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The impact of cryptocurrencies on investment portfolio returns	Kriptovaliutų įtaka investicinio portfelio grąžai

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INTRODUCTION

Cryptocurrencies are a relatively new investment class which has recently gained increasing interest from investors. Even though some cryptocurrency tokens, similarly to fiat money, could be used for payment purposes, they are frequently bought for sole purpose to sell in the secondary market and are often regarded as an investment (Fisch, 2019). Bitcoin and the rest of cryptocurrency market is well-known for its high volatility, though the questions arise on whether cryptocurrencies are here to stay or is it only a temporary bubble-like market that will eventually become obsolete (Subramanian & Rao, 2020). However, cryptocurrency market is expanding and at the time of writing this thesis, has reached approximately USD 2,197 Billion market capitalisation. Though both investors' and researchers' interests are rising in this relatively new market, cryptocurrencies as an asset are currently less researched than other, more traditional asset classes. Thus, there are multiple research directions which could be taken in order to better understand how cryptocurrencies function as a diversifier, hedge against risk or whether it can increase portfolio performance and be bought for long-term investment or only for speculative trading purposes. Although traditional assets may provide a steady return, investors are constantly looking for improved portfolio performance.

The research field expanded after Bitcoin price jump in 2017 and a vast fall during the following year. Researchers have analysed how integrated are cryptocurrencies and other financial assets, including stocks, gold, fiat money and others and the results are indecisive. Researchers, among which are Stubinger (2019), Koutmos (2020), Borgards & Czudaj (2020), Bouri, Das, Gupta, & Roubaud, (2018) find integration between cryptocurrencies and other assets and conclude they cannot be portfolio diversifiers. However, more researchers find evidence that cryptocurrency and other traditional financial assets do not have correlation and can be a good hedging opportunity, among who are Gil-Alana, Abakah, & Rojo (2020), Trabelsi (2018) and Tiwari, Raheem, & Kang (2019). Researchers do also analyse the impact of adding cryptocurrencies to other asset portfolios. Though they do often find significantly increased performance, they also find that its mostly due to the abnormal returns during high price jumps Symitsi & Chalvatzis (2019), Kajtazi & Moro (2019), Guesmi, Saadi, Abid, & Ftiti (2019). Furthermore, most researches consider only Bitcoin returns. Bitcoin is considerably significant within cryptocurrency market and its fluctuations have an impact on other token prices (Bouri, Roubaud, & Shahzad, 2020). Although this token does hold the majority stake in cryptocurrency market share, other tokens are gaining an increasingly significant part as well. Studies by (Symitsi & Chalvatzis, 2019), (Hu, Li, & Shen, 2020), (Kajtazi & Moro, 2019) and other find that adding Bitcoin to a diversified portfolio can bring improved returns, however, only during extreme

cryptocurrency price jumps. However, all of the mentioned researches consider only one token Bitcoin. Hence, it is of interest to assess the expected returns in a portfolio of more cryptocurrencies and during a longer time period. It is also key to compare traditional asset portfolios against investments diversified with cryptocurrencies and the impact on returns.

The problem of the thesis. What is the impact on investment portfolio returns by diversifying with cryptocurrencies.

The aim of the thesis. To evaluate the impact on returns by adding cryptocurrencies to an investment portfolio.

The objectives are:

1. To analyse cryptocurrencies' influence and importance for diversifying Investment portfolio in the existing literature;
2. To analyse research methods conducted in the scientific literature of cryptocurrency as part of an investment portfolio;
3. Based on the conducted analysis, develop a research methodology to measure the impact of cryptocurrencies on investment portfolio returns;
4. Execute an empirical research and evaluate results of cryptocurrency impact on returns in a traditional asset portfolio and provide suggestions based on the research outcome.

Research methods. First of all, the existing literature of cryptocurrencies key characteristics, investment risks and integration with other financial markets is explored and then researches investigating tokens as part of investment portfolio are analysed and systemized. Based on the current studies and their outcomes, the research direction, which is the impact of introducing cryptocurrencies other than solely Bitcoin to investment portfolios, is then examined to contribute with new research results. Then, existing study methods are systemized and model for this thesis purpose is developed. The portfolios are formed based on 4 methods: Equal Weights, Global Minimum Variance Constrained Global Minimum Variance and DCC-GARCH. Based on the derived weights, portfolio returns are measured and performance measures, including portfolio Betas and Sharpe ratios are analysed. Finally, portfolio results are assessed and compared cross-model and cross-portfolio and cryptocurrency impact is outlined.

Structure of thesis. This thesis consists of three main parts. The first part analyses cryptocurrencies as an investment, their characteristics and attributes of cryptocurrency market. Then, it investigates the cryptocurrency market relation to other financial markets and their integration analysis provided by scientific literature. Also, existing literature on investment portfolios diversified with cryptocurrencies are assessed. Then, methods used by other researchers analysing cryptocurrencies in investment portfolios are investigated. Also, the outcomes of earlier

studies are analysed to provide initial insights on cryptocurrencies' ability to diversify traditional investments. Based on described analysis, in the second part of the thesis, a methodology fit for this thesis purpose is selected and its steps are explained in detail. Also, chosen variables are outlined and research limitations are indicated. In the third part, data necessary for the research is gathered and empirical study is conducted. Data are analysed, portfolios including cryptocurrencies are formed and portfolio returns determined. Traditional asset portfolios are then compared with portfolios diversified with cryptocurrencies based on the portfolio performance measures. Finally, conclusions are drawn based on the outcome of the empirical research and recommendations are provided in the end.

1. CRYPTOCURRENCIES AS AN ALTERNATIVE ASSET IN AN INVESTMENT PORTFOLIO: THEORETICAL BACKGROUND

Although first cryptocurrency, Bitcoin, has been created back in 2008, tokens have taken mass interest only in the recent years. The number of researches has increased significantly since 2017, when Bitcoin had first price boom and was widely discussed in the financial markets. However, since the creation of cryptocurrencies till now it is often considered a speculative investment (Subramanian & Rao, 2020). This might be a reasonable implication, considering frequent market bubbles cryptocurrencies create and their high volatility (Symitsi & Chalvatzis, 2019). Also, some investors might not see the underlying value of tokens and argue they do not have the basis to be added to portfolios. Hence, the first part of this chapter will focus on key cryptocurrency characteristics and token development. Further, the risk associated to investment in cryptocurrencies is analysed to evaluate whether investors do consider that benefits might outweigh the current existing risks. Furthermore, the thesis overviews existing market characteristics. It also includes alternative coins along with Bitcoin for a better overview of the whole market. Also, integration with other markets is analysed to find whether other researchers obtain proof that cryptocurrencies could diversify the portfolios and possibly hedge against systematic risk. Next, the focus is on empirical researches including cryptocurrencies in investment portfolios with other traditional assets. Finally, the scientific models used in earlier studies are summarised to find fitting model for this thesis research and develop a methodology to evaluate cryptocurrency performance in traditional asset portfolio.

1.1. Cryptocurrency Development and Key Characteristics

Cryptocurrencies are digital currencies which are built on blockchain technology. Chan, Chu, Zhang, & Nadarajah, (2020) find that cryptocurrency market worth reached over 500 billion US dollars in year 2020. Bitcoin is currently dominating the cryptocurrency market with a highest capitalisation, however there are now thousands of cryptocurrencies created around the world. There is no doubt that these digital coins have offered innovation and ingenuity to the financial industry both as a standalone creation and by giving a push to the traditional financial institutions to offer innovative solutions to their clients. Though cryptocurrencies portray multiple benefits, they also have drawbacks, including, but not limited to lack of governance, speculation and very high volatility (Subramanian & Rao, 2020). In this chapter, cryptocurrencies and ICOs are defined, token market development is analysed and existing literature on cryptocurrencies as an asset for diversification on a traditional investment portfolio is reviewed.

Cryptocurrencies are built on blockchain technology, which enables to have quick, cheaper and decentralised transactions. Blockchain, according to Yoo, (2017) is a distributed ledger technology, where all of the transactions ever made are hardcoded into the system. Any adjustments made to the code would signal an error and due to this, blockchain based services are considered as relatively secure. Nonetheless, it has proven that it is not invincible to sophisticated hacker attacks (Caporale, Kang, Spagnolo, & Spagnolo, 2020). Having that in mind, blockchain still offers a variety of benefits to its users, among which are lower costs and faster services. This technology could also be used by traditional financial institutions, where it would help them reduce transaction, operational, administrative and other costs (Garg, et al., 2020). However, it is still currently mainly used by relatively new and innovative services in the finance industry, such as cryptocurrencies. Cryptocurrencies suggest a new way of payments, which do not require a central institution to oversee them and that could be considered as their main initial goal, which is also blockchain by definition – not having to be bind to financial institutions, governments or any other intermediaries. Without intermediaries, cryptocurrency platforms are allowed to make faster transactions and have lower costs, but they also have their downside: consumers might have less security over their funds.

Cryptocurrency ICO's. The Initial Coin Offering (ICO) is a process where Tokens are created. According to Fisch, (2019) ICO is similar to a crowdfunding device, where new businesses can raise capital for their projects. During an ICO, a company issues tokens to raise funds for the new technology, buildings or their operations. The first Initial Coin Offering took place in 2013, where tokens were issued by company Mastercoin. Since then, tokens have gained quite a lot of interest among businesses, which are keen to raise capital and investors. In comparison, in 2018 first quarter alone ICOs have raised USD 7,8 billion, when a well-known crowdfunding platform Kickstarter has raised only USD 3,9 billion since its start (Fisch, 2019). In a sense, Initial Public Offering (IPO) is similar to ICO, since both provide financing to the issuing company. Nevertheless, when a person acquires tokens, they do not get any share of the company but rather a prospect of early access to the product/technology, that business might deliver (Fisch, Masiak, Vismara, & Block, 2019). This implies that initially tokens carry no value and investors do not have a legal entitlement in a company (Huang, Meoli, & Vismara, 2020). Such approach, combined with the relatively loose regulation of ICOs create a window for speculations. Not all new coin offerings are based on real value projects and as a lot of nonprofessional private investors invest in ICOs, they are prone to increased investment risks, caused by a lack of due diligence (Fisch, Masiak, Vismara, & Block, 2019). According to Gan, Tsoukalas, & Netessine, (2019), in a research of 1450 ICOs, 271 were likely involved in fraud and investors have recorded nearly USD 273 million of losses. Nonetheless, the growth trend in number of new coin offerings and

investors is seen, which from the business perspective allows for an easier and quicker availability of funds and for investors a possibility to diversify portfolios with relatively high-risk assets.

Cryptocurrency characteristics. Indeed, even though cryptocurrencies are currencies which might be used as a form of payments, they are often regarded more as an investment opportunity rather than a currency (Ghysels & Nguyen, 2019). Fiat money are backed by their issuing governments. Their value fluctuates with the demand and supply for currency and one can nearly always expect to be able to exchange the currency for others. Also, fiat money is relatively heavily regulated by their central banks. According to Ali, et. al. (2014) money should possess the 3 main features listed below:

1. **A store of value**. This reflects the ability of a currency to purchase goods/services in the future instead of today;
2. **A medium of exchange** is a possibility to pay with the asset owned;
3. **A unit of account** indicates a capability of money to measure the worth of any item which is available for purchase.

According to researches such as Fauzi, Paiman, & Othman, (2020), it is questionable whether any of the 3 features listed above apply for cryptocurrencies. A store of value and unit of account are particularly peculiar and questionable due to relatively high fluctuations of tokens‘ value, speculations and quite relaxed regulation. However, cryptocurrencies can act as medium of exchange as tokens could be used for purchases, though not extensively yet. Fisch, (2019) finds that most of the coins issued from an ICO could be used as a form of payment within the issuing company only. However, Bitcoin has gained a wider acceptance range. It was firstly accepted as currency in a publishing company WordPress and currently can be used in hundreds of well-known businesses, including Microsoft, Tesla, Expedia and others (Adhami, Giudici, & Martinazzi, 2018). However, so far only very few tokens are supported by retailers. Hence, it raises a question whether cryptocurrencies can be regarded as money as they rarely perform functions of traditional fiat money.

Even if a new token is not widely accepted as a form of payment and investor does not wish or cannot use it for purchases in the issuing company, most tokens can be traded and exchanged in the secondary market after the Initial Coin Offering (Fisch, 2019). Cryptocurrencies are widely considered more as an investment nowadays rather than a currency, as people usually buy and hold tokens with the expectation to sell tokens on exchange at an appreciated price. Cryptocurrencies were defined as a new asset class by Corbet, Cumming, Lucey, Peat, & Vigne, (2020). Using tokens for trading purposes, investors anticipate growing returns on their investment, and the returns can be quite significant if the underlying technology is successful. However, according to Momtaz, (2020) 39,5% to 45,7% out of all ICO’s follow with negative returns on the

first day, which results in a lost value for the investors. Also, about 21% of the tokens get delisted from a major trading platform, which could at times reflect a scam behind a project, not enough trust from investors or simply a failure of the project (Momtaz, 2020). Hence, investing in ICO's can be relatively risky for non-professional investors as they are often volatile and speculative purchases (Domingo, Chousa, & Cabarcos, 2020), Corbet, et al. (2020). Various studies have examined possible success and failure factors of ICO, which impact the prosperity of the investment and can help investors evaluate the validity of tokens. Gächter & Gächter, (2020) finds there is a strong timing relation to the success of ICO, showing that amount raised increased if the ICO finds the right time spot to initiate the offering. Fisch, Momtaz, (2020) shows that backing by institutional investors lead to higher post ICO performance, which, they argue, might be the result of better due diligence and screening practices by these professional investors. Also, transparency on social media can lead to better results (Domingo, Chousa, & Cabarcos, 2020). Indeed, a research by Mai, Shan, Bai, Wang, & Chiang, (2018) showed that Bitcoin price fluctuations are heavily impacted by sentiments available on social media. Hence, as more information is provided on these channels, more investors can be interested in the project and invest. These features are important for investors looking for portfolio diversification and choosing tokens as an alternative. However, all researchers agree that it is a highly speculative asset class and investors should have extra care when choosing to invest in cryptocurrencies.

1.2. Cryptocurrency Investment Risk and Benefits

The stock market is quite heavily regulated both by laws and regulations and also by different Stock exchanges where equities trade. However, as cryptocurrencies are relatively new in the financial markets and decentralized by definition, few countries have imposed regulations adjusted specifically for cryptocurrency market yet, though it is becoming increasingly globally accepted. Cryptocurrency exchanges are relatively easy to establish and they are not as clustered as stock exchanges. There are a few main stock exchanges in the world, covering all major financial markets. According to their Market Capitalization, 5 largest ones are: New York, NASDAQ, Shanghai, Hong Kong and Shenzhen Stock Exchanges. These establishments take millions of trades each working day, generating trillions in value. According to Bagheri & Nakajima, (2004) stock exchanges are succesful partly due to transperancy and due to the fact that they are centralised. However, if we look at cryptocurrencies, they are decentralised by definition and their exchanges are currently quite less regulated. It is suggested by Collomb, De Filippi, & Sok, (2019) that if Securities and Exchange Commission (SEC) would register and regard cryptocurrency exchanges in the same way as security exchanges there would be a significant improvement in the current regulation setup and it could solve a significant amount of issues

surrounding token exchanges. Some of the largest issues for cryptocurrency exchanges are high rate of bankruptcy, hacks into their systems and weak transperancy. According to research conducted by Chu, (2018), approximately 45% of cryptocurrency trading venues fail. In addition, it is often the case that after they go out of business traders do not get their investments back either because platforms do not keep the necessary reserves, which can be attributed to a lack of common regulations, or a part of the funds were hacked into and stolen. One of these cases happened in 2014, when platform Mt. Gox, which was also one of the largest ones at the time, has been hacked and, according to Edwards, Hanley, Litan, & Weil, (2019) approximately one billion dollars of investors value were lost. It is noted by Chu, (2018), that clients investments were used to fund Mt. Gox's own operations. Cases like this creates uncertainty for the investors wishing to diversify their portfolios with cryptocurrencies and might be one of the reasons why institutional investors are still reluctunt to direct funds to cryptocurrency market. Nevertheless, even though there are visible issues with these exchanges, private investors are still willing to use them for investment as they are also relatively easy and quick to set-up, understand and start investing. Hence, investors are willing to take the risk of uncertainty and currently a lower level of regulation to diversify their portfolios with cryptocurrencies.

