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Portfolio optimization in the era of digital financialization using cryptocurrencies

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ABSTRACT

The Fourth industrial revolution has seen many innovative technologies that are now challenging traditional economies. The innovative and technological financial instruments are inspiring individuals and expert investors to investigate the broader investment spectrum, and consequently diversify their portfolios. Going beyond the conventional portfolios and developing state-of-the-art strategies that comply with the ever-changing financial and technological advancements are the keys to long term sustainability. Therefore, to cater to the needs of all segments of the society, the investment strategies during the fourth industrial revolution demand exposure to technological and digital financial innovations. This study investigates the impact of diversification with the addition of five cryptocurrencies from November 2015 to November 2019 on four traditional asset portfolios. The results show that the diversification increased the returns in most of the cases, and reduced the portfolio volatility in all portfolios, and also provided higher returns as compared to the traditional portfolios for the same level of risk. This study also revealed that the results might improve when short sales are allowed. Moreover, we can conclude that the addition of multiple cryptocurrencies in a portfolio provides enhanced results for diversification, and Ethereum provides a better diversification opportunity as compared to Bitcoin.

1. Introduction and literature review

The recent years have seen tremendous growth in innovative technologies that demand a restructuring of the traditional global economy. Many advances in technology are changing every aspect of the way that we live, work, commute or even think and process things; this is an era that is termed as the fourth industrial evolution by Klaus Schwab. Schwab (2017) defines the Fourth industrial revolution as a socio-technical process that is affecting the digital, physical, and biological domains. This change is based on the effective and innovative exploitation of new and emerging digital technologies, through their fusion and interaction with each other. Indeed, there is no denying that the recent digital transformation is influencing all the sectors and industries of the world, with new models and innovations that are frequently required to rely on digital technologies and systems (Geissbauer et al., n.d.). The financial systems are already experiencing the effects of one such technological advancement, in the form of digital currencies and blockchains (Su et al., 2020c; Tapscott and Tapscott, 2016). It is safe to say that these currencies and blockchains are challenging as well as changing the traditional financial system, that too rapidly. Klaus Schwab, in a piece of recent news,[1] coined in that the concept and practice of blockchain, is at the heart of the fourth industrial revolution. His article further indicated that in order for the fourth industrial revolution to be successful, Bitcoin – which is the most famous, and disruptive digital currency - must be given its due credit and importance, as it provides an open and borderless payment protocol to be exercised.

The invention of the digital currencies in 2008, and a sharp increase in the prices of Bitcoin during the year 2017, sparked immense criticism around this trend in the global financial and economic circles. The individuals who invested in the digital currencies, by buying or earning the coins, gained tremendous rewards during this period. The investment into, or the allocation of money to benefit from a financial initiative in the future is a common trait in human behavior, as an attempt to secure oneself against any uncertainty that one might face. To many, investing and managing an investment portfolio is a profession.

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[1] https://news.bitcoin.com/bitcoin-fourth-industrial-revolution/

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To some, however, it is a hobby, and to many, these investments provide financial security after retirement. Most often, employees in different companies are allowed to invest in retirement or provident funds. These funds are developed and managed to earn good rewards while also keeping their risks low in order to avoid any significant losses. Moreover, non-profit organizations utilize additional income from the endowment fund investments in order to operate and manage their activities. Investment, therefore, becomes a societal need, especially when it comes to managing or investing for one's retirement or endowment funds. As we are hovering in the fourth industrial revolution, the investments and their management has become an even more challenging task, especially with the advent of innovative technologies and sound financial systems. It is imperative to take advantage of the technological revolution, the upcoming financial systems, and the worldwide web in order to make wise investments to secure bright financial prospects and for the betterment of the society.

However, firstly, we need to get down to the basics of what cryptocurrencies are. The basic definition of cryptocurrencies states that it is a medium of exchange, but unlike traditional currency, it is independent of national borders and central banks (Maese et al., 2016). Cryptocurrencies are strings of complicated computational bits and blockchains that are designed to work as a means of payment or exchange of value. These blockchains that were first introduced by Nakamoto (2008), function as building blocks of the digital money system(s), with usually no central authority overseeing the ledgers, wealth creation processes or the security systems, and also have negligible counterparty risks involved. Cryptocurrencies have caught much attention from industry participants, individuals, and experts. The market capitalization of cryptocurrencies stands at 194+ billion USD, as of early in the year 2020. Interestingly, Bitcoin has taken the lead, as of now, with a market capitalization of 124 billion USD, making it the most popular cryptocurrency available in the market.

The cryptocurrencies and the blockchain technology, which make the digital currencies, are disrupting and challenging the traditional financial systems in many ways. The high costs of financial intermediaries, transactional delays, and paperwork, act as an added burden on the consumers. The technological advancements, that the currencies offer, not only do not require an intermediary to verify the transactions or identities of individuals, but also reduce the time required for these transactions, hence providing a transparent system for recording the data and information. In the same stride, the blockchain technologies are changing the banking system by possessing the capacity to facilitate smart contracts, electronic banking ledgers, and money remittances, that too on a global level (Peters and Panayi, 2016). Effective electronic business models are now being proposed using blockchain's peer to peer transaction mode (Su et al., 2020b; Zhang and Wen, 2017).

