of portfolio diversification, which has the main objective to reduce risk.

Despite this, risk may still be reduced if only a small percentage of a portfolio is allocated to cryptocurrency assets, as shown in table 6. While the optimal benchmark portfolio has a 5-year volatility of 25,74% with a Sharpe Ratio of 0,2301, volatility can be reduced to 25% while increasing the Sharpe Ratio to 0,2780 by allocating 2,44% and 0,09% of the portfolio to Bitcoin and Ethereum respectively.

To conclude, adding Bitcoin and Ethereum to already well-diversified portfolios will improve risk-return properties along with the Sharpe Ratio of said portfolio. Including both Bitcoin and Ethereum simultaneously seems to have a stronger effect on risk-return properties than only adding one of these cryptocurrencies separately. As demonstrated by spanning tests, Bitcoin and Ethereum significantly span the assets in the benchmark portfolio. To answer the research question, both Bitcoin and Ethereum seem to drastically increase risk levels of already well-diversified portfolios, which is contrary to the objective of portfolio diversification. Additionally, most rational investors will consider volatility levels of the portfolio which includes cryptocurrency assets to be too high. However, when allocation of the portfolio to cryptocurrency assets is kept to small amounts, portfolio risk levels may decrease, suggesting Bitcoin and Ethereum can effectively be used as diversification mechanisms for reducing risk.

6.1 Limitations of the research

Sharpe Ratios were used in this research as a global measure for portfolio performance. A common criticism for the Sharpe Ratio is that it relies on several estimations and is subject to biases (Gatfaoui, 2015, pp. 3-4, 15). For one, the formula operates based on expected returns instead of actual future returns. Because it is impossible to know the real future returns of an asset, returns are estimated by inspecting past performance and expected future market growth. Therefore, the accuracy of this analysis is highly dependent on the expected returns chosen estimated for each asset. While past performance is generally a good indicator of future asset returns, there is no guarantee that this will hold true in practice.

Furthermore, the Sharpe Ratio uses the standard deviation to measure the risk of an asset, which implies that asset returns are normally distributed. However, this is usually not the case, as the distributions are often skewed. For example, Bitcoin returns are skewed to the right (see Table 1). Additionally, the Sharpe Ratio is highly influenced by measurement intervals. In other words, the outcome of this study may be highly influenced by the timeframe at which price data was collected.

Another limitation of the study is that only three asset classes were incorporated in the benchmark portfolio. The study may have come to a different conclusion if a wider variety of assets was included in the benchmark portfolio, as a more diversified portfolio may be less influenced by the addition of cryptocurrency assets. Furthermore, price data was only collected over a five-year period, which had to be done because data for Ethereum does not exist far beyond this timeframe. Additionally, while the analysis suggests that the addition of Bitcoin and Ethereum to an already well-diversified portfolio will improve its risk-return properties, this conclusion is based on past returns and standard deviations of these assets. The assumption is made that returns and standard deviations will remain at similar levels in the future, but this is not necessarily true in practice. For one, volatility has historically been inconsistent and known to fluctuate highly depending on market conditions.

For the analysis in this study, the Wald Test was used to determine the significance of including Bitcoin and Ethereum in the benchmark portfolio. Multiple tests exist to assess spanning, but they will generally come to the same conclusion (Agresti, 2007, p. 12). However, when samples are not large enough, the Wald Test tends to over-reject the null hypothesis (Brière et al., 2015, p. 9; Schmitz & Hoffman, 2020, p. 14). Because of the inclusion of Ethereum in this study, weekly price data was only collected over a period of five years. A larger sample size may have contributed to the accuracy of the performed tests. Additionally, the application of other statistical tests may have allowed for comparison between different test statistics to obtain a more accurate conclusion.

6.2 The application of the findings for future research

Despite its limitations, this study contributed to the existing literature of mean-variance spanning tests and cryptocurrency price analysis. While spanning tests were previously performed on the addition of cryptocurrency assets to traditional asset portfolios, these studies generally only focused on Bitcoin. With this paper, Ethereum is also included in the analysis. Furthermore, mean-variance efficient frontiers are graphed to provide a clear image on the effect of Bitcoin and Ethereum on risk-return properties of these portfolios. Additionally, a framework is provided for investors seeking to include cryptocurrency assets in their portfolios while maintaining a low amount of risk exposure.

To continue on this research, future studies can focus on widening the scope of the analysis to even more cryptocurrency assets to assess their possible benefits to diversified portfolios. Additionally, a benchmark portfolio can be created that includes a wider variety of assets which have lower correlations for more diversification and a more accurate conclusion. Research can be performed on if the addition of cryptocurrency assets still has a positive influence on the performance of this benchmark portfolio.

Additionally, focus can be shifted back to Bitcoin to open the possibility of obtaining a wider timeframe of price data. This way, sample size can be increase and spanning tests may be more accurate. Another possibility is to incorporate other tests like the Likelihood-ratio Test, and the Lagrange Multiplier Test. Test statistics can consequently be compared to assess any possible differences in conclusions.

7. ACKNOWLEDGEMENTS

As a final remark, I would like to thank my supervisors prof. dr. Laura Spierdijk and dr. Vijay Bhaskar for their assistance in the execution of this study. Additionally, I want to thank the other students who were part of the same bachelor circle for their communication and assistance during my research.