Having less regulation arguably defines cryptocurrency tokens as a rather speculative and highly volatile asset class (Scheau, Crăciunescu, Brici, & Achim, 2020). There are cases when there is a legitimate technology behind ICO and the crowdfunding via token issue simply fails, though unfortunately, some of the tokens are created specifically for fraudulent pusposes. Those are cases such as scam by Ifan and Pincoin, which is considered to be one of the largest, where USD 650 million were stolen for GainBitcoin scheme, which took USD 300 million from investors without any return (Corbet, Cumming, Lucey, Peat, & Vigne, 2020). Both of the mentioned schemes had promised investors specific returns on their funds, however, they never delivered. Also, there is a relatively high number of speculative trades in the cryptocurrency market, which might impact their price. It was found by (Gandal, Hamrick, Moore, & Oberman, 2018) that suspicious trading activity on crypto exchange had an impact to rising Bitcoin price and returns. In addition, Scheau et al. (2020) and (Caporale, Kang, Spagnolo, & Spagnolo, 2020) find that cybercrime and hacker attacks also have a large influence on the development of cryptocurrency markets, which usually lead to lower returns and monetary losses for investors. It is agreed by Gandal et al. (2018), Scheau et al. (2020), Chu (2018) that a key cause of these main cryptocurrency issues listed above is due to poor regulation and that cryptocurrencies should be regulated similarly to other asset classes, such as stocks. These issues are discussed by regulating authorities, however, as cryptocurrencies are relatively new to the market, they are yet to set a clear governance. There are general rules set for cryptocurrency market, though arguably, they

could be stricter (Anson, 2018). Main arising issue is that tokens do not have a clear definition which asset class they belong to. Cryptocurrencies are increasingly defined as securities, but laws are not yet established to be the same as for stocks, bonds, etc. (Collomb, De Filippi, & Sok, 2019). At the time this paper was written, one of the largest cryptocurrencies Ripple was just charged by the SEC for issuing unregistered securities (SEC, (2020)). There are speculations this could mean a start for stricter regulations for more tokens, however, Ripple is not charged yet. Collomb, De Filippi, & Sok (2019) find, that due to existing large differences in token regulation among different regions, there might be "regulatory arbitrage" opportunities. That might be a window of opportunity for increased speculation among token issuers. Although adding cryptocurrency tokens to their investment portfolios is rather new for many investors and it does bring considerable risks, however, there are possible upsides to such diversification.

Investors know that increased investment risk usually means a possibility of higher returns. Indeed, there are plenty benefits to the cryptocurrencies, hence the increased attention and interest from the financial markets and investors. Below are some of the upsides which Chuen, Guo, & Wang, (2018) have identified for Bitcoin, but they can be attributed to most cryptocurrencies:

1. **Speed.** Transactions involving cryptocurrencies are completed very fast and funds can be usually transferred within minutes.
2. **Transparanc**y. Since all transactions are posted to the whole cryptocurrency network, they are all kept within blockchain and all miners can access them.
3. **Low transaction fee**s. There might either be no costs to make a transaction or a relatively low cost if one wished to make a faster transaction.
4. **Flexibility**. It is easy to set up a wallet for cryptocurrencies and they are not location dependent.
5. **Decentralization.** This might be both a benefit and a drawback. Due to decentralization it is possible to have cheaper and faster transactions. However, as previously described, it also brings risks for possible market manipulations and speculation.

All of the attributes mentioned above draws the attention of investors, who either wish to use cryptocurrencies as a medium of exchange or wish to sell tokens in a secondary market, as the technology itself is promising. Hu, Parlour, & Rajan (2019) finds in the study, that buying a cryptocurrency during an ICO and selling it in the secondary market after month can give, on average 20.000% return, when buying and also selling in the secondary market gives investors approximately 46,3% return. They do note that results are largely skewed, however, it does show prospect that an early jump on board could bring relatively large returns. If we take a look at Bitcoin, according to data retrieved from Coindesk when it first started trading in 2010 it sold for

USD 0,07. Currently, at the start of 2022 it is trading above USD 41.000,00, which is indeed a very large upside, though it has not received such investor attention from the very start. Bitcoin had first increased to USD 900,00 in 2014, stayed approximately flat until 2017 when it reached USD 17.000,00 and then dropped again to USD 3000,00. It does show there is quite a large unpredictability in the cryptocurrency market, as returns drop and rise at a relatively high rate. Though, given the right time, one can earn a large profit from investing in Cryptocurrency market. Certainly, not all tokens are successful, Adhami, Giudici, & Martinazzi, (2018) find that around 19% of tokens fail during their ICOs, meaning they do not get the minimum funding required, but that brings 81% rate of successful ICOs, which is relatively high.

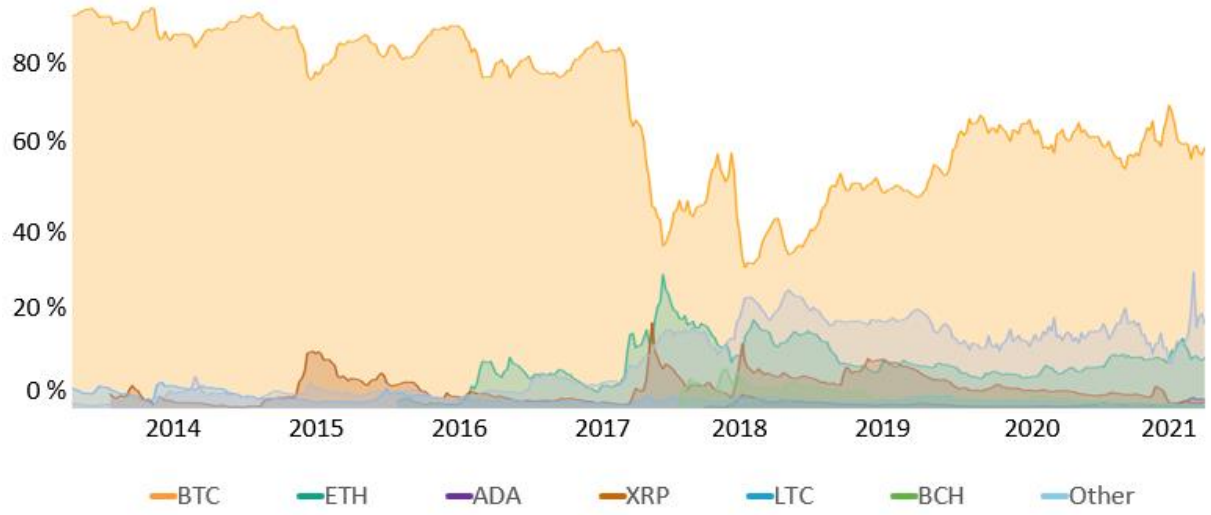
Cryptocurrencies do have their risks but they also bring a possibility of increased returns given that the right time and projects are chosen to invest in. Trading tokens do have similarities when compared to trading stocks and in both markets increased risks usually anticipate a prospect of higher returns. A stock market is well established while tokens' secondary market is relatively new, though it is gaining investor interest at an increasing rate. Hence, it is important to analyse how tokens can diversify investment portfolios and whether they could be a valuable enhancement to investors.

1.3. Cryptocurrency Market Development and Relation to Other Financial Markets

Cryptocurrency tokens have gained increasing attention in the financial industry from investors. However, it has only recently expanded to current lengths and has not always been seen as a possible asset for diversification. The first cryptocurrency created was Bitcoin. It was described in Nakamoto (2008) whitepaper, which might be a single person pseudonym or a group of people – that is unknown to this day, as person/people behind pseudonym were never found or identified. Nevertheless, Bitcoin changed the financial industry by introducing a new way of finance. At the time of writing this thesis, the approximate Market Capitalisation of Bitcoin alone, according to CoinMarketCap is USD 868 billion. As Subramanian & Rao, (2020) suggest, Bitcoin is a peer-to-peer platform, allowing to make transactions directly between people. According to Warren, (2020) Bitcoin can be mined by using processing power of a computer. Using this way, one would mine coins and there is a limited amount of Bitcoin to mine, that is 21 million coins. Bitcoin was also the first token which started trading. According to Reuters data, number of existing tokens from 2014 to the start of 2017 was, on average, above 500. Tokens, as a means of investment acquired a great deal of interest when Bitcoin, currently the largest token by market capitalisation, has gained a 1900 % value increase in 2017 alone. After this boom, other tokens also gained increasing attention and the number of tokens grew to above 2000 by the end of 2018.

Figure 1

Market capitalisation of largest cryptocurrencies



Source: coinmarketcap.com

Market capitalisations of other tokens have followed this trend, which can be seen in Figure 1. Here, 6 largest cryptocurrencies listed on CoinMarketCap are depicted by the percent of the market they take. "Others" are all other tokens listed and their cumulative market share. Bitcoin dominance is depicted by orange marked field. It can be seen that it had a large drop in the market share in 2017 when other cryptocurrencies gained increased attention. "Other" cryptocurrencies show a large growth starting from 2017, their combined value have surpassed Ethereum in 2018, which is the 2nd largest cryptocurrency. This movement reflects increased investor interest in other tokens, however, a clear market control of Bitcoin can be seen. Bitcoin price movements and changes in its market capitalisation has a great effect on total cryptocurrency market. Bouri, Roubaud, & Shahzad, (2020) study shows that an increase in Bitcoin price often leads to gains in other large cryptocurrencies. They find that about 20% of all Cryptocurrency variations can be explained by Bitcoin price movement. The effect is shown to be especially strong for Ripple and Litecoin. Hu, Parlour, & Rajan, (2019) also find that Bitcoin returns have a heavy impact on other tokens' returns in the secondary market. (Smales, 2020) also discovered by forming a cryptocurrency portfolio, that most of the returns can be explained by Bitcoin returns. Authors argue, this might create large issues should a large portion of Bitcoin be acquired by a few large institutional investors. Then, they could have a control over the whole tokens market and if they liquidate their holdings, market might come to a crash. This also creates issues for smaller cryptocurrencies, as it might show a lack of interest or trust in the individual projects behind tokens, considering that large part of all prices is impacted by Bitcoin. It raises a question about possible

future performance of cryptocurrency market and its stability. Subramanian & Rao (2020) argue that Bitcoin price will eventually become 0. Considering that token market is highly dependent on this cryptocurrency, means it could crash and come to a halt if this scenario comes through. Nevertheless, at the time of writing this thesis Bitcoin is soaring to new heights and its price has climbed over USD 40.000, which draws increasing attention from investors. However, this might be another movement similar to a price bubble, which was found at the Bitcoin crash of 2018 by Malladi & Dheeriya, (2020). Indeed, when the price of Bitcoin soared by the end of 2017 bringing large returns to investors, it quickly came down to approximately a third of its high price in 2018. Hence, Corbet, Cumming, Lucey, Peat, & Vigne, (2020) and Subramanian & Rao (2020) regard cryptocurrencies as highly volatile and speculative assets.

It is of interest for researchers to find how similar cryptocurrencies are to other asset classes and whether token prices are impacted by those assets. In other words, how integrated cryptocurrency market is with other, rather traditional financial markets. Borgards & Czudaj, (2020) find that although stock markets and tokens are largely different, both of these markets are prone to Overreactions, showing signs in similarity between investor behaviour. Stubinger, (2019) finds by analysing S&P market index and Bitcoin, that stock markets hold considerable amount of information about future cryptocurrency returns, showing there might be integration. The author also considers this finding to show considerable doubt for Efficient Market Hypothesis. Furthermore, Koutmos (2020) portray that implied Forex and stock market volatilities are significant determinants of Bitcoin returns. On the other hand, Isah & Raheem (2019) show that tokens can predict stock prices rather than other way around. Bouri, Das, Gupta, & Roubaud (2018) unveil evidence there are spill overs between Bitcoin and other asset classes, strongest of which were commodities, thus showing that cryptocurrency market is not isolated from others. However, there are other studies conveying that cryptocurrency markets are not related to others and could be a great option for hedging. Gil-Alana, Abakah, & Rojo (2020) finds that cryptocurrencies can be set apart from other key financial assets as they found no cointegration with them. Hence, the authors claim tokens could be a good diversifier. Also, Trabelsi (2018) finds no spill overs between cryptocurrency and other widely traded asset classes, such as commodities, fiat money and stock indices. Tiwari, Raheem, & Kang (2019) in an empirical analysis find very low correlations with the stock market, also indicating that tokens could act as a hedge in a portfolio. Considering these studies, it is clear there is no joint common opinion of how these relatively new cryptocurrency markets relate to other, more traditional and common financial assets. The results may vary based on the time period of researches, the cryptocurrencies and assets chosen. Also, often Bitcoin is chosen as a sole cryptocurrency to reflect cryptocurrency market, which, as discussed earlier, might not reflect the whole market, because other cryptocurrencies are currently increasing their

market share. Though, on the other hand, Bitcoin still dominates among all cryptocurrencies and Bouri, Roubaud, & Shahzad (2020) find its returns also impact other token prices.

Another point of interest for investors is the possible returns from cryptocurrencies as an investment. Multiple authors have analysed portfolio returns with addition of cryptocurrency to portfolio of traditional asset classes. However, most of them usually add Bitcoin alone to represent the whole cryptocurrency market. Subramanian & Rao (2020) find that Bitcoin does not act as a suitable hedge against most asset classes including S&P index and Crude Oil due to high volatility and price shocks. The authors argue Bitcoin is too speculative and that it is one of the largest price bubbles. Kliber, Marszałek, Musiałkowska, & Świerczyńska (2019) also found Bitcoin to be a weak hedge for stock markets in various countries which largely differ by their economic situation. Furthermore, Symitsi & Chalvatzis, (2019) depicts that although Bitcoin can bring extensive returns, that can only be done if bought at a very specific time and held during a price jump. However, the study shows that it does not prove to be a good hedge for long-term portfolio diversification, since the risk is not offset by its volatility. A similar observation is made by Hu, Li, & Shen (2020), who find that incorporating Bitcoin into stock portfolio will benefit the portfolio only when extreme returns and price increases are identified and Bitcoin is obtained at this point. On the other hand, Kajtazi & Moro (2019) shows that Bitcoin can be a great hedging opportunity, though not through volatility reduction but rather through increased returns. This study also shows that Bitcoin is a highly speculative asset hence, it might not always be a good cryptocurrency for long-term hedge as the returns highly fluctuate and its performance is evaluated as bubble like. On the other hand, Guesmi, Saadi, Abid, & Ftiti (2019) find that a short position in Bitcoin provides a well hedging position against different asset classes among which are gold, equities and oil. They find that the reason for it is low correlation with other financial assets and high average returns. Furthermore, Mariana, Ekaputra, & Husodo (2020) find that Bitcoin can be a safe-haven for S&P500, but only for short-term. Hence, the outcomes and observations are conflicting, though all of the evidence obtained agree that Bitcoin is a highly volatile and speculative asset. It is mostly valued in portfolios for its ability to showcase vast returns, however, due to volatility Bitcoin does not safeguard against investment risk.

Even though Bitcoin is by far the largest cryptocurrency, well known and often chosen by investors, it might not reflect the whole token market bearing in mind that other cryptocurrencies are gaining increasing popularity. There is a significantly lower amount of research which consider other cryptocurrencies apart from Bitcoin as part of the investment portfolios. Bouri, Shahzad, & Roubaud (2020) analysed 8 large cryptocurrencies to identify which could be considered as safe-haven or hedging options. They find Stellar, Ripple and Bitcoin to share similar safe-haven properties against US equity indices, while Nem, Dash and Ethereum are found to be hedges

against US equity sectors. The authors argue these findings show that US equity investors can benefit from diversification with cryptocurrencies and could improve their returns. Furthermore, Sheets & Xiaoqiong (2019) by assessing 10 cryptocurrencies also find that cryptocurrencies can bring significant returns compared to US stock indices. However, it is suggested that only risk seeking investors should consider tokens for investment purposes, as the returns can reach 50% one month and fall by the same amount during the following one. Hence, it is often noted by studies that only risk seeking investors should consider diversifying their portfolios with cryptocurrencies. Nevertheless, current studies do suggest that cryptocurrencies can enhance the performance of an investment portfolio, however currently, there are limited studies considering other cryptocurrencies apart from Bitcoin for diversification.