In addition to this, the blockchain technology also allows firms, of any size, to raise funds through peer-to-peer, globally distributed share offerings, or the initial coin offerings. The initial coin offerings not only brings the global investors together but also removes the requirement of any intermediaries, investment bankers, or auditors, which automatically reduces the costs incurred to the relevant companies. In the year 2018 alone, a staggering amount of 550 million USD was raised through initial coin offerings (ICO), a figure that was higher than the amount raised through any traditional channels (Perez et al., 2020). The technical algorithm that makes the blockchain can reduce transactional costs for stakeholders, eliminate the third-party intermediaries, and also improve the entrepreneurial financing ecosystem (Ahluwalia et al., 2020). With a new form of crowdfunding undertaken through the advent of cryptocurrencies, the factors that drive the ICO returns are also studied in detail. Domingo et al. (Domingo et al., 2020) based an empirical study on 125 ICOs, spanning from a period that started in December 2017 till December 2018. This study reported that bitcoin spot and futures returns tend to have a positive effect on the ICO returns. In contrast, the presale period of the ICO tends to have a negative effect on the ICO returns.

Over the years, the increase in the research conducted on cryptocurrencies and the underlying blockchain technology has been profound. While individuals are fearlessly using the currency for payments, mining to earn rewards, or direct buying and selling for investment purposes, the experts are skeptical of the different aspects of the currency, and its subsequent future. With the skepticism, hype, and investments in the cryptocurrencies, the researchers have been exploring and investigating the universe of digital currencies. Cryptocurrencies, Bitcoin, and blockchain are also considered to be a significant part of the evolving FinTech. Although the focus of the research conducted in the diameter of FinTech, from the years of 2007 to 2013, was on the business models and mobile payments, researchers were putting in more effort into studying the blockchain and bitcoins from the year 2013 and onwards (Liu et al., 2020). While many researchers focused their research on the positives of the cryptocurrencies and blockchains, some suggested moderating the expectations regarding their benefits to the society, and the potential value that they might possess, along with the high potential of illicit use anywhere along the way (Corbet et al., 2019). Furthermore, it is not just the technology behind the cryptocurrencies and the digital currencies that is disruptive for the financial systems. The leading cryptocurrency Bitcoin, and the blockchain technology, had given way to 30 percent cumulated average abnormal returns when the companies changed their names to include the buzzwords that were related to cryptocurrencies (Sharma et al., 2020).

Cryptocurrencies and blockchain technologies are shaping the financial systems, and are a significant part of the ongoing global financial innovation. Khraisha and Arthur (2018) defined financial innovation as a process that is carried out by any institution involving the creation and adoption of new products and platforms. The latest products and platforms enable technologies to introduce innovative ways in which financial activities can be carried out. They further suggested that blockchain and PayPal are financial innovations that have been introduced by non-financial institutions. Bianchetti et al. (2018) commented that cryptocurrencies had brought two main innovations into the limelight. These innovations included the technology behind the blockchain or ledgers and the decentralized ways of governance. Many authors have argued that the blockchain technology that works behind the cryptocurrencies is a potential breakthrough in financial innovation (Glaser and Bezzenberger, 2015; Su et al., 2019; Vora, 2015). Olusegun Vincent& Olaniyi Evans (2019) also conducted an empirical study, showing that higher levels of financial inclusion and development were observed in China, India, Nigeria, and South Africa, for higher levels of cryptocurrency, internet usage, and mobile subscriptions.

In addition to financial innovation, blockchain technologies and cryptocurrencies also help in developing financial inclusion. Financial inclusion is a process that guarantees availability, ease of access, and usage of formal financial systems, for all the members of a particular economy, Moreover, it also entails the use of financial services (Allen et al., 2016). Rodima-Taylor and Grimes (Rodima-Taylor and Grimes, 2018) argued that remittances through cryptocurrencies and mobile transfers could facilitate a shift in paradigm in financial inclusion and locally innovative ecosystems. They also suggest that digital financial inclusion would be likely to provide solutions to a significant chunk of the unbanked people so that they can effectively communicate with the formal financial systems. It may, therefore, be argued that the digitalization of financial systems, through financial innovation in the form of blockchain and cryptocurrencies, provides financial inclusiveness to the marginal components of the society.

In the extant literature, various authors have discussed the effects of financial innovation on the portfolio risk diversification. The financial innovations have not only brought down the costs associated with the traditional financial systems, but have also provided a broader range of technologically sophisticated, and innovative products into the market. Allen and Gale (Franklin and Douglas, 1994) also had a traditional point of view, wherein they believe that the financial innovations facilitate the risk minimization of the portfolios, by providing better

diversification features. In contrast, Simsek (2013a, 2013b) argued that due to the speculative trading, innovative instruments, increase the riskiness of the portfolios. With the rise in the prices, interest rates, and the attention is given to cryptocurrencies and other financial innovations during the Fourth industrial revolution, research on the prospects of diversification of the products is indeed the need of the hour.