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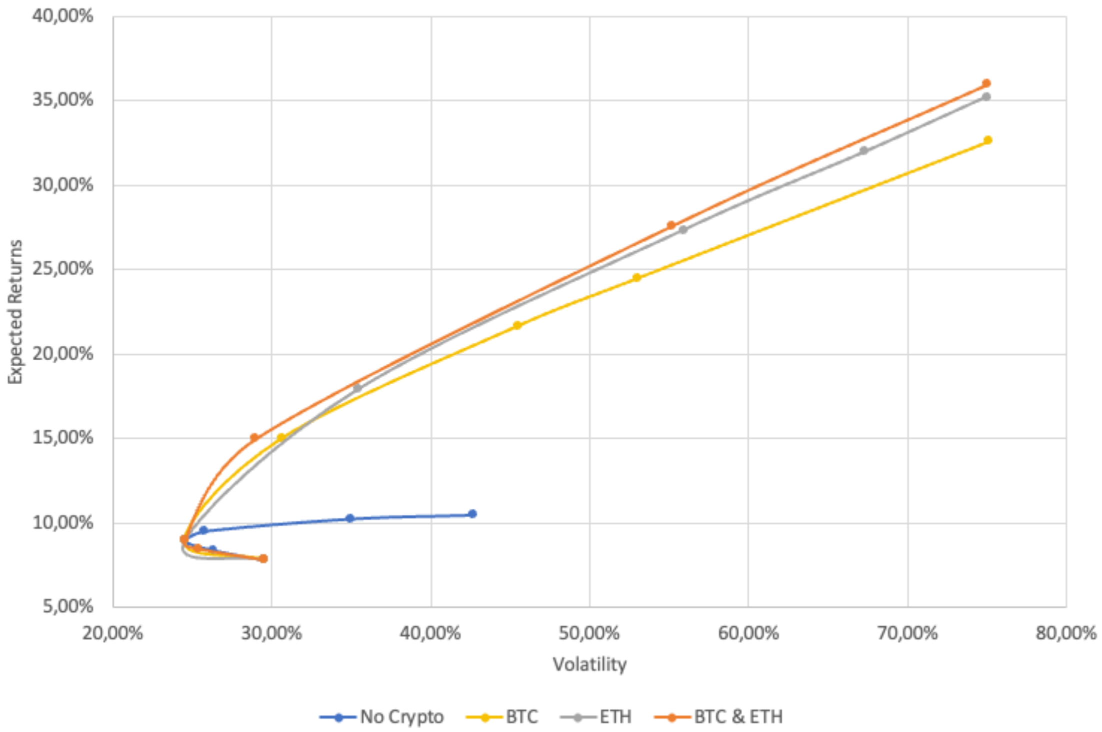
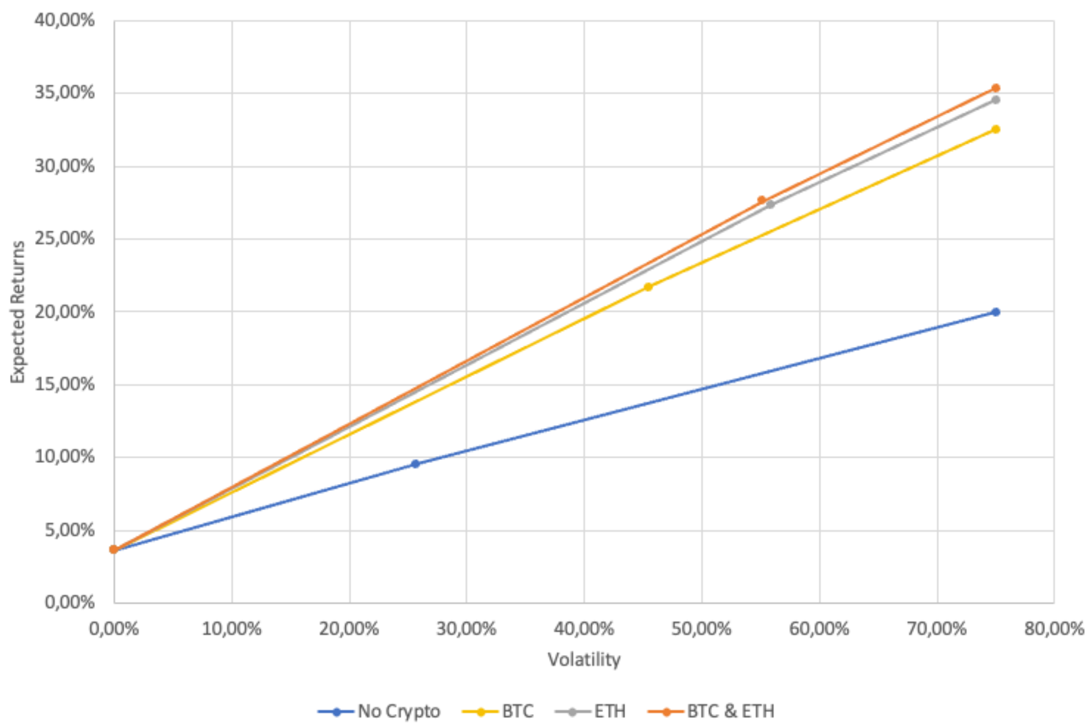
9. APPENDIX



Appendix A: Mean-variance efficient frontier with and without the addition of cryptocurrency assets to the portfolio.



Appendix B: Capital allocation lines with and without the addition of cryptocurrency assets to the portfolio.