Trading stocks do portray similarities to trading cryptocurrencies. They are both traded on exchanges and are considered as relatively high-risk assets. It is also found by Stubinger (2019) and Bouri, et. al. (2018) that both cryptocurrency and stock markets can be related and some information on the future token returns are explained by stocks. Usually, other traditional assets are considered as well in order to measure the cryptocurrency influence on a truly diversified portfolio. Fiat money are commonly considered as well, as they are the closest asset to cryptocurrencies by definition, even though they usually deteriorate in purpose as earlier discussed. Also, gold is commonly chosen as it carries relatively lower investment risk and is quite common between investors wishing to diversify their portfolios and risk. All of the assets mentioned were included with cryptocurrencies in studies such as Subramanian & Rao, (2020), Trabelsi (2018), Gajardo, (2018), Symitsi & Chalvatzis (2019), Bouri, et. al. (2018), Guesmi et. al. (2019), Kajtazi & Moro (2019). However, most of these studies have considered solely Bitcoin to reflect the cryptocurrency market and including a larger sample of cryptocurrencies could portray different results and provide further insights.

1.4. Cryptocurrencies in Investment Portfolios

As it is outlined in the previous sub-chapter, there are few studies which include cryptocurrencies other than Bitcoin in their return analysis. However, among those exploring multiple cryptocurrencies and solely Bitcoin, there are also few which analyse the economic impact of cryptocurrencies on the portfolio. As outlined before, studies often research the level of cryptocurrency market integration with other markets, though not their performance. To study the impact of tokens as an investment, a portfolio should be formed to begin with. The Modern Portfolio Theory (MPT) was found by Markowitz (1952), where the theory was developed and key characteristics described. In the mentioned paper, researcher explores how to reach maximum returns with the appropriate level of risk. Thus, when investing in Financial Market, increased risk

usually means possibility for higher returns and Markowitz explores how to lower investment risk to the extent possible while also maximizing returns. Markowitz, 1952 finds that diversification is extremely important for a well-constructed portfolio. Choosing several assets from an asset class can help minimize the risk associated to specific investments, furthermore, there is a possibility to diversify across different asset classes. Although systematic risk would remain, the overall portfolio risk is possible to manage. The variance of returns is described as risk in the mentioned research. This depicts, that ability to minimize variance would decrease the portfolio risk, provided that it is combined with including diverse assets which subsequently can then provide increased returns and a well-put portfolio. However, cryptocurrencies are known to be quite volatile and, thus, risky assets (Symitsi & Chalvatzis, 2019), (Hu, Li, & Shen, 2020). Thus, it is of interest to study whether the high volatility added by cryptocurrencies can be offset by increased returns. Also, Markowitz, (1952) suggests evaluating correlation between portfolio assets. Correlation helps identify how assets are related to each other in a single portfolio. It provides an insight to whether assets are affected by the same information, if they are affected by the same systematic risk. It can also guide whether particular investments could assist in hedging against some of the risks. Overall, to form an optimal portfolio, it is suggested to choose the assets to obtain a lowest portfolio volatility with largest returns.

However, once the portfolios are formed, they should then be further analysed to draw conclusions which of them are performing better than others and which could be the preferred choice for the investor. One of the measures to do that is portfolio standard deviation. This measure is often used in scientific research, also when studying cryptocurrencies in investment portfolios, examples are Tiwari, Raheem, & Kang (2019), Sheets & Xiaoqiong (2019). The portfolio standard deviation usually measures the volatility of portfolio returns. These statistics can then be compared cross-portfolio and the lower the measure is, the less risk portfolio carries. Portfolio Betas are another often used measures for financial data and evaluating portfolio performance. Betas show how well portfolio performs compared to the overall market risk. It would be expected that cryptocurrency portfolio Betas would be larger than traditional asset portfolios due to high volatility. One more often used metric for portfolio performance is Sharpe ratio. This ratio was developed by William F. Sharpe. It considers both the returns and risk of each portfolio (Sharpe, 1964). Sharpe ratio is often used to compare cryptocurrency and traditional investments, it was employed in Symitsi & Chalvatzis (2019), their study finds higher Sharpe ratios in Bitcoin portfolios compared to traditional assets. Also, Sharpe ratios are used in Kajtazi & Moro, (2019), who find better Sharpe ratios in most of their analysed Bitcoin portfolios. Since Sharpe ratio compares and combines both the portfolio risk and returns into one measure, different portfolios

can be compared quite well with each other in regards to two of the most important factors for investors.

However, it should be mentioned that in order for portfolio measures to work markets should not be strongly efficient. The Efficient Market hypothesis was analysed by Fama, (1969), who described three possible forms of market efficiency: weak form, semi-strong and strong forms. In the weak form of market efficiency, securities would reflect only the historical company data in stock prices; semi-strong form would imply that stock prices reflect both historical and current available information on securities; strong form implies that all historical and all current company-related information is reflected in security prices, hence there could not be any insider trading (Fama, 1969). If strong form of market efficiency would exist in the market, it would not be possible to make any excess returns, as all the fundamental information of the company would always be reflected in security prices. However, there are various studies denying existence of strong market efficiency. One of the reasons is there could not be any abnormal returns or bubbles in the market, however, as discussed earlier in this thesis, market bubbles for cryptocurrencies are quite frequent. Also, tokens are not an exception within the market – other securities are also prone to market bubbles. E.g. the financial crisis would not have been able to form if markets were strongly efficient, as the securities would have been valued correctly from the start. Hence, it is worth analysing and finding the most optimal strategy for portfolios, as excess returns can be earned. This is especially relevant for cryptocurrencies, where returns are quite volatile and there are various possibilities for gaining high returns. However, downturns can be just as significant.

Cryptocurrencies, compared to traditional investments are less explored in the context of portfolio investments. Nevertheless, they have gained more interest following the price jumps of Bitcoin. In the study by Petukhina, Trimborn, Härdle, & Elendner (2021), the researchers have firstly differentiated portfolios by the type of investor: diversification seeking, risk-averse and return-maximizing. They find that investors who wish to minimize risk would get the least benefits of including cryptocurrencies to their portfolios. This is an expected result, since tokens are highly speculative and risky assets. The research outlines that risk-averse investors would choose mostly traditional assets to invest in and leave cryptocurrencies out of the portfolio. However, it is found that inclusion of cryptocurrencies for risk-seeking investors are beneficial: they produce increased returns and diversification. Another finding was that diversification across cryptocurrencies, not only among traditional asset classes, are also beneficial for increasing portfolio performance. However, it is noted that too much diversification will also limit portfolio efficiency, hence there is no need to over-diversify in order to achieve good portfolio measures and results. Platanakis & Urquhart (2020) also find that addition of cryptocurrencies adds substantial benefit to portfolios. This research focus is on adding Bitcoin to stocks and Bonds portfolio. They find that risk-adjusted

returns in portfolios including Bitcoin always outperform traditional asset portfolios. Also, Bitcoin had the largest share in their studied portfolios, which is contrary to the traditional portfolio theory. On the contrary, the research by Tavares, Caldeira, & Júnior (2020) find that returns where not enhanced when cryptocurrencies were introduced to a stock-only portfolio. These portfolios did not outperform the non-diversified ones and in some cases, even underperformed. Portfolios including tokens produced lower Sharpe ratios and diversification did not increase returns or performance. However, this research also aligns with others in finding that traditional methods usually do not include cryptocurrencies when optimizing portfolios as they tend to minimize risk. Castro, Tito, Brandão, & Gomes (2020) have researched a way to provide a better model for portfolios including cryptocurrencies, as mentioned earlier, it is a usual case for cryptocurrencies to end up with insignificant weights in a diversified portfolio by using the traditional portfolio theories, which minimize variance. The mentioned research has instead opted for a different approach and have applied the Omega measure, which, according to the research paper, is more comprehensive and better suited for portfolios which include cryptocurrencies. The results of this research reflect that cryptocurrencies do improve the financial returns of portfolios however, they also increase the risk, which may not be suitable for risk averse investors. The study has also looked at and evaluated cryptocurrency-only portfolios. These have not provided definitive results on what weights should be used to obtain most optimal result. Nevertheless, it was confirmed that asset weights, which provide good Sharpe-Omega ratios should be opted for. Hence, there are contradicting findings when it comes to evaluating cryptocurrencies in traditional asset portfolios. On one hand side, all studies confirm that cryptocurrencies do increase the volatility and hence the risk in the portfolio, however on another, they usually also provide a prospect of higher portfolio returns. When it comes to portfolio formation, the studies based on portfolio theory usually include either insignificant cryptocurrency weights in a portfolio or none at all. It is confirmed by all mentioned studies that risk-averse investors would not be suggested to invest in cryptocurrencies.

To sum up, a large portion of researches investigating the impact of cryptocurrencies in a portfolio usually include only Bitcoin and also a relatively short period of time. It is of interest to enhance the former studies by introducing other cryptocurrencies in traditional asset portfolios to investigate if there is a difference between their portfolio performance. It is expected, that based on the Portfolio Theory, cryptocurrencies will have a small stake in the traditional asset portfolios due to their high volatility – this is also confirmed by the studies analysed before. Hence, if this research data results produce such outcome, it should be accommodated for to be able to properly investigate the cryptocurrency benefits or drawbacks in the portfolios formed. Also, a longer time period might produce different outcomes, as it will not be focused on bubble periods only but

rather have a wide range of returns, allowing to better investigate the dynamics of cryptocurrency investments. Hence, the produced results and portfolio measures could be more widely applied and considered. In addition to this, studies primarily focus on cryptocurrency inclusion to Stock portfolios, but it is of interest to also evaluate what impact it would have on a more asset-wise diverse portfolio.

1.5. Cryptocurrency Portfolio Model Analysis

Although scientific research of cryptocurrencies in investment portfolios is still relatively limited, the field is expanding. Number of studies have been rising since Bitcoin price boom in 2017. Hence, the following part will analyse studies performed by researchers and the models they have used to analyse cryptocurrency impact on portfolio.

Scientists, analysing cryptocurrencies' impact on investment portfolios have used various econometric models depending on a specific scientific problem. Most authors, as mentioned earlier, analyse whether cryptocurrencies could be good diversifiers, safe-havens or hedges. In these studies, a commonly used method is GARCH and its variations. In the studies carried out by Subramanian & Rao, (2020), also Guesmi, et. al. (2019) exponential GARCH is applied to capture the volatility of Bitcoin and then DCC GARCH model to verify whether Bitcoin can be a good Hedge for portfolio. The former mentioned authors specifically analyse if Bitcoin could hedge against four traditional asset classes, measuring the cross-asset volatility. Authors find that Bitcoin was not an optimal choice in their research and would not be included in the analysed portfolios. Also, Guesmi, et. al. (2019) investigate the spill-over effects between Bitcoin and traditional assets, analysing whether Bitcoin could be a good hedge and diversifier. This research finds Bitcoin to hedge the portfolio well, compared to including traditional assets only, also, they find that including Bitcoin will reduce the overall portfolio risk. A very similar approach was also used by Tiwari, et. al. (2019), though this research was conducted with ADDC-EGARCH. They also contribute to the evidence that Bitcoin is a great asset for hedging against risk with other assets, in this case the stock market. The mentioned research focus is solely on the S&P 500 index with cryptocurrencies. The mentioned study also finds Litecoin to be an effective hedge against index risk. Stubinger, (2019) applied optimal causal path algorithm and found it to be a fit model for identifying S&P 500 returns, which then outperformed cryptocurrencies even during their price rise. VAR method is used by Trabelsi, (2018) and also spill over index to measure the volatilities and possible spill overs between cryptocurrencies, stock markets and commodities. Researcher finds cryptocurrencies to have little to none systematic risk, which is deemed attractive to investors, as it can be a good diversifier. Similarly to the mentioned research, Bouri et. al. (2018) also analysed spill overs between Bitcoin and other assets, however, they have used VAR-asymmetric

GARCH method. The mentioned study finds some existing spill overs between Bitcoin and other asset classes returns. As can be observed in this analysis, key cryptocurrency analysed in most studies is Bitcoin alone. The most common model to test whether these tokens could be hedges, safe-havens or diversifiers is GARCH. However, it is of interest to find which portfolio strategies can bring improved returns when including cryptocurrencies.

Thus, there are a few studies which measure the return change after adding cryptocurrencies to a portfolio. Sheets & Xiaoqiong (2019) have analysed a few cryptocurrencies with stock market indices, by comparing their returns and most common statistical measures. They find that cryptocurrencies are extremely volatile and there are major variations in their performance, which concludes they can bring an upturn of 50% in returns during one month and decrease by the same percentage during the next one. Furthermore, an extensive research was done by Symitsi & Chalvatzis, (2019) to evaluate the economic impact of cryptocurrency returns on a diversified investment portfolio, firstly by carrying out multivariate GARCH method to analyse volatilities between the assets and then goes further to investigate economic returns. The study finds Bitcoin to add tremendous diversification benefits, both in terms of returns and portfolio measures, such as Sharpe ratio. The research also finds transaction costs to not take a toll on the economic gains. There are very few studies analysing the returns apart from volatility research to identify the economic impact of cryptocurrencies in a traditional asset portfolio. This is where the study may contribute in addition to considering more cryptocurrencies than Bitcoin alone.

Investors might be interested in the possible upturn or loss of returns by adding cryptocurrencies to their portfolios. So far, there has been only few studies mentioned above analysing such cases. Most empirical studies analyse token volatility and the possibilities of using these investments to hedge the risk of other assets or measure cryptocurrency volatility. Also, the key focus point of most studies found are solely focusing on one cryptocurrency – Bitcoin. Even though it is the largest cryptocurrency and well-known among investors, it is worth investigating whether other tokens could have either similar or better performance in a given portfolio. Furthermore, the outcomes of the studies described do not provide definitive answers – part of the studies results show Bitcoin to be a great diversifier against systematic risks and most market securities. However, others find the mentioned token to add excess volatility and deviations to the portfolio, which do not pay-off for the given returns.

To sum up the first chapter, cryptocurrencies provide a new, digital way of finance by employing blockchain technology. Currently, cryptocurrencies have not reached the level of most traditional investment yet: they are not accepted worldwide as payments, not all countries have regulations in place to overlook the market and tokens carry large investment risks with frequent market bubbles. However, they do have benefits to the investors: trading is quick and easy to set

up, there are possibilities for large upturns given the right investing time, market is constantly expanding and transaction fees are relatively low. Although Bitcoin is by far the largest capitalisation cryptocurrency, there are a few others which are also taking lead places. There are multiple authors analysing the integration of cryptocurrency and other financial markets. The results of such studies provide multiple outcomes, where few find that Bitcoin is integrated with most of the securities, while others show it might be a fit diversifier against systematic risk. Also, the research field of returns by adding cryptocurrencies to traditional asset portfolios is relatively small and heavily focused on Bitcoin alone.

This research can contribute to the existing empirical researches by adding a few dimensions in the research. Firstly, more cryptocurrencies than solely Bitcoin shall be added and the portfolio performance evaluated. Cryptocurrency market has shown that not only Bitcoin should be considered for the overall market performance. Secondly, the time-range is usually quite small in the analysed studies, thus a larger timeframe will be considered. Then, apart from cross-volatility analysis, the portfolio returns will also be obtained along with measuring the performance measures. The output should provide better insights into whether it is worth considering adding cryptocurrencies to traditional asset portfolios and if it can bring economic benefits to the investors.