The classification of cryptocurrencies as currencies, financial assets, commodities, or other forms of a financial product, has raised a considerable amount of discussion, as well as criticism with researchers, who have varied opinions on this matter. Empirical studies in the past have shown that uninformed users have approached the cryptocurrencies as an alternative form of an investment vehicle, instead of an alternative transactional vehicle (Glaser et al., 2014). Studies show that Bitcoin does not correlate with traditional assets, such as stock and bonds, and is primarily used as a speculative investment, rather than a medium of exchange (Baur et al., 2018). Some researchers argue that Bitcoin does not behave like a conventional currency, asset, or security. However, it somewhat resembles a technology-driven product, a bubble event, or even an emerging asset class (White et al., 2020). They argued that the magnitude of the long-term appreciation of Bitcoin is much higher than the paper currencies. They further discussed that the characteristics of the risk and return, and the inverse correlation with other currencies could make Bitcoin, a potentially viable portfolio investment. Researchers undertook further research, on the efficiency of the cryptocurrencies (Tran and Leirvik, 2020; Urquhart, 2016; Hu et al., 2019), the price discovery (Kapar and Olmo, 2019), volatility (Ardia et al., 2019; Baur and Dimpfl, 2018) and the conditional tail-risk (Borri, 2019), are some of the contributions of the digital currencies, towards market efficiency, pricing, and risk behavior.

The investments in cryptocurrencies saw a rise during the year 2017 when Bitcoin was brought into the limelight by an upsurge in its price. Many naïve and experienced investors invested in these cryptocurrencies. On the other hand, the experts were criticizing the speculative nature of these currencies. This emerging technological currency opened many avenues for researchers who were interested in the financial markets. It was observed that while investing in a single cryptocurrency was considered to be a riskier deal, the fund managers and researchers explored the diversification through portfolio investment, which somewhat buffered the risk factor. Based on the time between the year 2010–2013, Brière et al. (2015) investigated more in-depth the potential of Bitcoin as a tool to diversify a portfolio of traditional, and alternative assets. They concluded that if Bitcoin is included in the portfolio, even if representing it in a relatively smaller proportion, it may significantly improve the risk and return profile of a well-diversified portfolio. Platanakis et al. (2018) ran a comparative analysis of the Markowitz Optimal Portfolio (Markowitz, 1952), for four cryptocurrencies, with the Naïve (*1/N*) Portfolio, and concluded that the Naïve Portfolio performed just as well, if not better than the Markowitz Optimal Portfolio. Brauneis and Mestel applied the Markowitz's mean-variance analysis, in order to test the risk and return benefits of a portfolio of the top 500 cryptocurrencies, according to the market capitalization (Brauneis and Mestel, 2019). They also provided a comparative analysis of the different portfolios, based on the data available from January 2015 to December 2017.

The inclusion of Bitcoin, in a traditional hedging portfolio of gold, oil, and equities, reduces the risk of the portfolio by a considerable level. Guesmi et al. (2019) and Su et al., 2020a, 2020d, also argued that a short position in the market, hedges the risk in different financial asset investments. The inclusion of Bitcoin, in a well-diversified portfolio which comprises of different asset classes, provides certain significant statistical benefits when it comes to diversification (Symitsi and Chalvatzis, 2019). Symitsi and Chalvatzis provided an extensive analysis of the economic value of Bitcoin and suggested that the decrease in the portfolio risk comes from the low correlations between the assets and Bitcoin. Also, further contributing to the literature, Platanakis and Urquhart highlighted that, given the higher potential estimation error in a portfolio of cryptocurrencies, the portfolio theory might face significant difficulties (Platanakis and Urquhart, 2019). In another research study, Liu, (2019) analyzed the results of portfolio diversification on six different portfolios of the ten cryptocurrencies taken into account and found that the Naïve Portfolio performed better than all the other portfolios when calculating the return and risk profile using the Sharpe ratio. Moreover, Trimborn et al. (2017) suggested a liquidity bound risk-return optimization approach due to the low liquidity of the cryptocurrencies while optimizing a portfolio of stocks, bonds, and commodities. Using the mean-variance optimization, and the risk-parity on a data of cryptocurrencies, spanning from January 2015 to December 2017, Petukhina et al. (2018) observed that cryptocurrencies provided higher returns, and were particularly useful for strategies that demanded higher returns, and did not play an active role in the minimizing variance.

Additionally, in their paper, Kajtazi and Moro (2019) considered three different geographical locations, i.e., the US, European, and Chinses markets, in order to study the diversification properties of three different portfolios, with the inclusion of Bitcoin. They analyzed the performance of the Naïve, long-only, and semi-constrained portfolios in the three markets, with the inclusion of Bitcoin, on a set of daily data, spanning from February 2012 to January 2017. The results showed that Bitcoin might have played an active role in the diversification of existing, well-diversified portfolios, primarily by increasing the returns than in reducing the risk of the portfolios. In addition to this, Borri (2019) also suggested that a well-diversified portfolio of cryptocurrencies provided better risk-adjusted, and conditional returns, as compared to the individual cryptocurrencies, when analyzing the data of four cryptocurrencies in the period spanning from January 2017 to April 2018. Table 1 provides a summary of the research conducted on the diversification of portfolios using different cryptocurrencies.

Whether cryptocurrency is considered to be a financial or speculative investment asset, or as an innovative technological product, the endowment fund managers have also shown interest in the investments made in cryptocurrency, primarily to diversify their portfolios. In October 2018, several articles were published stating that a fund manager at Yale University, USA, had invested in a cryptocurrency fund[2]. In April 2019, Bloomberg published that one of the largest endowment funds at Harvard University (USA) took part in a crypto token sale. Furthermore, in April 2019, CCN[3] also published a survey, quoting that 94% (141 out of 150) endowment funds had invested in cryptocurrencies in the last 12 months. Moreover, Virginia's police department not only invested in the endowment fund, but in the year 2019, it also became the first institution in America to invest their pension funds in the blockchain-based technology[4].

Hence, this paper suggests the diversification of the existing portfolios with multiple cryptocurrencies. The existing portfolios are developed from the stocks from the general firms, stocks from technological companies, currency, and commodities. The selection of the stocks is based on their performance, and the top-performing stocks have been chosen for the analysis. The data used in the study spanned from November 2015 to November 2019. During this time, the cryptocurrencies experienced a sharp upward growth (2017, max = $19497.40), high volatility (2017- current), and also a decline (2019, ~$3,300).

This study contributes to the existing literature in three ways. Firstly, the study investigates the diversification of multiple portfolios by adding multiple cryptocurrencies in the existing portfolios on a

[2] https://www.bloomberg.com/news/articles/2018-10-05/yale-is-said-to-invest-in-crypto-fund-that-raised-400-million

[3] https://www.ccn.com/shock-survey-94-of-endowments-already-invested-in-crypto-industry/

[4] https://hedgetrade.com/pension-funds-with-cryptocurrency-gain-momentum/

Table 1
Summary of literature review on diversification of portfolios with cryptocurrencies.

Authors	Variables	Data Range	Results
(Brière et al., 2015)	Bitcoin, stocks, bonds, hard currencies, real estate, hedge funds, commodities	July 23, 2010 – December 27, 2013 (weekly)	Including bitcoin even in a small proportion in a well-diversified portfolio may improve risk-return characteristics.
(Trimborn et al., 2017)	42 cryptocurrencies, S&P 100, Barclays Capital US Aggregate Index, S&P GSCI	April 22, 2014 – October 30, 2017 (daily)	Including cryptocurrencies in the portfolio can bring significant gains to the investors. Bitcoin is not the most appealing cryptocurrency in terms of risk-return optimization.
(Platanakis et al., 2018)	Bitcoin, Litecoin, Ripple, and Dash on (cryptocurrencies only)	February 21, 2014 – January 26, 2018 (Weekly data)	Naïve diversification is good, if not better than the optimal mean-variance.
(Petukhina et al., 2018)	55 cryptocurrencies, 5 equity indices, 4 fixed income securities, 4 currencies, 2 commodities	January 2015-December 2017 (daily)	Cryptocurrencies can improve the risk-return profile of a portfolio. The observation is more useful for high-targeted returns strategies.
(Platanakis and Urquhart, 2019)	Bitcoin, Litecoin, Ripple, and Dash on (cryptocurrencies only)	February 21, 2014 – May 4, 2018 (weekly data)	Sophisticated portfolio techniques that control the estimation errors are preferred
(Brauneis and Mestel, 2019)	500 cryptocurrencies	January 2015-December 2017 (daily)	Substantial potential for risk reduction, when several cryptocurrencies are mixed. In terms of Sharpe ratio and equivalent certainty returns, the 1/N portfolio outperforms single cryptocurrencies and more than 75% of the mean-variance optimal portfolios.
(Guesmi et al., 2019)	Bitcoin, gold, oil, MSCI Emerging market index, MSCI global market index, implied volatility index	January 2012-January 5, 2018	Adding Bitcoin to a portfolio of gold, oil, and equity reduces the portfolio's risk considerably. A short position in Bitcoin allows for hedging against the different markets.
(Symitsi and Chalvatzis, 2019)	Bitcoin, currencies, gold, oil, real estate, and bonds	September 20, 2011 – July 14, 2017 (daily)	Significant diversification benefits were being observed for equal-weighted, and optimal mean-variance portfolios.
(Liu, 2019)	10 cryptocurrencies	August 07, 2015 – April 9, 2018 (trading days)	Diversification among cryptocurrencies can enhance the Sharpe ratio and the utility; Most models cannot beat the naïve (1/N) rule under the Sharpe ratio criteria.
(Kajtazi and Moro, 2019)	Bitcoin (indexed in USD, Euros, CNY), equities, fixed income, commodities, real estate, currencies and alternative investments in the US, Europe, and Chinese Markets	February 2012 – January 31, 2017 (daily)	Adding Bitcoin to a well-diversified portfolio improves its performance by increasing the returns more than the reduction in the volatility. Bitcoin may have a role in diversification.
(Borri, 2019)	Bitcoin, Ether, Ripple, Litecoin	January 17, 2017 – April 15, 2018 (daily)	The portfolio of cryptocurrencies provides better risk-adjusted and conditional returns than the individual cryptocurrencies.