2. RESEARCH METHODOLOGY FOR MEASURING THE IMPACT OF CRYPTOCURRENCIES ON INVESTMENT PORTFOLIO RETURNS

The following chapter consists of 4 parts. The first one shortly describes the research to be employed, outlines analysis goal and differences from earlier studies. Considering this analysis, the research aim is then formed. Furthermore, in the second and third parts of the research variables and steps to test the aim are outlined and explained in detail. Firstly, traditional assets and the rationale for choosing them are outlined, which then form the conventional investments part of the portfolio. Then, cryptocurrencies chosen for the following study are defined and their main characteristics are outlined. Thus, the research steps which analyse the portfolios formed are then listed and explained. The key characteristics and differences of each portfolio strategy are determined and their computational steps defined. In the last part of this chapter, study limitations are identified in order to be able to analyse and interpret the study results in a proper manner.

2.1. The Overview of Research Structure for Measuring the Impact of Cryptocurrencies on Investment Portfolio Returns

In this thesis, the research goal is to evaluate the impact on investment portfolio by adding cryptocurrencies as an additional asset for diversification to a traditional asset portfolio. To estimate the impact and change of returns, it should be evaluated whether cryptocurrencies can act as a hedge in a chosen portfolio and whether they can enhance the portfolio performance/returns. As analysed in the previous chapter, earlier studies, analysing cryptocurrencies with traditional assets, have heavily employed GARCH models. To better identify the optimal investment weights, a few scientific models will be employed in this research to compare returns and portfolio measures. Firstly, a naïve or Equal Weights strategy shall be considered, as it often outperforms other statistical methods in studies. Then, Global Minimum Variance and Constrained Global Minimum Variance models are employed, to minimize portfolio volatility, which is in accordance to Market Portfolio Theory discussed in the previous chapter. Finally, a Dynamic Conditional Correlation (DCC) GARCH model is employed for the portfolio weights. As outlined earlier, there are very few studies analysing the returns of portfolios by adding cryptocurrencies. Thus, using the portfolio weights obtained by the models outlined, portfolio returns shall be calculated and compared. The comparison spreads between cross-portfolio data and cross-model data. Results will add to the existing literature and might be useful for choosing the optimal investment model. To compare the models, portfolio measures are then analysed, providing an insight to most optimal choice. This might not lead to one optimal portfolio and provide contradicting results; hence, few indices are analysed and compared.

This study will aim to evaluate cryptocurrency impact in a diversified portfolio and to measure its effect on portfolio returns. It also aims to add to existing scientific literature by providing a wider time-frame analysed, add more cryptocurrencies than Bitcoin, find optimal weights and measure the performance of tokens in a traditional asset portfolio.

For evaluation, the **aim of the research is:** to evaluate what impact do cryptocurrencies have in traditional asset portfolios.

It is an important aspect that this study will include more cryptocurrencies than Bitcoin only to better explore impact of the cryptocurrency market, instead of focusing solely on 1 token.

2.2. Determination of Traditional Assets and Cryptocurrencies for Investment Portfolios

Traditional assets. To construct a well-diversified portfolio, a few traditional asset classes shall be considered along cryptocurrencies. To account for stocks, S&P 500 index and its daily prices will be considered, which are obtained from DataStream. Stocks are most commonly included in studies researching the impact of cryptocurrencies in portfolios. It is due to the fact that stocks do provide relatively higher volatility and risk, however also a possibility for increased returns, which is similar to cryptocurrencies. Then, DXY Dollar Index is added. This index presents dollar's value compared to other currencies such as Euro, which has a largest weight in the index, Pound sterling, Japanese Yen and others. S&P EURO Futures Index Spot will reflect the currency investment market for Euro. As cryptocurrencies have characteristics similar to currencies, it is important to include these currency investments to analyse how tokens improve investment portfolio and whether it acts more as a hedge or enhances portfolio returns. Furthermore, a GSCI Gold index shall be added to the portfolio as it is an asset considered as a store of value and often included in diversified portfolios. Hence, the portfolio would have an index for stocks and a cryptocurrency, which reflect higher volatility and return assets, as well as more stable and less risky assets, such as currency and gold. Thus, it forms a diversified portfolio, which is then able to evaluate the impact of cryptocurrencies on these investments.

Cryptocurrencies. Finally, largest capitalisation cryptocurrencies shall be added to portfolio, that is Bitcoin, Ethereum, Ripple, Bitcoin cash, Litecoin and Cardano. Cryptocurrency prices are taken from CoinDesk and CoinMarketCap. It is important to include large capitalisation cryptocurrencies and those which have been in the market for a few years, as tokens tend to either last a short time or increase their stake in the market for a short period of time and then return to a small market share, which makes them improper to study for the impact on longer term investment portfolios. The market shares of each cryptocurrency are outlined in Table 1, along with token release dates.

Table 1

Cryptocurrencies included in the study

Cryptocurrency	Price	Market capitalisation	Market share	Release date
Bitcoin	32.285.234,00	616.145.951.141,95	41,14%	2011
Ethereum	2.498,47	290.327.323.614,82	19,38%	2015
Ripple	0,86	39.458.068.594,75	3,27%	2012
Bitcoin Cash	583,12	10.926.315.563,44	2,63%	2017
Litecoin	158,69	10.550.345.239,33	0,73%	2011
Cardano	1,53	48.992.484.154,04	0,70%	2015

Prepared by the author, data retrieved from CoinMarketCap.com

As it is reflected in Table 1, the release dates of chosen cryptocurrencies have quite different release years. To be able to compare the returns and other measures, portfolios will be evaluated starting from 2 dates: 2013 and 2017. Bitcoin, Litecoin and Ripple will be measured with traditional assets starting from 2013, while Cardano, Bitcoin Cash and Ethereum will be measured from 2017. This is done to be able to assess and compare the results to the extent possible, so that portfolios can be evaluated not only by individual results but also by assessing across different cryptocurrencies' goodness of fit and impact on the portfolios. Since the intention is to measure whether cryptocurrencies can enhance a diversified portfolio, each chosen token will be paired with the traditional assets, namely the S&P 500 index, DXY Dollar index, S&P Euro Futures Index Spot and GSCI Gold index, so that it is possible to measure which cryptocurrencies are well diversifiers and can enhance the portfolio performance.

Thus, a total of 8 portfolios will be formed. Two portfolios shall include only the Traditional assets and measure their returns. These portfolios will enable a comparison between traditional asset-only investments and portfolios diversified with tokens. Hence, a total of 6 token portfolios shall then be formed, where each portfolio has four traditional investments and 1 cryptocurrency. In portfolios starting from year 2013, each asset has 1915 number of observations and others, starting from year 2017 each has 912 observations. From the final dataset of prices, daily returns are then calculated and multiplied by 100 to retrieve daily returns in percent.

2.3. Research Steps for Measuring the Impact of Cryptocurrencies on Investment Portfolio Returns

Having the variables gathered in place and their daily returns in percent, the further steps are to form portfolios and then evaluate each return in order to analyse the impact of cryptocurrencies on investment portfolio. Initially, each variable's statistics are assessed to gain initial insight into returns. Then, to model portfolios, firstly, portfolio weights are defined with 4

different models. Furthermore, portfolio returns are derived employing obtained weights and finally, portfolio returns are assessed with different portfolio measures. The analysis should reflect whether cryptocurrencies perform well in traditional asset portfolios and how different statistics change by adding/removing tokens. Each research step is detailed below:

1. **Portfolio weights**. First of all, an evaluation on portfolio weights is necessary. There will be 4 different methods on placing the portfolio weights.

1.1.Equal weights portfolio.

In this study, research will be conducted by firstly placing equal weights for each asset in the portfolio so it can capture the real impact cryptocurrencies can make on portfolio returns. It is often found in studies, that naive strategies outperform others by their results. This strategy is relatively easy and efficient to use. Hence, the weights in this scenario will be calculated using 1/N formula, where N is the number of variables in a certain portfolio.

1.2.Global Minimum Variance (GMV) portfolio.

This strategy, by definition, minimizes the total portfolio variance. Such model, reducing the overall portfolio variance and, hence, the risk was proposed by Markowitz, (1952). GMV solves for the following problem:

$$\begin{aligned} &\min w_i' \sum_i w_i \\ &\sum w_i = 1 \end{aligned} \tag{1}$$

where w_i is a weight of an asset in a portfolio and the sum of all calculated weightings are equal to 1. Firstly, covariance between portfolio assets is calculated by the following equation:

$$Cov(r_a, r_b) = \sum_{t=1}^{D} \frac{(r_{a,t} - \bar{r}_a)(r_{b,t} - \bar{r}_b)}{n-1} \tag{2}$$

where $r_{a,t}$ - $\bar{r}_a$ are excess returns of an asset return, calculated by subtracting asset's mean from its return at time t;

n is a number of observations, i.e. number of trading days.

Given the calculated covariance, the Covariance matrix is then calculated between all assets in each portfolio as depicted by Formula 3:

$$\sum = \left(\frac{1}{n}\right) X^T X \tag{3}$$

where $\sum$ is a covariance matrix nxn; X is a Dxn matrix of the excess returns described above; X^T is a transpose of X matrix; n is the number of trading days. Finally, portfolio variance is calculated and minimized, i.e. the weight of each asset is chosen such as the total portfolio variance could then be minimized:

$$V = \theta^T \sum \theta \quad (4)$$

where $\sum$ is the n x n covariance matrix;

θ is the weighting put into each individual stock.

Applying a minimum variance strategy might be preferred by risk-averse investors, who choose least volatile options. Though it is important to test the returns these models bring as they might not provide optimal results.

1.3.Constrained Global Minimum Variance (CGMV).

As it is relatively usual for cryptocurrencies to end up with negative weights in minimum variance portfolios, the following constraint will be introduced:

$$\theta \geq 0$$

This constraint will ensure weightings are non-negative and cryptocurrencies have a part in the portfolio. Depending on the results of analysis, additional constraints may be introduced and will be outlined in the empirical research part of this thesis. The constraint might be introduced for cryptocurrencies to have a larger stake in the portfolio for a better evaluation of the analysis.

1.4.Dynamic Conditional Correlation GARCH (DCC-GARCH).

To account for time varying interdependencies (correlations), DCC-GARCH model is used. Since financial data is rarely homoscedastic, this estimation process is able to account for volatilities and can fit the model relatively better. The model is implemented using 2 steps:

(1) Elements for the diagonal matrix are estimated by univariate GARCH model:

$$D_t = diag(\sigma_{1,t}, \sigma_{2,t}, \dots, \sigma_{n,t}) \quad (5)$$

where each $\sigma_{i,t}$ follows GARCH process,

(2) Then, to obtain the matrix of conditional correlation, residuals are standardized and applied in the multivariate GARCH model.

The forecasted out of sample values are obtained from this model, which provide an outlook based on the dynamics from the historical data instead of constant.

The results for the first step of research are obtained using the following software: OX Metrics, IBM SPSS, and Microsoft Excel.

2. **Portfolio returns.** Having the weights of portfolios defined, daily portfolio returns are obtained for each portfolio and model. Returns are then evaluated and compared both cross-model and cross-portfolio to assess which investment portfolios have returned greatest economic results and whether it is worth diversifying with cryptocurrencies.
3. **Performance measures.** A few ratios and other indicators will be applied to measure the performance of a portfolio: portfolio standard deviation, portfolio Betas and Sharpe ratios. Portfolio standard deviation shall reflect the portfolio risk while Sharpe ratio depicts risk-adjusted returns. Portfolio Betas indicate the risk of portfolio compared to the market.

3.1. The portfolio standard deviation is calculated by employing the following formula:

$$\sigma_p = \sqrt{\sum_{a=1}^{n-1} \sum_{b=a+1}^{n} (\sigma_{ab} * \theta_a * \theta_b)} \quad (6)$$

where a and b are assets in portfolio;

σ_p is the portfolio standard deviation;

θ_a and θ_b are weights of investments in a selected portfolio;

σ_{ab} is the covariance of selected assets;

n is the number of assets in the portfolio.

The portfolio standard deviation allows assessing the deviations and risk for the given portfolio. Since the standard deviation units are the same as when measuring returns, it allows for logical comparison between the models. This measure is also in line with previously discussed Modern Portfolio Theory and allows to asses risk.

3.2. Next performance measure evaluated is Portfolio Beta. These Betas, as expressed in formula 8, are calculated by adding all weights of assets multiplied by individual investment betas.

$$\beta_p = \sum_{a=1}^{n} \theta_a \beta_a \quad (8)$$

Where β_p is an overall portfolio Beta;

θ_a is the weight of each security in the portfolio;

β_a are individual Betas for every asset;

n is the number of securities.

Since security weights are obtained in the first step of the analysis, individual Betas are then to be assessed before calculating portfolio Betas. Firstly, return market standard deviation is computed

and then the correlation between market returns and chosen asset returns. Then, security standard deviation is divided by the mentioned metric of the market and multiplied by the calculated correlation. After each asset Beta is calculated, portfolio Betas are calculated employing Formula 8. Portfolio Betas help compare the models both in terms of risk against the market as well as with each other.

3.3. **Sharpe ratios.** The third portfolio performance measure are Sharpe ratios, Formula 9 depicts the calculation employed.

$$Sharpe\ ratio = \frac{r_p - r_f}{\sigma_p} \quad (9)$$

Where r_p and r_f are portfolio and risk-free returns, respectively;

σ_p is the portfolio standard deviation of returns.

Portfolio returns are calculated with each model weights and then the average of these returns is derived to obtain the expected return. Having all the returns calculated as described, portfolio standard deviation is computed. The Sharpe ratio provides a few insights to portfolio. Firstly, it depicts the relation between portfolio risk and its returns. The higher the ratio – the better portfolio measure is and the portfolio is a more optimal choice. Computing only returns or risk might not provide a full overview thus, this risk-adjusted measure allows a greater insight. Sharpe ratio also enables comparison between models.

The outlined research steps should help define optimal asset weights for different strategies and identify which portfolios are optimal. After comparing the portfolio measures with returns, it can be assessed what impact do cryptocurrencies have on traditional asset investments, whether they can diversify and protect against systematic risk, also, if the addition of tokens provides better returns for investors.

2.4. Research Limitations

It is important to outline limitations for the study thus; the results can be accurately evaluated. Firstly, cryptocurrency data are quite spread out between different platforms. Since prices and other cryptocurrency data may be different between exchanges, there might be small discrepancies if data are compared between the exchanges. Also, although the time window starts from 2013 for 3 cryptocurrencies namely Bitcoin, Litecoin and XRP, other 3 tokens Cardano, Bitcoin Cash and Ethereum start in 2017. As cryptocurrencies are relatively new in financial markets, most of them do not have a long history of trading yet. Or, if they have been trading in the market for a longer period, they might have a small share of the total market. Hence, they would not represent the cryptocurrency market well. Also, it is important to mention that some of

the cryptocurrencies both in 2013 and 2017 portfolios have started trading earlier as outlined in Table 1, however, to be able to generalize and better reflect on the results, returns starting from later dates were added to portfolios.

Regarding traditional assets in a portfolio, more could be selected to better reflect the overall market. Although assets were chosen to depict large asset classes, which are also considered well diversifiers for cryptocurrencies, there could be more investments, indexes or assets chosen to better reveal each market. However, as there will be 1 cryptocurrency per each portfolio, 4 traditional assets are considered to be sufficient for the study, as they should not completely overwhelm cryptocurrency in the portfolio. Since there are 5 assets in every portfolio considered, it is well balanced with 1 token each.

Overall, this study could provide new insights into how different cryptocurrencies affect portfolios, what investment results they provide and whether investors might consider them alongside other investment assets. The empirical study will consider optimal weights for different financial portfolios, asses potential returns and shall consider the optimal choice of portfolio based on few performance measures. This research also adds to the existing studies by considering a wider range of cryptocurrencies, namely 6 large capitalisation tokens, which allows for better comparison of token market. Also, a longer time frame is chosen - 3 cryptocurrency portfolios are analysed from year 2013 and the rest are added from year 2017. Finally, portfolio returns are measured and assessed instead of focusing entirely on volatility.