recent data set. In the previous studies, either the portfolio of cryptocurrencies or the diversification using Bitcoin only is investigated. In this context, the only two studies that have been conducted by taking into account multiple cryptocurrencies are by Trimborn et al. (2017) and Petukhina et al. (2018), on a data set extracted from a period spanning from 2014 to 2017. However, the past two years are crucial in terms of the growth in cryptocurrencies, a decline (lowest value of $3,236.76 for bitcoin), and an eventual recovery in the prices of the cryptocurrencies, which was presumed to be a bubble, that has survived so far.

Secondly, the study provides risk-return profiles, with and without the addition of cryptocurrencies in the existing portfolios, and also provides a comparison of the efficient frontier for the mean-variance analysis. It is interesting to put forth that such an analysis has not been carried out previously for the portfolios, with several cryptocurrencies taken into account. Therefore, making this study the first of its kind, in this regard. Furthermore, we have also used various metrics for portfolio optimization. These include the Naïve portfolio, the mean-variance portfolio, and the optimization using the Sharpe ration. The analysis has revealed that the diversified portfolios that take into account cryptocurrencies provide better returns for a given level of risk when compared to the asset portfolios without any cryptocurrencies.

Furthermore, our results also show that including cryptocurrencies in an existing portfolio, significantly reduces the risk, and also increases the Sharpe ratio. In some cases, the returns provided by the diversified portfolios have been higher, while simultaneously reducing the risk. We also observed that when the short sales of assets are allowed, the results for diversification improve significantly.

Thirdly, our study also highlights that Ethereum provides better diversification results as compared to the results of diversification achieved through Bitcoin. In the literature, most studies have been conducted on the diversification achieved through Bitcoin only. Hence, our study encourages financial analysts, and investors, to explore cryptocurrencies other than Bitcoin, for their investment and diversification purposes.

The rest of the paper is organized as follows. Section 2 provides the data and methodologies used in the study. In Section 3, the results of different portfolios, and their diversification using different cryptocurrencies are summarized. Discussion on the results and other findings are presented in Section 4. Section 5 concludes the paper.

2. Data and methodology

In this section, we provide the methodology that we take into account, for the data analysis, along with the data set. It must also be known that the standard measures for portfolio optimization are being used in this particular study. Moreover, the study evaluates four different portfolios for the performance analysis with the addition of cryptocurrencies. The performance is measured according to three different portfolio matrics. The first one is the Naïve portfolio, which propagates the equal distribution of the weights across all the components of the portfolio. The second metric used is the Markowitz Mean-Variance portfolio, which maximizes the expected return of the portfolio, for a given variance, in order to plot the efficient frontier for each of the asset classes, and also its diversification using the different cryptocurrencies. Thirdly, an Optimized Sharpe ratio is also used in order to investigate the portfolios' performance.

Table 2
Assets used in the study.

Cryptocurrencies	*Stocks (Technological firms)*	*Stocks*	*Currency Exchange rates*	*Commodities*
Bitcoin	Microsoft Corporation (MSFT)	Berkshire Hathaway Inc (BRKa)	US Dollar/Euros	Copper
Ethereum	Apple Inc (AAPL)	JPMorgan Chase & co. (JPM)	US Dollar/Japanese Yen	Gold
Ripple	Alphabet Class Inc A (GOOGL)	Johnson & Johnson (JNJ)	US Dollar/Canadian Dollar	Coffee
Bitcoin Cash	Amazon.com Inc (AMZN)	Procter & Gamble Company (PG)	US Dollar/British Pound	
Litecoin	Facebook Inc (FB)	Visa Inc Class A (V)	US Dollar/Australian Dollar	

2.1. Data

The study explores the effects of cryptocurrencies on the portfolios of different asset classes. The cryptocurrencies used in the analysis, Bitcoin, Ethereum, Ripple, Bitcoin Cash, and Litecoin, are the top five cryptocurrencies according to the market cap. The data on the cryptocurrencies is collected from coinmarketcap.com, from November 10, 2015, to November 09, 2019, daily. The data on cryptocurrencies account for 1460 entries on each of the currencies, with a total of 7300 observations for all cryptocurrencies. The study also considers multiple portfolios and optimization techniques with the addition of cryptocurrencies in the existing portfolios on stocks, technological firm stocks, currencies, and commodities. Furthermore, the data for each of the assets is taken for the same period and has been collected from Bloomberg.com. Table 2 provides a comprehensive list of all the assets and currencies used in this study. In addition to the data on cryptocurrencies and assets, the risk-free rates used in the study are the 1-year US Treasury note rates, recorded on November 09, 2019.

Table 3 provides the descriptive statistics of the stocks, currencies, commodities, and cryptocurrencies that are used in the study. It is observed that four out of the five cryptocurrencies taken into consideration, provide exceptional returns, where Ethereum provided an average annualized return of 92.4%. Interestingly, the volatility of the cryptocurrencies is also exceptionally high, with Bitcoin cash experiencing the highest volatility at nearly 130%. It is noteworthy that the innovative financial products are difficult to value. The evaluation is difficult in the case of cryptocurrencies, especially since they exhibit bubble-like features as well (Frehen et al., 2013). A high level of kurtosis has also been observed in some of the cryptocurrencies. The highest kurtosis has been reported in XRP, at the value of 42.2, indicating the presence of extreme risk. However, the kurtosis of other cryptocurrencies is comparable with most technological or other company stocks. For instance, the kurtosis for Bitcoin and Ethereum stands at a numerical value around 4, and for Apple, Google, Microsoft, and JP Morgan, the same stands in a similar range as well. Facebook and Johnsons & Johnsons also have high kurtosis values at 23 and 14, respectively. The high values of kurtosis and skewness open further prospects of research in the cryptocurrencies and the investment universe.

2.2. Optimization techniques

In this subsection, we provide the optimization techniques that have been used in the study. After collecting the data on cryptocurrencies and assets daily, we have calculated the log-returns by using the formula,

$$r_{i,t} = \log\left[\frac{P_{i,t}}{P_{i,t-1}}\right],$$

where $P_{i,t}$ is the price of i^{th} asset in the data at time t. $P_{i,t-1}$ is the price of the same asset at time t- 1 (that is on the previous day), $r_{i,t}$ is the return on asset i, at time t. Using the data, we have calculated the expected return μ_i and standard deviation σ_i for asset i by using the following formulae.

$$\mu_i = \mathbf{E}(r_i) = \frac{\sum_{t=1}^{n} r_{i,t}}{n},$$

$$\sigma_i = \sqrt{\frac{\sum_{t=1}^{n} (r_{i,t} - \mu_i)^2}{n-1}},$$

where t is the number of observations for asset i. Once the returns and

Table 3
This table provides descriptive statistics (mean, median, maximum, and minimum returns, standard deviation, volatility, skewness, and kurtosis) of daily returns in USD of the assets, currencies, commodities, and cryptocurrencies used in the study over the period between November 10, 2015, and November 09, 2019.

	MSFT	AAPL	GOOGl	AMZN	FB	B Rka	JPM	JnJ	P&G	V	USD/EUR	USD/JPY
Mean	0.100%	0.080%	0.054%	0.099%	0.057%	0.049%	0.065%	0.027%	0.045%	0.081%	-0.003%	-0.011%
Ann mean	25.410%	20.284%	13.826%	25.219%	14.437%	12.577%	16.603%	6.857%	11.580%	20.555%	-0.667%	-2.919%
Median	0.104%	0.076%	0.093%	0.136%	0.072%	0.036%	0.035%	0.053%	0.045%	0.168%	0.000%	0.000%
Standard Deviation	1.397%	1.553%	1.420%	1.774%	1.838%	1.031%	1.322%	1.039%	0.999%	1.272%	0.454%	0.541%
Volatility	22.303%	24.796%	22.682%	28.334%	29.355%	16.471%	21.104%	16.597%	15.957%	20.310%	7.256%	8.647%
Kurtosis	3.693	4.780	4.500	6.049	23.034	5.447	3.516	14.321	7.068	3.604	2.963	5.213
Skewness	-0.101	-0.418	-0.338	0.113	-1.088	-0.475	0.014	-1.664	0.309	-0.158	-0.277	-0.596
Minimum	-7.44%	-10.49%	-7.798%	-8.142%	-21.02%	-6.15%	-7.20%	-10.58%	-4.245%	-5.414%	-2.995%	-3.772%
Maximum	7.298%	6.805%	9.185%	12.413%	14.429%	4.973%	8.000%	4.839%	8.433%	7.179%	2.430%	2.223%
Observations	1007	1007	1007	1007	1007	1007	1007	1007	1007	1007	1043	1043