3. MEASURING THE IMPACT OF CRYPTOCURRENCIES ON PORTFOLIO RETURNS

In this part of the thesis, effects of cryptocurrencies in an investment portfolio will be analysed. 8 portfolios are formed and 4 statistical models are employed. To compare and analyse the effect of cryptocurrencies in a portfolio, two portfolios containing only Traditional assets are formed, each contains four assets: DXY Dollar Index, S&P 500 index, GSCI Gold index and Euro Futures S&P index. Then, six portfolios are built of the mentioned assets adding 1 cryptocurrency each. Thus, there are five assets in each token portfolio. First of all, each variable will be analysed to gain a better understanding of the impact they might have on the portfolio. Then, correlations between each asset are analysed to gain insight on how well the portfolios could perform against systematic risk and whether they are affected by the same market information or some assets could provide hedging opportunities. Furthermore, four statistical models are employed to obtain optimal portfolio weights – Equal Weights (EW) or naïve strategy, Global Minimum Variance (GMV), Constrained Global Minimum Variance (CGMV) and Dynamic Conditional Correlation (DCC) GARCH CGMV model. Each model will provide different model weights, which then shall be employed in portfolio returns analysis. It is in interest of this thesis to compare whether larger cryptocurrency stake could provide higher returns and whether token portfolios outperform traditional assets. After evaluating return data, portfolio measures shall be estimated and analysed: portfolio Betas, standard deviations and Sharpe ratios. Furthermore, to improve the insight to different portfolios, long-term hold investment strategy shall be analysed. All analysis on portfolios will be analysed both cross-model and cross-portfolio, with the emphasis on comparison between Traditional and token portfolios. Finally, at the end of this chapter, conclusions are drawn evaluating the analysed measures and returns and assessing what impact do tokens have on the traditional asset portfolios, if cryptocurrencies can help hedge against systematic risk and whether they could outperform traditional asset-only portfolios.

3.1. Analysis of Asset data in Investment Portfolios

Firstly, before analysing portfolio data, each variable was analysed. This analysis provides initial insight into investments and their expected impact on portfolios. Table 2 presents statistical fundamentals for better grasp of the data in portfolios and already some differences between traditional assets and cryptocurrency data are observed. Also, differences between two periods starting from 2013 and 2017 can be evaluated for traditional assets. These statistics will provide

an improved insight into later formed portfolios and their returns, explaining their deviations and volatility.

Table 2

Portfolio variable analysis

Asset	Minimum statistic	Maximum statistic	Mean	Std. deviation	Variance	Skewness	Kurtosis
			2013-2021				
GSCI Gold	-4,9307	5,7610	0,0230	0,9369	0,8780	0,1260	4,2570
S&P	-11,9841	9,3828	0,0534	1,1000	1,2100	-0,6780	20,2970
Euro futures	-2,0610	3,3508	-0,0044	0,4960	0,2460	0,1110	2,3360
DXY	-2,0996	2,4997	0,0064	0,4142	0,1720	0,0490	2,2300
Bitcoin	-27,0901	35,8493	0,3195	4,4734	20,0110	0,2650	6,9420
Litecoin	-40,1857	129,0954	0,3819	7,6019	57,7900	4,6230	63,7130
XRP	-46,0105	83,4642	0,5798	7,7990	60,8240	2,2350	19,5010
			2017-2021				
GSCI Gold	-4,9307	5,7610	0,0439	0,9530	0,9080	-0,0550	6,1670
S&P	-11,9841	9,3828	0,0634	1,3750	1,8910	-0,6850	16,5210
Euro futures	-1,9075	1,5731	0,0035	0,4285	0,1840	-0,0340	0,8480
DXY	-1,6823	1,6019	-0,0023	0,3675	0,1350	0,2130	1,6170
Cardano	-50,0000	140,0000	0,6783	10,8373	117,4480	3,5810	36,9860
BTC Cash	-42,9589	53,9691	0,1864	7,6387	58,3490	1,3940	11,3880
ETH	-34,5295	26,6265	0,1355	5,5166	30,4320	-0,1830	4,6230

Source: prepared by the author. Statistics obtained through IBM SPSS software.

Looking at descriptive statistics shown in Table 2, there are some clear differences between cryptocurrencies and other assets in portfolio. Firstly, it is apparent by Minimum and Maximum statistics that cryptocurrencies are considerably more prone to extensive increases and drops. Out of the considered sample, in the portfolio starting from year 2013, Litecoin had largest daily increase reaching 129 and second largest low with -40. Largest maximum daily return and the lowest one in portfolio starting from year 2017 both belong to Cardano. It is evident from the earlier mentioned studies and these statistics, that cryptocurrencies are heavily affected by news and investor emotions. Looking at the traditional assets and their Minimum/Maximum statistics, they already prove to be greatly more stable. Both highest and lowest daily increase/decrease are marked by S&P, though it is still 1,5 times lower compared to the lowest cryptocurrency. Studying the Mean, both in the 2013 and 2017 portfolios Cryptocurrencies show the highest returns. Hence, even with their unpredictable jumps, over a longer period of time they have brought a higher return to investors compared to other considered assets if they were kept in a portfolio for the whole

period. Also, currency indexes were the only ones to have negative mean returns. From year 2013 portfolio, Euro futures provide a mean return of -0,0044 and in 2017 portfolio DXY had a -0,0023. Without considering the negative returns, currencies still brought the lowest mean return in the whole portfolio. However, currencies were also the steadiest assets – this is reflected by their relatively low standard deviation and variance, reflecting a less risky nature of the assets compared to the others selected in the portfolio. The second lowest volatility asset was GSCI, followed by S&P. Cryptocurrencies repeatedly reflect higher volatility and risk showing highest standard deviation and variance statistics. This also shows that their volatility is not affected only by a few high/low observations – it exhibits a constant pattern in their price moves. In regards to data distribution, skewness and kurtosis showcase similar insights to other statistics. Out of traditional assets considered, according to skewness, closest to a symmetrical distribution are GSCI Gold, Euro Futures S&P index and DXY index. These assets considering data from 2013 are also nearest to normal distribution kurtosis, compared to other assets in portfolio, however, from 2017 they are not. From traditional assets, only S&P index shows slightly negative skewness and comparably high kurtosis. Some of the cryptocurrencies also depict close to normal distributions, namely Bitcoin and Ethereum. Their skewness is within normal distribution and while kurtosis is not, out of all cryptocurrencies considered, Bitcoin and Ethereum also are nearest to it. This gives indication that their return data are less affected by outliers and is more evenly spread out with a more balanced distribution than other cryptocurrencies in portfolio.

Correlations between assets. The correlations between assets are tested using Pearson's correlation. In Table 3, the correlations between S&P, DXY Dollar, Euro Futures S&P, GSCI Gold and each of the cryptocurrencies (but not between cryptocurrencies, as each portfolio will have only 1 cryptocurrency) are tested. Table 3 depicts that most of the traditional assets have quite low correlation. Both in 2013 and 2017 portfolios DXY Dollar index and Euro Futures Spot index are heavily negatively correlated with >0,9 correlation coefficients which are significant as well, which must always be true as Euro has the largest weight in DXY Dollar index among all measured currencies and as dollar appreciates, euro depreciates and vice versa. Also, other moderate correlations are between GSCI Gold and DXY Dollar & Euro Futures. It is usual that Gold and Dollar often have a negative relationship, which is also reflected here and this also concludes a moderate positive relationship between Euro and Gold. All other correlations are relatively low, between the traditional assets and cryptocurrencies. However, out of the correlations on the lower end, in 2017 portfolio S&P had some positive correlation with Cardano and BTC Cash, which indicates they might not be great hedges in the same portfolio, but as the correlations are still relatively low, they are considerable for diversification purposes. However,

Ethereum had a negative correlation with DXY Dollar and does show a possibility of a hedge when put in the same portfolio.

Table 3

Correlations between portfolio assets

	2013-2021			
	S&P	**DXY Dollar**	**Euro Futures S&P**	**GSCI Gold**
Bitcoin	-0,023	-0,047*	0,059*	0,037
Litecoin	0,088**	0,014	-0,015	0
Ripple	0,092**	-0,025	0,024	0,021
S&P	1,000	0,036	-0,039	-0,013
DXY Dollar	0,036	1,000	-0,930**	-0,360**
Euro Futures	-0,039	-0,930**	1,000	0,318**
GSCI Gold	-0,013	-0,360**	0,318**	1,000
	2017-2021			
	S&P	**DXY Dollar**	**Euro Futures S&P**	**GSCI Gold**
Cardano	0,202**	0,013	-0,024	0,072*
BTC Cash	0,145**	-0,039	0,034	0,082*
Ethereum	-0,063	-0,106**	0,095**	0,063
S&P	1,000	-0,024	0,017	0,085*
DXY Dollar	-0,024	1,000	-0,943**	-0,391**
Euro Futures	0,017	-0,943**	1,000	0,346**
GSCI Gold	0,085*	-0,391**	0,346**	1,000

Source: prepared by the author. Statistics obtained through IBM SPSS software.

Considering all correlations, there are not many which stand out as relatively significant, showcasing that portfolios are quite diversified and assets do not move completely in the same direction.

3.2. Determination of Asset Weights in Investment Portfolios

As outlined in the research steps part of this thesis, the portfolio weights are then identified for each portfolio, which are depicted in Table 4. The Equal Weights (EW) portfolio simply divides 1 by total number of assets in the portfolio. Since most portfolios have 5 assets, each asset's weight is 0,20, except for Traditional assets portfolio, which contains 4 assets and each weight is 0,25. The Global Minimum Variance (GMV) portfolios distribute weights so that total portfolio variance is minimized (steps are described more thoroughly in the Research steps part of this thesis). Firstly, the non-constrained portfolio is considered. It is expected that cryptocurrencies would have small weights in such portfolio as their returns are generally more variant as it is reflected in Table 1. Hence, the GMV portfolios also did not include or included only a small part

of cryptocurrencies. In Bitcoin portfolio, cryptocurrency has a negative weight, though relatively small. This reflects that in order to minimize variance, investor should short Bitcoin. S&P has a stake of only 0,5%, GSCI Gold 2% and the rest is divided between DXY Dollar and Euro Futures 54% and 43%, respectively. This result shows that in the given portfolio between the chosen assets, in order for the whole portfolio to have a minimum variance, most of it should be comprised of currency investments. And the variance is then, indeed, relatively low, 0,007 only.

Table 4

Variable weights in each portfolio

			EW			
All assets			0,2000			
			GMV			
	Cryptocurrency	S&P	DXY Dollar	Euro Futures	GSCI Gold	Portfolio variance
Traditional	0,000000	0,002343	0,536986	0,444531	0,016140	0,004266
Bitcoin	-0,000243	0,006181	0,539133	0,434534	0,020395	0,006734
Litecoin	0,000057	0,006168	0,539042	0,434367	0,020366	0,006735
Ripple	0,000038	0,006178	0,539062	0,434358	0,020364	0,006735
Cardano	0,000063	0,002245	0,536988	0,444616	0,016087	0,004266
BTC Cash	0,000003	0,002341	0,536986	0,444531	0,016139	0,004266
Ethereum	0,000529	0,002482	0,537017	0,443956	0,016016	0,004258
			CGMV			
	Cryptocurrency	S&P	DXY Dollar	Euro Futures	GSCI Gold	Portfolio variance
Traditional	0,000000	0,250000	0,413619	0,336381	0,000000	0,119574
Bitcoin	0,250000	0,028050	0,461362	0,260588	0,000000	1,252840
Litecoin	0,250000	0,000000	0,377757	0,367810	0,004433	3,610625
Ripple	0,250000	0,000000	0,464893	0,285107	0,000000	3,796266
Cardano	0,250000	0,000000	0,336971	0,413029	0,000000	7,315348
BTC Cash	0,250000	0,000000	0,494365	0,255635	0,000000	3,633569
Ethereum	0,250000	0,065380	0,549382	0,135238	0,000000	1,859794

Source: calculated and prepared by the author. EW – Equal Weights model, GMV – Global Minimum Variance model, CGMV - Constrained Global Minimum Variance model.

In Global minimum variance portfolios, it is usual to have quite concentrated investment weights, which happens with these ones as well. Bitcoin GMV portfolio is the only one that has a negative weight. Other cryptocurrencies have, although small, long positions in portfolios. The smallest of these is Bitcoin Cash and the largest is Ethereum. Both of these cryptocurrencies are included with dates starting from 2017, showing that longer periods may not necessarily provide more stability in portfolios containing cryptocurrencies. From traditional assets it is observed that greater parts of currency investments minimize the chosen portfolios most. With S&P and GSCI there is a clear

jump between 2013 and 2017 portfolios. Both of these assets' portions are approximately halved in portfolios starting from 2017. This change also brings down the total minimum variance from approx. 0,00673 in 2013 portfolios to 0,00427 variance. Nevertheless, both variances are relatively low. Comparing cryptocurrency portfolios with Traditional asset one, it shows relatively similar results for portfolio weights. This is quite expected result, since cryptocurrencies are, nevertheless, more volatile and riskier, hence they are not chosen in any other portfolio as well under GMV and all other assets are identical to token portfolios. However, an interesting outcome from Traditional assets portfolio is that it does not have the lowest variance – Ethereum portfolio does. Although variance in Ethereum case is only minorly lower, but it portrays the fact that among analysed portfolios, including a small part of Ethereum and Euro Futures and Gold can result in a bit lower risk than Traditional assets portfolio. The GMV portfolios demonstrate what could be expected by exploring cryptocurrency market – for risk averse investors, tokens may not be a first choice of investment. Not only tokens, but stocks are considered as well as relatively risky (reflected by S&P index in this research) and thus, also included in quite small percentages. The safest choices, considering variance, are the currency market. It is quite curious that GSCI Gold is also included in relatively limited volumes. Hence, according to these results, if an investor is highly risk averse, currency market might be a valuable option to include. The smallest portfolio variance was obtained in Ethereum portfolio with a value 0,004257. Here, Ethereum part is also the largest among all other cryptocurrencies in other portfolios. Thus, in order to minimize the total investment volatility, Ethereum can be a good cryptocurrency to choose. This result might also reflect, that since 2017 there has been a smaller number of market bubbles in cryptocurrency market, allowing Ethereum to perform relatively well in diversifying and minimizing investment risk. However, the difference between Ethereum weight compared to other portfolios is relatively small.

To account for the fact that in global minimum variance portfolios cryptocurrencies take either a very small, almost non-existent part/weight, the constraints for the **Constrained Global Minimum Variance (CGMV)** portfolio were chosen to account for that. Firstly, as introduced in research steps, portfolio weights were chosen to be non-negative as in $w \geq 0$, i.e. so that all assets would be considered as either long positions or would simply not be included in portfolios. However, the only negative weight out of 6 portfolios was Bitcoin with value -0,000243, hence constraining it to be 0 will not change other weights significantly to minimize the variance of the portfolio. Thus, the following constraint was implemented:

$$w_i \geq 0{,}25$$

where w_i is a weight of a cryptocurrency in a portfolio.

This constraint allows cryptocurrencies to take significant part in portfolios while minimizing other assets' variances. Without adding this constraint, cryptocurrencies are practically omitted from portfolios, thus not allowing evaluation of their impact on portfolio returns. As 25% weight allows cryptocurrencies to be present and have only long positions, it also allows for diversification. As was seen in the GMV portfolios, there was a concentration on weights on currency investments. This constraint also includes cryptocurrencies, though by excluding S&P 500 index investment and Gold investments minimizing the variance between other assets. However, the 2 mentioned assets had relatively small portions in the portfolios without constraints as well, so this change did not have a large effect in regards to total distribution of weights in the portfolio. S&P did end up with small, yet still a part in 2 of cryptocurrency portfolios, namely Bitcoin and Ethereum with 0,02805 and 0,065380, respectively. Hence, even though stocks are considered relatively riskier (reflected by S&P 500 index), they can in this case help minimize the portfolio variance. The most important statistic obtained from CGMV model are portfolio variances. It is immediately seen that, comparing to GMV, variances have increased by relatively large amount. The total average variance for all 6 portfolios in CGMV is 3,578 while GMV portfolios had average of only 0,006. The largest portfolio variance among cryptocurrency investments was obtained in Cardano portfolio, while the lowest is calculated in Bitcoin portfolio. Comparing token investment results with Traditional asset-only portfolio, the latter one had the lowest variance. As with GMV model S&P index was almost nonexistent in the mentioned portfolio, the constraint was added for S&P weight to be larger or equal to 25%. This constraint allows for levelling the variance a bit between Traditional asset and cryptocurrency portfolios and grants better comparison, as all portfolios then have a riskier component to it and are relatively greater diversified. As expected, portfolio included the minimum allowed weight for S&P index, 25% in order to minimize variance of all included asset returns. Other assets depicted relatively similar weights to cryptocurrency portfolios. However, the variance was lowest when tokens were excluded even though S&P index was largely considered. This result indicates, that cryptocurrencies, as a relatively new asset, are largely more volatile and adds vast fluctuations when compared to rather conventional risk prone assets such as stocks. Most of the variances in portfolios including cryptocurrencies, even though larger, are not tremendous. Thus, although cryptocurrencies are relatively volatile assets, for an investor who is moderately prone to risk adding cryptocurrencies might still be an option. Hence, considering this information, it is important to find what turnover impact does each strategy have on the total returns. The findings could then assist in determining whether the increased risk is worth the investment and which strategy seems most prosperous.

The fourth method used to form portfolios is **DCC-GARCH** method, which is, as previously noted in this thesis, often used in financial data analysis. This is due to the fact that DCC-GARCH model, unlike most others, is a dynamic model. Instead of forecasting volatility based on mean/constant variance, it employs previous known volatilities into its' forecasting model. This is especially applicable for financial data, considering it is constantly changing and earlier obtained volatilities should be accounted for when estimating or fitting the model to better represent its dynamics. Prices and returns regularly do not fluctuate around a constant mean, hence the chosen model should also account for these volatilities and not show a static figure. Since DCC-GARCH does incorporate the dynamics of financial assets and often demonstrates relatively fine results, it is also applied in this thesis.

As described in the research steps, first, univariate GARCH models are defined. In order to apply GARCH, variables' autocorrelation is considered. As seen in Appendices 1 and 2, the variables that show autocorrelation are S&P 500, Litecoin, Ripple, Cardano returns. To account for this, a lag of 1 for the respective variables is used in the 1st step of the model. A Lag must be included in order to proceed with GARCH model. After each portfolio undergoes univariate GARCH estimation, then multivariate GARCH models are estimated, using parameters obtained from univariate models. Following the output of the second step, variance-covariance matrices can be calculated. These matrices are then added to the CGMV models to attain portfolio weights. As previously, there are two constraints added: the weights are not negative and cryptocurrency part in each portfolio must be either equal to or greater than 25% (in Traditional portfolio S&P index is set equal to or greater than 25%). The estimated weights are reflected in Table 5.

Table 5

DCC-GARCH CGMV model weights

	Cryptocurrency	S&P	DXY Dollar	Euro Futures	GSCI Gold	Portfolio variance
			2013-2021			
Traditional	0,000000	0,250000	0,401819	0,336443	0,011738	0,032064
Bitcoin	0,275592	0,028373	0,000024	0,288419	0,407592	0,149869
Litecoin	0,250000	0,208272	0,000000	0,541728	0,000000	3,399369
Ripple	0,250000	0,369523	0,000000	0,380477	0,000000	0,032612
			2017-2021			
Traditional	0,000000	0,250000	0,459965	0,257785	0,032250	0,122965
Cardano	0,250000	0,000000	0,704431	0,000000	0,045569	6,381886
BTC Cash	0,250000	0,259343	0,000297	0,458801	0,031559	0,122876
Ethereum	0,250000	0,258406	0,000000	0,456907	0,034687	1,232099

Source: calculated and prepared by the author. EW – Equal Weights model, GMV – Global Minimum Variance model, CGMV - Constrained Global Minimum Variance model.

Since the constraint on cryptocurrencies is applied, some of the portfolio variances are relatively high. Just as with CGMV model, largest portfolio variance is in Cardano portfolio. However, DCC produced quite lower variances overall. There are only 2 variances above 3: in Litecoin and Cardano portfolios. In comparison, in CGMV portfolio the results for portfolio variance higher than 3 were in four portfolios: Litecoin, Ripple, Cardano and BTC Cash. In addition, all CGMV results were at least higher than 1, whereas in DCC, 3 cryptocurrencies depicted outcomes lower than 1. Also, the weights in DCC portfolio are also significantly different. First large difference is that in Bitcoin portfolio, token weight is chosen larger than the constraint weight (25%), which is the only case among the portfolios and models considered. Furthermore, S&P has a relatively large stake in all token portfolios, apart from Bitcoin Cash and Bitcoin, whereas in CGMV, S&P was either excluded from portfolios or had a minor stake. Traditional portfolio, similarly to other considered models, gave the smallest portfolio variance. This portfolio had largest weight in DXY index then followed by Euro Futures, while S&P output was lowest possible given the constraint of 25%. Since both cryptocurrencies and S&P index could be considered as riskier compared to other included assets, it is of interest to evaluate whether larger stakes can also bring better overall portfolio results.

3.3. Investigation of Cryptocurrency Impact on Investment Portfolio Returns

After determining the weights of each asset in the portfolios, returns are calculated and their statistics compared. In each of the portfolio strategies, weights for each of the assets were selected and then used to calculate total portfolio returns, considering an investor would choose parts accordingly. In Table 6, the portfolio return statistics are depicted. Since each of the 6 cryptocurrency portfolios contain same 4 traditional investments and 1 crypto each, portfolios are denoted by cryptocurrencies they contain. The only exception is Traditional assets portfolio, which consists of 4 investments, namely S&P 500, Gold, Euro and Dollar indices. Firstly, Equal Weights portfolio, where naïve strategy was used, have landed in the middle in terms of returns between these portfolios. With this strategy, any differences between cryptocurrency portfolio returns are impacted solely by cryptocurrencies as all other assets have the same impact on portfolio returns, apart from the start date difference. The lowest return of the portfolio is -12,52% in the portfolio containing Cardano, though this portfolio also has the highest return of 28,17%. The second lowest return in EW portfolio was the BTC Cash portfolio with -11,11%, but its highest was relatively low, 10,6%. This reflects that, in the analysed period, return increases have been comparably smaller than drops, when compared with other portfolios. Returns in the portfolio containing Bitcoin had a smallest drop when compared to others. Thus, even though Bitcoin is considered highly unstable, it does not fall/rise as much as other cryptocurrencies.

Table 6

Portfolio returns for each analysed strategy

Cryptocurrency	EW			GMV			CGMV		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
2013-2021									
Traditional	-3,447	3,742	0,020	-0,537	0,525	0,015	-2,972	2,590	0,015
Bitcoin	-5,242	7,164	0,080	-0,514	0,532	0,002	-6,198	8,945	0,083
Litecoin	-9,755	25,520	0,092	-0,516	0,532	0,002	-9,760	32,285	0,096
Ripple	-9,236	16,716	0,132	-0,516	0,532	0,002	-11,580	20,833	0,147
2017-2021									
Traditional	-3,447	3,742	0,027	-0,241	0,414	0,001	-2,972	2,590	0,016
Cardano	-12,520	28,173	0,157	-0,240	0,414	0,001	-12,556	34,912	0,170
BTC Cash	-11,112	10,601	0,059	-0,241	0,414	0,001	-10,490	13,503	0,046
Ethereum	-5,874	5,602	0,049	-0,241	0,412	0,001	-7,414	6,588	0,037

Source: calculated and prepared by the author. EW – Equal Weights model, GMV – Global Minimum Variance model, CGMV - Constrained Global Minimum Variance model.

Looking at the mean of EW portfolios, the smallest is Ethereum with a 0,049% mean returns. The largest is Ripple, showcasing 0,132% average portfolio returns. Although it is the highest mean, it is still quite low. Traditional assets portfolio, compared to cryptocurrency portfolios, had a smallest Min, Max and Mean result. Although this outcome shows a possibility for lower drop in returns, however, maximum returns are quite insignificant as well. Comparing it to token portfolios, mean returns are almost half or more of what cryptocurrency portfolios earned. There are limited possibilities to gain immense returns, hence, traditional investments may not be for the risk-seeking investor.

Turning to **GMV portfolio results**, the first clear difference is the difference between highest and lowest returns. In the naïve portfolio, there were quite big jumps to both profit and loss sides, however in GMV, starting from year 2013 all downsides were approximately -0,515% and upsides 0,532%, while in the portfolio from year 2017 they were approx. -0,214% and 0,412%, respectively. These results are explained by the fact that GMV portfolio is heavily concentrated between currency investments only. GMV models usually tend to be concentrated to minimize the variance. However, the mean for 2013 and 2017 portfolios are 0,002% and 0,001%, respectively. Though these are lower than returns on the EW portfolio, but considering how small they are overall, this is not an extensively large difference. However, the risk is definitely larger in EW portfolio, and considering that mean returns on 4 of the 6 portfolios are only approx. 0,07% higher that GMV, it might not be worth investing in for some investors who are risk averse. Traditional asset portfolio performed quite well using GMV model when measured against token portfolios. Although Minimum and Maximum values are quite close to cryptocurrency portfolios, the mean

returns are more than 0,01% greater, depicting similar risk with a higher return. Such result proves that a risk averse investor might consider adding only traditional assets to their portfolios, which show less volatility along with more stable returns. Also, those investors would choose GMV strategy instead of EW, since traditional investment portfolio produced similar mean returns, though EW depicts quite larger fluctuations.

CGMV portfolio results. This portfolio includes a largest part of cryptocurrency out of the 3 portfolio strategies considered before, namely 25% of the total weight. The deviations between minimum and maximum values are larger as well, as can be expected. Compared to the EW, average of the minimum values in the portfolio are 8,9% in EW and 9,7% in CGMV, however the average of Max values is 15,6% in EW and 19,5% in CGMV, which is a considerable difference. Such result reflects that choosing a larger portion of cryptocurrencies in a given portfolio might increase the returns more than decrease them. Also, the average of 6 token portfolio's means in EW is comparatively close to the average of means in the CGMV portfolio, which are 0,095% and 0,097%, respectively. It is important to note that portfolios are reflecting positive means, depicting that all chosen portfolios would bring an upturn to investors. In addition, comparing Traditional asset portfolio with tokens, it repeatedly provides least return for investors. Looking at 2013 portfolios, both CGMV and GMV provided exactly the same mean return for Traditional asset portfolios, however CGMV contains significantly larger fluctuations, which is expected, since it holds 25% weight in S&P index. Considering this, a risk-averse investor would choose to invest in Traditional assets employing GMV model. Among all models and portfolios, it brings a similar return for Traditional assets, however, with considerably low fluctuations. Having that said, Traditional asset portfolios determine greatly lower results than token ones. This is true not solely for significant high and low values, though also for average outcomes. This would imply that in the long run, investing in high risk and fluctuation assets do pay-off return wise.

Furthermore, portfolio results with **DCC-GARCH** CGMV model weights are measured and presented in Table 7. Compared to CGMV model, it depicts relatively similar Minimum and Maximum daily returns. Bitcoin portfolio shows largest differences between the 2 models: the largest loss in DCC-GARCH model is 3% lower than in CGMV, and the maximum upturn is 1% higher. Other models' Minimum and Maximum statistics are either a bit lower in DCC-GARCH model, or roughly equal. However, all but two portfolios in DCC-GARCH model show larger mean returns, the only exceptions are Cardano and Traditional 2013 portfolio, though they are also nearly equivalent. As outlined previously, DCC-GARCH CGMV model included larger weights for cryptocurrencies and S&P index, which would be considered riskier compared to other analyzed assets.

Table 7

Portfolio returns for DCC-GARCH CGMV model

Cryptocurrency	Min	Max	Mean
	2013-2021		
Traditional	-2,987768	2,520448	0,014695
Bitcoin	-9,323331	9,982211	0,097644
Litecoin	-11,538146	32,234862	0,104160
Ripple	-12,104624	20,631500	0,162834
	2017-2021		
Traditional	-3,141718	2,566141	0,017096
Cardano	-11,942195	35,281583	0,169792
BTC Cash	-13,740110	13,504783	0,065956
Ethereum	-6,766055	6,463897	0,053175

Source: calculated and prepared by the author. EW – Equal Weights model, GMV – Global Minimum Variance model, CGMV - Constrained Global Minimum Variance model.

The results show how including more volatile assets into consideration affect the portfolio returns. Higher mean returns show, that including more cryptocurrencies and other volatile assets, on average, can bring higher returns as well. That implies that investment risk, in the analysed case also pays-off, providing investors with larger profits. Furthermore, considering DCC-GARCH Min and Max daily return portfolio statistics, additional observation could be spotted: almost all Max statistics are either higher than Min statistics or virtually equal. This consideration implies, that including a substantial part of cryptocurrency and S&P assets in a portfolio could bring a generous daily return, while daily return loss would be subtler. Hence, the markets, especially regarding cryptocurrencies, may be quicker to react to positive market information and new cryptocurrencies. However, the downturns are a bit slower and not as drastic as the upturns. Thus, taking DCC-GARCH CGMV model results, it is worth investing more in cryptocurrencies to gain larger returns, considering that investor is risk-seeking and can manage a volatile portfolio.

To sum up all of the portfolios considered, highest returns and volatility are depicted in CGMV portfolio, EW is in the middle and GMV presents lowest returns and lowest risk as well. Cryptocurrencies definitely add quite significant volatility to a portfolio and given that an investor chooses the right time, extreme returns can be achieved. However, the opposite also stands: in case the market receives negative information/event on cryptocurrencies, prices shall fall sharply and although this is true for most of the investments, cryptocurrencies are considered to be relatively more sensitive to market information and emotions. Although GMV portfolio computes for the minimum total portfolio variance and has quite low variance, the returns are certainly low as well. This only stresses that more risk usually does show larger returns, though given that investments are made at the right time. Comparing traditional asset portfolio with token, the

former option can be beneficial for risk averse investors. It provides relatively low fluctuations with quite stable returns. Gains are lower in traditional asset portfolios, however, adding any cryptocurrency increases fluctuations significantly, which is not acceptable to all investors. Considering this, cryptocurrencies can be great diversifiers in a traditional assets' portfolio, notably when investors are risk-seeking. Although they are quite risky as investments, they can also diversify and hedge against some systematic risks within traditional investments. If an investor is risk averse, they might then consider choosing investing only in traditional assets by using GMV model.

3.4. Examination of Cryptocurrency Impact on Portfolio Returns Performance Measures

After evaluating daily returns of portfolios and different models, portfolio measures shall be evaluated, which include Portfolio Betas, portfolio standard deviation and Sharpe ratio. All these measures assist in evaluating whether the portfolio is worth investing in, taking into consideration not only absolute returns, but also accounting for risk that particular portfolios carry. For this analysis, only three out of four earlier considered models are evaluated: Dynamic Conditional Correlation-GARCH (DCC-GARCH), Global Minimum Variance (GMV) and Equal Weights (EW). Constrained Global Minimum Variance (CGMV) portfolio is omitted, since it depicts relatively similar results to DCC-GARCH in terms of portfolio weights and returns, however, DCC GARCH fits the financial data better, hence it is considered for further analysis. EW did provide quite similar returns to DCC-GARCH and CGMV models as well, nevertheless, it is also worth evaluating whether naïve strategy results shall beat other scientific models, as is often the case in empirical studies.

In the table below, two portfolio measures (Beta and Standard deviation) for three models and eight portfolios are depicted. Looking at portfolio Betas, all are below 1. A beta smaller than one reflects a portfolio, which carries less risk than the market. Hence, all of the portfolios carry less risk than the market. The lowest beta is depicted in DCC-GARCH Ethereum portfolio and the highest is in Traditional 2013 portfolio. Comparing the models, all DCC portfolios gave output above 0,8 and below 0,9. Between Traditional portfolios, 2013 has a higher Beta than 2017 Traditional portfolio, this is also the case for GMV and EW models, it reflects there have been more fluctuations during the longer period, which is frequently the case. However, it is observed that Ethereum and BTC Cash have lower Betas than Traditional portfolio, showing some cryptocurrencies can be good diversifiers for traditional assets not only in terms of returns, but risk as well.