	(USD/CAD)	(USD/GBP)	(USD/AUD)	Copper	Gold	Coffee	Bitcoin	Ethereum	XRP	Bitcoin cash	Litecoin
Mean	0.000%	0.016%	0.002%	0.019%	0.026%	-0.006%	0.224%	0.362%	0.284%	-0.045%	0.205%
Ann mean	-0.087%	4.123%	0.598%	4.771%	6.720%	-1.54%	57.02%	92.366%	72.53%	-11.5%	52.196%
Median	0.021%	0.013%	-0.015%	0.034%	0.023%	0.000%	0.218%	-0.045%	-0.32%	-0.34%	0.000%
Standard Deviation	0.462%	0.629%	0.561%	1.431%	1.156%	1.766%	3.959%	6.072%	7.132%	8.132%	5.658%
Volatility	7.385%	10.044%	8.952%	22.85%	18.46%	28.20%	63.22%	96.95%	113.9%	129.9%	90.35%
Kurtosis	1.283	31.354	1.034	2.174	6.467	0.609	4.391	4.221	42.248	7.057	11.875
Skewness	-0.202	2.132	0.203	-0.141	0.213	0.104	-0.115	0.220	3.080	0.603	1.207
Minimum	-1.955%	-2.996%	-1.970%	-7.03%	-5.18%	-6.40%	-20.8%	-31.55%	-61.63%	-44.60%	-39.52%
Maximum	1.933%	8.401%	2.401%	5.499%	6.014%	6.662%	22.51%	30.277%	102.7%	43.16%	51.035%
Observations	1043	1043	1043	1020	1020	1007	1460	1460	1460	839	1460

the standard deviations are calculated, we annualize the values for both. The performance of each portfolio is recorded for its expected return, standard deviation, and optimal portfolio using the Markowitz Mean-Variance analysis and the Sharpe ratio. The expected returns and the standard deviations, as calculated above, provide the return and risk characteristics for individual assets daily. Moreover, these are the basis of calculating the portfolio returns, and the variance that is required in the Markowitz Mean-Variance optimization, and also in calculating the Sharpe ratios for each portfolio.

Markowitz Mean-Variance optimization

In 1952, Markowitz (1952) established the theoretical contributions that played a critical role in various aspects of corporate finance and global financial economics. These contributions eventually won him a Nobel Prize later on and also helped establish the modern portfolio theory (MPT). Markowitz also provided a conceptual framework to find the optimal weights of the assets in an investment portfolio. These assets were those that provided a maximum expected portfolio return for a given level of risk in the portfolio. The dual problem is to find the optimal weights of the assets that provide a minimum level of risk for a given expected portfolio return.

Before formally identifying the concerns regarding the optimization for the Markowitz Mean-Variance analysis, we calculated the return on a portfolio, $\mathbf{E}(R)$, that consisted of m assets, as mentioned below:

$$\mathbf{E}(R) = \sum_{j=1}^{m} w_j \mu_j,$$

where μ_j is the return on the asset j, and w_j is the weight of the asset j in the portfolio. The variance of the portfolio is calculated as,

$$Variance = w^T \Sigma w,$$

where $w = (w_1, w_2, ..., w_n)$ is the vector of weights, and Σ denotes the variance-covariance matrix of the assets in the portfolio. Hence, in this study, we have formulated the following version of the Markowitz Mean-Variance analysis

$$\textbf{Max } \mathbf{E}(R)$$

subject to $w^T \Sigma w = \alpha$,

$$\sum_{i=1}^{m} w_i = 1,$$

$$w_i \geq 0, \ for\ all\ i,$$

where α is the given level of risk, as measured by the variance. The second condition constrains the sum of the weights to be equal to 1, while the last condition enforces the long positions in all the assets. We maximized the portfolio returns, subject to a given level of risk in the portfolio. The solution of the problem provides the optimal weights required for the maximum expected return of the portfolio, given a certain level of risk. Moreover, the maximum amount of the expected portfolio returns against a given level of risk provides an efficient frontier of the problem set.

In this paper, we have solved the problem mentioned above for varying levels of risks and plotted the efficient frontier of the portfolios considered in the study. In addition to this, we also optimize the Sharpe ratio for each of the portfolios in order to observe the effects of diversification through cryptocurrencies.

Sharpe ratio

The Sharpe ratio is defined as a measure of the excessive returns, over a risk-free rate of return per unit of the risk in the portfolio. It is calculated as,

$$\text{Sharpe Ratio} = \frac{\mathbf{E}(R) - R_f}{\text{Standard deviation}},$$

where R_f is the annualized risk-free rate, and the standard deviation is the square root of the variance. The formula is a measure of risk-adjusted returns and had been developed by Sharpe (1966). The formula is used to calculate the performance of an individual asset, as well as of a portfolio. It further helps in comparing the performance of two or more investments or portfolios. A Sharpe ratio that is greater than one is considered to be acceptable. Additionally, the higher the value of the Sharpe ratio, the more excessive returns on the risk-free rate, the portfolio, or the assets provide.

In addition to providing an efficient frontier for different portfolios, we solve the optimization problem of maximizing the Sharpe Ratio, subject to the constraint on the weights in a portfolio, that is:

$$\textbf{Max } \frac{\mathbf{E}(R) - R_f}{\text{Standard deviation}}$$

subject to

$$\sum_{i=1}^{m} w_i = 1,$$

where w_i are the weights of the assets in a portfolio. The second condition, $\sum_{i=1}^{m} w_i = 1$, in the above formula, says that the sum of all weights in the assets is equal to 1. The above problem is solved, first by allowing long positions in the assets, only indicating that the weights in each asset that constitute the portfolio are either positive or zero, that is, $w_i \geq 0 \, \forall \, i$. The optimization problem is also solved by allowing short sales in the cryptocurrencies to achieve an optimized solution. The later is achieved by removing the condition of $w_i \geq 0 \, \forall \, i$, on the weights. The problem is solved for each portfolio in the settings, using the solver routine in Excel.