Table 8

Portfolio Betas and standard deviations

Portfolio	DCC Beta	GMV Beta	EW Beta	DCC Std. dev.	GMV Std. dev.	EW Std. dev.
			2013-2021			
Traditional	0,89874	0,95237	0,90062	0,61922	0,46060	0,73668
BTC	0,89999	0,95154	0,87392	1,78864	0,46365	1,48380
Litecoin	0,89066	0,95150	0,89487	2,39772	0,46501	2,10934
Ripple	0,87675	0,95150	0,91243	2,54381	0,46488	2,14833
			2017-2021			
Traditional	0,84646	0,88912	0,84790	0,65350	0,40630	0,78057
Cardano	0,89698	0,88914	0,86315	3,01001	0,40684	2,79074
BTC Cash	0,82903	0,88912	0,84246	2,49159	0,40632	2,15135
Ethereum	0,81674	0,88903	0,83249	1,95910	0,40905	1,72474

Source: calculated and prepared by the author. EW – Equal Weights model, GMV – Global Minimum Variance model, CGMV - Constrained Global Minimum Variance model.

GMV model Betas are relatively more spread out than DCC comparing years 2013 versus 2017 portfolios, however, there are almost no differences between portfolios within those years. All 2013 portfolios have approx. 0,95 Betas, while 2017 portfolios have approx. 0,89 Betas. This is explained due to high clustering in GMV portfolios, where key assets chosen by the model are DXY dollar index and Euro S&P. Since these assets are key, Betas are then also close to identical. This model also shows that comparing long-term investments versus shorter, the former one carries more risk and fluctuations, hence the higher Beta. In most of the cases, EW portfolios have larger Betas than DCC model, reflecting that in this case, it did not perform better than a more scientific DCC-GARCH method. The two exceptions are Bitcoin portfolio and Cardano – DCC portfolios do have a larger portion of cryptocurrencies (25%) than EW model (20%), hence the Betas display this 5% increase in one of the portfolio assets increase the overall portfolio risk and increasing other asset stakes while lowering the cryptocurrency stake might enhance the portfolio performance. Looking at portfolio standard deviations reflected in Table 8, the results are greater skewed than Betas. Firstly, Traditional portfolio standard deviations are lowest among others portraying the lowest fluctuations. Furthermore, the standard deviation in the mentioned portfolios with DCC-GARCH and EW models are approximately 1% and lower than in others asset portfolios. DCC model measures are most skewed, with largest portfolio standard deviation depicted by Cardano portfolio and reaching 3%, while lowest is depicted by Traditional 2013 portfolio showing 0,62%. In EW this difference is lower, where Cardano depicts 2,8% and Traditional 2013 – 0,74%. Cardano portfolio, similarly to Beta, is shown to be one of the most risk carrying tokens, however Bitcoin portfolio, unlike with Beta measurement, carries one of the

lowest risks. Its standard deviation in DCC is approximately 1,8% and 1,5% in EW model. Thus, adding Bitcoin to traditional asset portfolios, compared to other tokens can bring quite successful results. GMV portfolio once more depicts quite similar results between portfolios, which is caused by concentrated assets. It's observed that Traditional portfolio standard deviations are not significantly lower in GMV compared to DCC and EW models. Also, Betas were higher in GMV than in two other models, showing that overall risk can be minimized by diversifying portfolio. In GMV, mainly two assets take majority of the portfolio, whereas DCC includes more assets and EW takes all securities into consideration. Thus, if investor is interested in choosing mostly traditional securities, they might choose DCC-GARCH model's weights as it depicts an optimal choice for Beta and standard deviation. In this case, naïve strategy is less effective than DCC. Comparing token portfolios, all EW model portfolios have lower standard deviation than DCC, depicting that larger percentage in cryptocurrency add higher deviations to all portfolios. However, since EW betas are higher than DCC, these results do not provide a definitive output in which token portfolio to invest. Hence, the third portfolio measure Sharpe ratio shall be evaluated below. Nonetheless, according to the statistics discussed, if investor focus is solely on traditional assets, then they would choose DCC model, which provides definitive output for these assets. However, it is difficult to determine whether investing solely in traditional assets or adding tokens would be beneficial, as the results are contradicting. Portfolio Betas in Traditional asset portfolios were higher than some of the token ones, even though standard deviations were lower compared to all token portfolios. Thus, results are skewed and more statistics are necessary to provide a definitive output for the analysed sample. Hence, portfolio Sharpe ratios are further analysed, which might provide better insight to both the choice of optimal portfolio and model.

Sharpe ratio provides insight into portfolio's balance between its risk and returns. It may help compare both the portfolios and whether it is worth investing in tokens and compare the models, i.e. which weights are optimal comparing the returns with risk. In Table 9, Sharpe ratios for portfolios and three of the models analysed are depicted. Firstly, looking at cross-model data, it is observed that GMV provides best results in almost all of the portfolios. The larger Sharpe ratio is, the better portfolio performance is observed. The highest Sharpe ratios are in GMV 2017 portfolios. This can be explained by a significantly low variance and standard deviation within this model, which is due to high clustering of assets only with low deviations. However, this result portrays that the returns are worth investing in as well with GMV model weights, compared to its risk and that taking these two factors into consideration, it is the most optimal option. Furthermore, DCC-GARCH and EW models provided relatively similar results both from absolute figures perspective and between models and portfolios. Largest Sharpe ratios are observed in Traditional asset portfolios, while the lowest are in Cardano portfolio.

Table 9

Portfolio Sharpe ratios

Portfolio	DCC Sharpe ratio	GMV Sharpe ratio	EW Sharpe ratio
	2013-2021		
Traditional	0,22888	0,14474	0,18881
Bitcoin	0,07826	0,14628	0,11893
Litecoin	0,06383	0,14600	0,06976
Ripple	0,06782	0,14603	0,05705
	2017-2021		
Traditional	0,32652	0,37926	0,27081
Cardano	0,04756	0,37869	0,06815
BTC Cash	0,09536	0,37924	0,10177
Ethereum	0,13000	0,37701	0,13498

Source: calculated and prepared by the author. EW – Equal Weights model, GMV – Global Minimum Variance model, CGMV - Constrained Global Minimum Variance model.

Traditional assets have outperformed others by far, depicting the most optimal case between risk and returns out of all portfolios analysed. Considering token portfolios, in DCC model, Ethereum performed significantly better compared to other token portfolios, while with EW model, Bitcoin, Bitcoin Cash and Ethereum have all provided similar results. Hence, in terms of token portfolios, and comparison between DCC and naïve strategy, the latter would be the optimal choice. However, out of all models, GMV provided the greatest result for the investor seeking lower risk and smaller fluctuations for the portfolio returns. Considering token portfolios versus Traditional asset portfolio, traditional assets have taken the lead. Most of the portfolio measures analysed have returned favourable results. Traditional portfolios standard deviations are lower and Sharpe ratios are larger. It is most evident in 2017 portfolios, while 2013 Traditional portfolio indicators are closer to token ones. Comparing only between token portfolios, the optimal choice is Bitcoin, Ethereum and Bitcoin Cash. These cryptocurrencies provide better ratios, which also shows less risk with better returns for the investors. They prove to be relatively more stable among other cryptocurrencies considered and could be an option for risk-seeking investors.

Provided that cryptocurrencies are relatively new type of investments and their fluctuations are quite high, while most traditional portfolio measures are based on asset volatility, cryptocurrencies would usually end up at the bottom of the results. However, more and more investors would choose cryptocurrencies as part of their investment portfolios, which could partly be due to speculative trading. However, it could also be evaluated whether cryptocurrencies can provide an upturn to the portfolios if they are held relatively long-term. The long-term portfolio returns are depicted in Table 10, these returns are calculated with model weights provided by earlier steps of the research for each portfolio.

Table 10

Portfolio all period returns

Portfolio	DCC	GMV	EW
	2013-2021		
Traditional	123,37 %	8,75 %	104,53 %
Bitcoin	3731,62 %	5,69 %	2172,51 %
Litecoin	142,14 %	16,93 %	117,82 %
Ripple	135,85 %	16,93 %	104,59 %
	2017-2021		
Traditional	58,34 %	7,56 %	57,16 %
Cardano	13,04 %	7,43 %	57,21 %
BTC Cash	79,82 %	7,56 %	74,08 %
Ethereum	166,40 %	9,31 %	147,78 %

Source: calculated and prepared by the author. EW – Equal Weights model, GMV – Global Minimum Variance model, CGMV - Constrained Global Minimum Variance model.

First of all, considering the cross-portfolio data, similarly to all of the cases, lowest returns are provided by Traditional asset portfolios. The largest returns – by far – are depicted by Bitcoin portfolio. These results support keeping cryptocurrencies for long-term investment. Although daily returns of tokens are highly volatile and they do provide an increased risk, most of the token portfolios have outperformed traditional asset-only ones. The only token portfolio which was outperformed by traditional assets is Cardano with DCC-GARCH model weights. It also provided a relatively low result, compared to all other models. Looking at cross-model data, lowest returns lie with GMV model. Compared to other models, it provides a steady, low risk return, which is preferred by risk-averse investors. Although the returns are low, they are positive and might be worth investing in long-term. Comparing DCC-GARCH and EW, largest returns, apart from Cardano, are returned by DCC model weights. In DCC, token weights are larger compared to EW, thus, the results show that adding a larger stake of cryptocurrency to long-term investing can provide larger overall portfolio returns. Highest returns are obtained with Bitcoin portfolio, where DCC gives a 3732% return. The second largest token return is Ethereum. It implies that two largest capitalisation tokens are also the best performers within the market. The result could also show more trust from investors towards these two tokens – they are relatively more known than others within the market. Nevertheless, all tokens (except Cardano) provide a higher return than traditional portfolio. Thus, risk-seeking investors might consider including tokens into their portfolios: they do diversify a portfolio, have some hedging opportunities against market risk and have performed well within last few years of investing. However, cryptocurrencies are volatile, high-risk assets prone to large deviations, hence the assessment is individual to each investor's abilities and required risk level. Comparing between models, investors seeking risk would choose

DCC model, as it has outperformed EW naïve strategy in the given case. Risk-averse investors could choose GMV model weights, which provide relatively high stability, low risk and small deviations with positive returns. Thus, although portfolio measures have not provided favourable results to token portfolios, long term "hold" strategy does show a possibility of high upturn. Hence, short-term investment in tokens prove to be very high risk and unpredictable, though current output for long-term investment proves to be profitable.

Considering the analysis performed in chapter 3, conclusions for cryptocurrency performance in investment portfolios are drawn. First of all, it is assessed from key statistics of each variable that tokens are highly volatile assets. S&P 500 index, which is the highest volatility traditional asset considered in this thesis, provides 1,5 times lower maximum daily upturn and loss than the lowest cryptocurrency Bitcoin. This result supports most studies defined in the first chapter of this research, confirming cryptocurrencies are largely volatile and thus, high risk investments. It is also found, that Bitcoin and Ethereum are least affected by outliers, depicting smoother patterns compared to other tokens considered. Furthermore, the analysis of correlations between assets in portfolios estimates cryptocurrencies to be relatively favourable diversifiers. Token correlations with Traditional assets are low, which determines possibilities to hedge against systematic risks of the market. Also, as established in the literature, a diversified portfolio is preferred by investors in order to protect against asset specific risks as well. Portfolio with highly correlated assets is not a favourable option, hence the investments formed in this thesis could protect the invested stake from various risks.

As the initial analysis of the data confirm earlier set expectations, portfolio weights are then established employing 4 models: Equal Weights (EW), Global Minimum Variance (GMV), Constrained Global Minimum Variance (CGMV) and Dynamic Conditional Correlation (DCC) GARCH CGMV models. All models estimate an optimal weight for each asset which altogether minimize portfolio variance. DCC-GARCH, unlike other three models considered, takes into consideration the volatilities of historical returns and adapts into a more dynamic model. The lowest portfolio variance is obtained with GMV model. It is also the most concentrated portfolio, where only two assets take a significant majority (approx. 97%) of the overall portfolio – DXY Dollar index and Euro Futures S&P index. Also, it is analysed within GMV portfolios, that Ethereum portfolio holds lowest variance – not the traditional asset portfolio. It is an important find in terms of this study, as it implies Ethereum might be a choice even for a risk-averse investor, adding to diversification benefits. CGMV model, which includes a 25% weight on cryptocurrencies and 25% weight on S&P 500 index in Traditional asset portfolios. Compared to GMV, average variance of CGMV is 3,578, while GMV is 0,006 - a large difference, supported by the higher stake in risky assets. With CGMV portfolio, Traditional assets clearly stand-out

against token portfolios, where variance is 10 times lower than in considered lowest variance cryptocurrency portfolio. Although DCC-GARCH produced overall lower portfolio variances than CGMV, both models provide relatively similar outcomes: traditional portfolios have outperformed most tokens in terms of variance, however in DCC model, both cryptocurrencies and S&P 500 index have higher weights. To evaluate the portfolios, returns are then determined. Although GMV model provides stability, the returns are quite low. Highest returns are derived with CGMV and DCC-GARCH models, where Cardano and Ripple take lead. Returns in cryptocurrency portfolios are also significantly higher than in traditional asset-only ones, once again determining that higher risk may lead to higher returns. The earlier determined most stable tokens (Ethereum and Bitcoin) did not estimate highest returns. Considering these statistics do not provide a determined single optimal model, portfolio statistics were assessed: portfolio betas, standard deviations and Sharpe ratios. Although GMV model determines lowest standard deviations and relatively high Sharpe ratios, model also reflects mostly highest Betas. This might be due to the fact there is almost no diversification in GMV model. Between EW and DCC-GARCH models, Bitcoin and Ethereum depict best results among cryptocurrency portfolios with highest Sharpe ratios and lowest standard deviations. This also supports earlier determined portfolio variance measures. However, traditional assets take the lead with both largest Sharpe ratios among all portfolios and significantly lower portfolio standard deviation. However, traditional asset Betas are one of the highest comparing to other portfolios. These results imply, that in terms of stability compared to return deviation, traditional asset-only portfolios outperform cryptocurrency ones, however, they do reflect lower diversification drawbacks and are relatively more prone to systematic risks. Also, after assessing the long-term hold strategy returns, it is analysed that cryptocurrencies can bring significantly higher returns than traditional assets-only. Although they come with increased risk, Ethereum and Bitcoin reflect highest returns among all portfolios (not all models with exception to GMV, but GMV includes insignificant part of these cryptocurrencies). Combined with the earlier outcome, indicating Bitcoin and Ethereum also had greatest portfolio measures among token portfolios, investors, who are risk-seeking, might consider adding mentioned tokens to their portfolios. Although traditional asset portfolios depict mostly lower returns, they are positive and have better portfolio measures. Thus, risk-averse investors might favour these investments over including cryptocurrencies and still gain reasonable return.

Thus, cryptocurrencies do diversify traditional asset portfolios and partly provide hedge against systematic risks. However, due to their volatile nature, they also increase overall portfolio return deviation, thus increasing the overall portfolio risk. Although traditional asset-only portfolios provide better performance measure results, cryptocurrency portfolios also provide

advanced economic benefits. The analysed data proves that greater risk can increase investment returns. Risk-averse investors would likely hold traditional assets only, which provide lower portfolio variance, standard deviation and high Sharpe ratios. These investments also provide a relatively stable return. However, investors prone to risk could deem cryptocurrency risk as acceptable, as these portfolios provide significantly greater returns. Among all cryptocurrencies considered, finest outcomes are measured with Bitcoin and Ethereum. These tokens both carry large returns as well as excellent portfolio measures: their portfolio standard deviations are lowest combined with largest Sharpe ratios and Betas lower than 1. By adding cryptocurrencies, portfolio is also more diversified and protected against some of the systematic risks. Also, a long-term portfolio return depicts cryptocurrencies to significantly increase portfolio returns as well.

CONCLUSIONS AND RECOMMENDATIONS

Cryptocurrencies have gained increasing interest in the scientific literature following the first large Bitcoin price boom in 2017. Although the conclusion on whether tokens can be considered as investment is not definitive, various studies conclude that most investors buy cryptocurrencies solely for the purpose of reselling in the secondary market instead of using them as a currency to buy other assets. As investments, tokens are high risk, volatile assets. They often produce price bubbles within cryptocurrency market and are insignificantly regulated as well, providing opportunities for hacker attacks and investment loss. However, blockchain technology allows a new way of finance and provides opportunities to diversify investment portfolios. Although there are hundreds of cryptocurrencies, it is worth analysing those which are present in the market for a longer period of time and hold a relatively large percent of market capitalisation, since many tokens remain in the market for only a short period of time, holding an insignificant market share. This logic is also followed by most researchers, however, frequently only a single cryptocurrency Bitcoin is considered. Though most empirical studies of cryptocurrencies as investments are based on assessing whether they can assist in hedging the portfolio, the findings for market integration between cryptocurrencies and traditional investments are indecisive. The research field of token performance in investment portfolios is relatively limited. However, similarly to earlier discussed studies, the focus is mostly on Bitcoin alone. The outcomes of these studies are contradicting as well, which may be caused by particular time frames analysed, also, different traditional markets and models studied.

Though study methods in empirical research including cryptocurrencies in investment portfolios vary, most commonly used model is GARCH and its variants. Thus, DCC-GARCH together with other statistical methods, namely Global Minimum Variance and Constrained Global Minimum Variance, which minimize the variance of portfolio by choosing optimal asset weights are employed. Minimizing the variance is one of the measures suggested by the Modern Portfolio Theory, however, the returns must be analysed as well. Thus, the returns are derived employing the weights obtained with the mentioned models. The returns are then evaluated and compared within models and portfolios to assess the differences and performance of traditional asset-only portfolios and their changes after adding cryptocurrencies.

This research includes 6 cryptocurrencies – Bitcoin, Ethereum, Litecoin, Ripple, Cardano and Bitcoin Cash and 4 traditional assets: S&P 500 index, DXY Dollar index, Euro Futures S&P index and GSCI Gold index. The initial analysis of chosen cryptocurrencies and traditional assets show low integration between the markets and considers tokens to be a possible hedge against

systematic risks. The portfolio weight analysis reflects that lowest variance is obtained by adding 2 traditional assets only: DXY Dollar and Euro Futures indices. Other cryptocurrencies have either insignificant weights and Bitcoin is even shorted. After adding a constraint for cryptocurrency weights to equal or be greater than 25%, portfolio variances increase significantly. These results are then paired with return data. Portfolios including cryptocurrencies outperform Traditional asset returns. Largest returns are obtained with DCC-GARCH portfolio, which, in contrast with other models, includes largest amount for cryptocurrency and S&P 500 investments. Then, performance measures are obtained and evaluated: portfolio Betas, portfolio standard deviations and Sharpe ratios. The most optimal results regarding standard deviation and Sharpe ratios are obtained in Traditional asset portfolios. They outperform cryptocurrency portfolios by far, demonstrating an optimal choice between risk and returns. However, portfolio Betas are lower in some of the cryptocurrency portfolios, which support a diversification argument. In terms of cryptocurrency portfolios, they have provided significantly greater returns both in long-term investing and daily returns, however, due to heavy volatility and risk, their portfolio measures are not optimal if assessed against traditional asset portfolios. The preferred choice of cryptocurrencies to add in an investment portfolio for diversification are Bitcoin and Ethereum. Both tokens provide large returns, relatively low portfolio standard deviation and high Sharpe ratios.

Recommendations.

1. Considering the results retrieved with empirical study, the most optimal choice for risk averse investors would be traditional asset portfolios with GMV model weights. They have returned lowest portfolio variance, Sharpe ratios and standard deviations. Traditional investments have also provided positive stable returns. However, higher risk tolerance investors could favour portfolios diversified with cryptocurrencies, as they provide significantly increased returns. Considering cryptocurrencies are added, optimal choices are Ethereum and Bitcoin, which provide favourable portfolio performance measures along with increased returns.
2. Acknowledging research limitations, additional traditional assets could be studied in further researches. Although this analysis includes major traditional asset indexes, it would be beneficial to add more assets in order to assess the overall market better. Furthermore, considering cryptocurrencies are traded on many different exchanges, the prices vary and differences may arise comparing the data.
3. Additional new performance measures could be considered. Since most existing statistical portfolio performance measures account heavily for volatility, cryptocurrencies have been outperformed by traditional assets due to their frequent fluctuations. Although the models employed in this thesis were considered optimal options by most analysed researches, new improved models might be developed to better evaluate cryptocurrencies as a new asset class.

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KRIPTOVALIUTŲ ĮTAKA INVESTICINIO PORTFELIO GRĄŽAI

Eglė RIMŠAITĖ

Magistro baigiamasis darbas

Finansų ir bankininkystės programa

Ekonomikos ir verslo administravimo fakultetas, Vilniaus universitetas

Darbo vadovė doc. Dr. Alfreda Šapkauskienė Vilnius, 2022

SANTRAUKA

59 lapai, 10 lentelių, 3 paveikslai, 59 šaltiniai.

Pagrindinis šio magistro baigiamojo darbo tikslas yra įvertinti kriptovaliutų įtaką diversifikuoto investicinio portfelio grąžai.

Darbą sudaro 3 pagrindinės dalys: literatūros, vertinančios kriptovaliutų investicinę naudą, analizė; tinkamos tyrimo metodologijos parinkimas, paaiškinimas ir detalizavimas; empirinio tyrimo atlikimas bei rezultatų vertinimas, taip pat išvadų ir rekomendacijų pateikimas.

Mokslinėje literatūroje kriptovaliutos neretai yra analizuojamos kaip portfelio diversifikavimo priemonė. Empiriniai tyrimai, vertinantys kriptovaliutų įtaką investicinių portfelių grąžai pateikia nevienareikšmiškus rezultatus, bei dažnai įtraukia vienintelę kriptovaliutą Bitcoin. Tam, kad tiksliau įvertinti visą kriptovaliutų įtaką, į tyrimus galima būtų įtraukti papildomas didelės kapitalizacijos kriptovaliutas.

Nustatyta, kad nagrinėtoje mokslinėje literatūroje dažnai naudojamas tyrimo metodas yra GARCH modeliai. Šiam tyrimui atlikti buvo pasirinkti 4 modeliai portfelių svoriams nustatyti: vienodų svorių, minimalios globalios dispersijos bei apribotos minimalios globalios dispersijos modeliai bei DCC-GARCH metodas. Sudaryti 2 tradicinių investicijų portfeliai bei 6 kriptovaliutų modeliai, kurių kiekvieną sudaro tradicinės valiutos bei viena kriptovaliuta. Įvertinus modelių svorius, apskaičiuotos portfelių grąžos. Tuomet buvo įvertinti investicinių portfelių gražų rodikliai: portfelių beta rodikliai, portfelių standartiniai nuokrypiai bei Šarpo rodikliai.

Nustatyta, kad kriptovaliutų investiciniai portfeliai suteikia didesnę grąžą, tačiau rizikos bei kintamumo požiūriu nepralenkia tradicinių investicijų. Įvertinus portfelių vertinimo kriterijus nustatyta, kad rizikos vengiantys investuotojai rinktųsi tradicines investicijas bei minimalios globalios dispersijos modelio svorius. Jie suteikia didžiausius Šarpo rodiklius ir mažiausius portfelių standartinius nuokrypius ir dispersijas. Tiesa, tradicinių investicijų portfelių Betos yra didesnės. Tačiau tikintis didesnio pelno, verta investuoti į Bitcoin bei Ethereum kriptovaliutų portfelius su DCC-GARCH modelio svoriais. Šie investiciniai portfeliai pasižymi sąlyginai aukštu Šarpo rodikliu bei žemu portfelio standartiniu nuokrypiu, o teikiama investicinė grąža yra itin didelė.

Išvadose ir rekomendacijose apibendrinama pagrindinė darbe pateikta informacija bei kertinės išvados, taip pat nurodomi tyrimo apribojimai. Nurodoma, kad tolimesniuose tyrimuose galėtų būti įtraukta papildomų tradicinių investicinių vienetų. Taip pat, kadangi pagrindiniai modelių vertinimo kriterijai yra grindžiami kintamumu, kriptovaliutoms galėtų būti pritaikyti nauji vertinimo modeliai.

APPENDICES

Appendix 1. Autocorrelation in 2013 portfolio variables

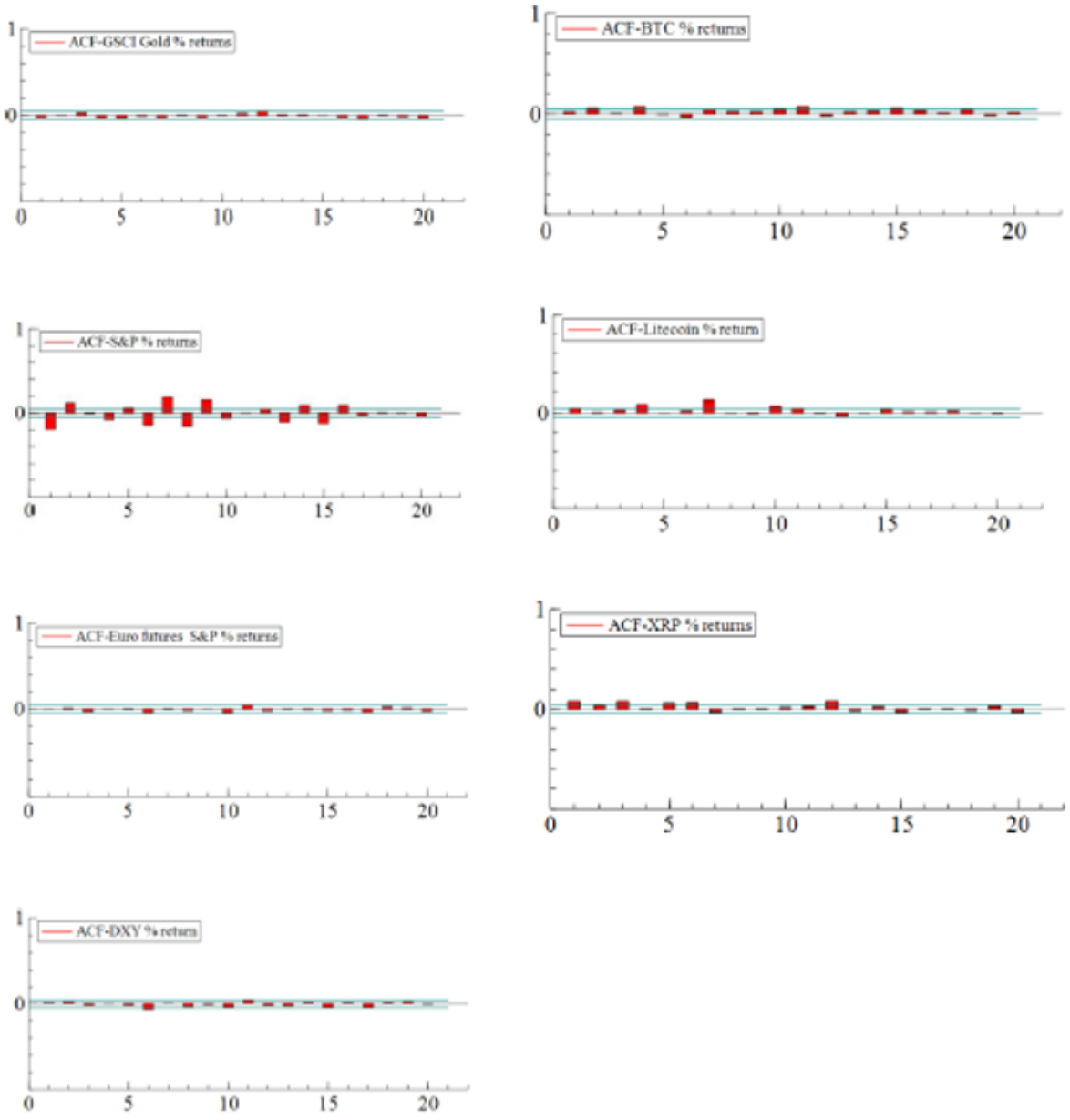

Figure 2. Autocorrelation of variables in portfolios years 2013-2021

Source: data gathered by the author, graphs extracted with OX Metrics software.

Appendix 2. Autocorrelation in 2017 portfolio variables

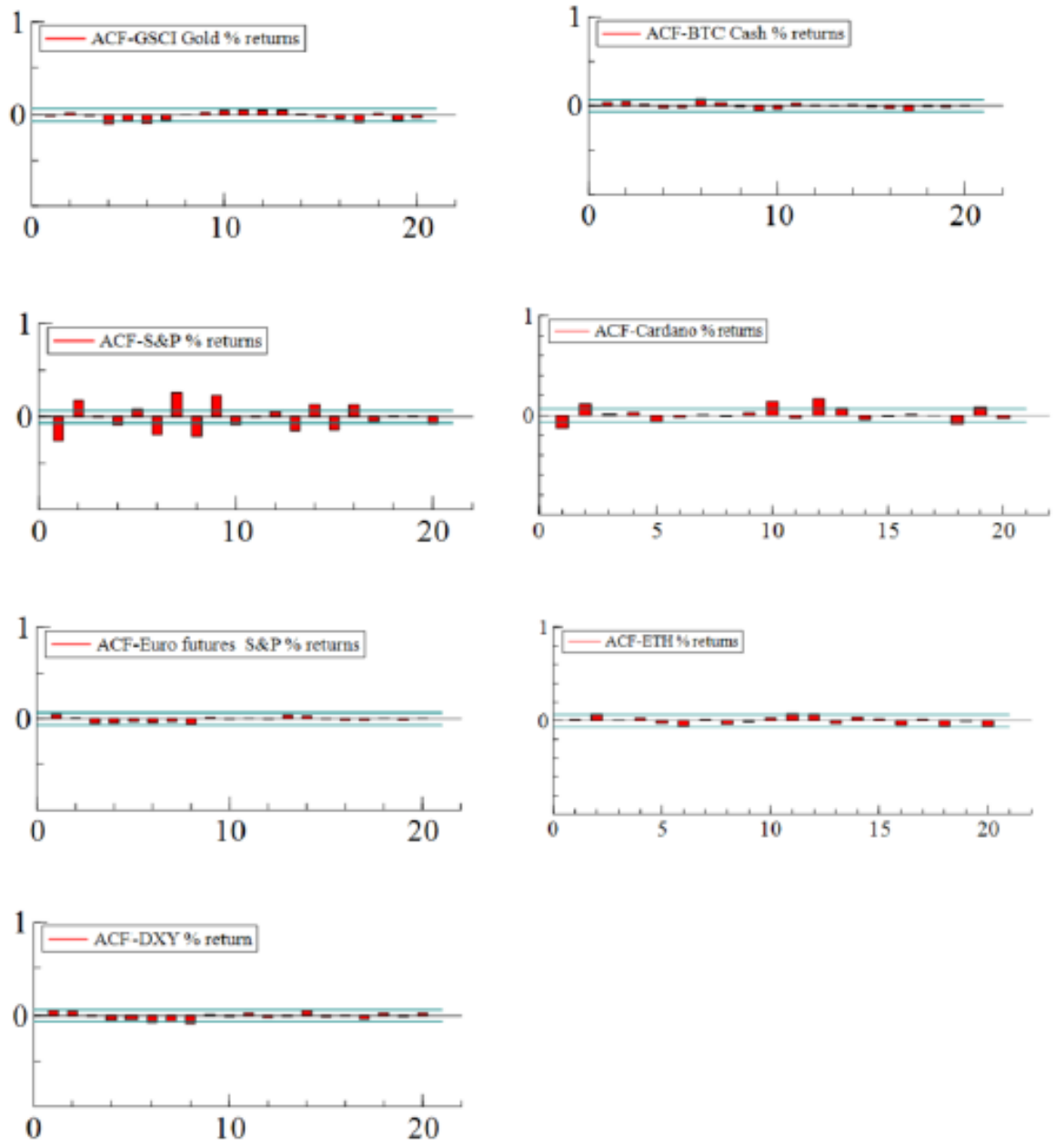

Figure 3. Autocorrelation of variables in portfolios years 2017-2021.

Source: data gathered by the author, graphs extracted with OX Metrics software.