The study also investigates the diversification of the existing asset portfolios by including cryptocurrencies considered for this research. Four asset portfolios are being considered: Stocks of Technological companies, Stocks of top-performing companies, Currency Exchange rates in dollars against five currencies, and three commodities. In the next section, we provide the results on the efficient frontiers of the portfolios and the resulting portfolios after diversification using cryptocurrencies. Additionally, we also carry out a comparative analysis of the naïve portfolios, and the diversified naïve portfolios in each of the identified categories.

3. Results

This section presents the results of different asset portfolios, along with the diversification using cryptocurrencies. Cryptocurrencies tend to be riskier, and provide higher returns as compared to the other asset classes. Therefore, an investigation on diversifying different asset portfolios is required in order to implement the diversification strategies. We argue that in the fourth industrial revolution, the financial markets are also evolving with the emergence of cryptocurrencies and blockchain technologies. Therefore, an asset portfolio must be examined for diversification opportunities, using the technologically advanced cryptocurrencies. For the portfolios in each of the asset classes, we have studied the Naïve portfolio, the efficient frontier using the Markowitz mean-variance analysis for varying risk levels, and the optimized Sharpe ratio. Moreover, we have repeated the process by including cryptocurrencies in each of the portfolios and compared the performance of the portfolios for the return and risk profiles.

Fig. 1 provides the risk and return profile or the efficient frontier for a cryptocurrency portfolio. It can be observed that the cryptocurrencies' portfolio tends to increase the returns when the risk is increased. By understanding this trend, a positive relationship between the return and risk has been observed in the case of the cryptocurrency portfolio. This observation regarding the cryptocurrency portfolio also allows us to explore the diversification of the existing portfolios of different assets, by including cryptocurrencies. Brière et al. (2015) observed a similar relationship between Bitcoin returns and volatility and concluded that the addition of Bitcoin in the asset portfolio might help investors to achieve the diversification benefits. When dividing the returns into high

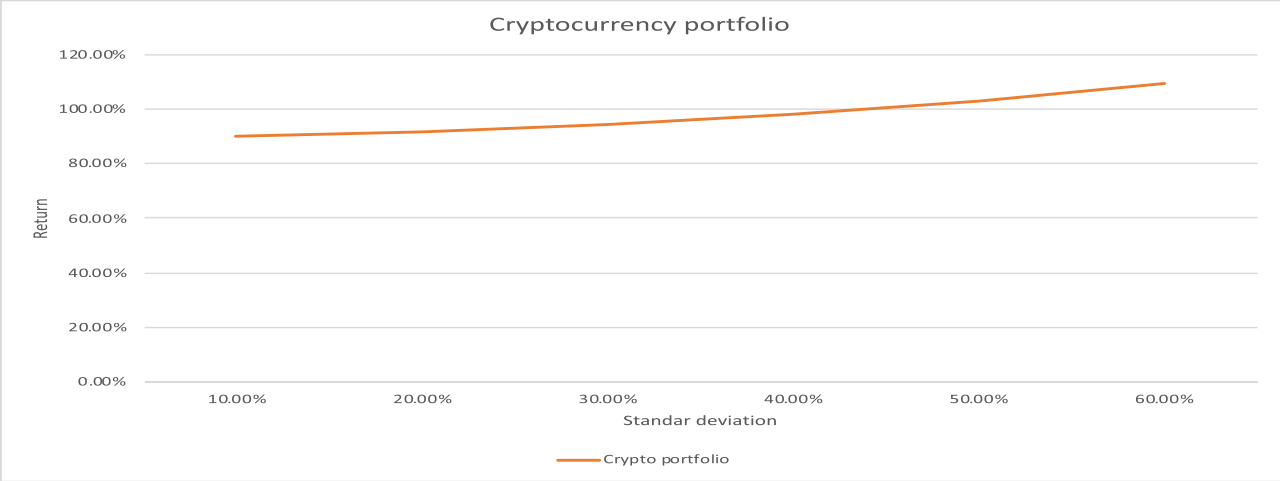

Fig. 1. Efficient portfolio for a cryptocurrency portfolio.

and low price volatility regimes, Koutmos (2019) observed that a higher volatility regime is associated with higher mean returns. However, he also observed that the returns in the high volatility regime do not always reward the investors for the higher levels of volatility, and are prone to tail risks when compared with the low volatility regimes. Hence, we have analyzed the diversification of the existing portfolios using multiple cryptocurrencies next in this section.

Table 4 provides two portfolios that consisted solely of the five cryptocurrencies that are taken into account for this study. The first portfolio is a naïve portfolio, where the investment is equally distributed in all the cryptocurrencies. The same table also provides the statistics for the optimized Sharpe ratio. To calculate the Sharpe ratio, we have used the annualized US Treasury note rates of 1.58% as of November 9, 2019. The maximum Sharpe ratio that was achieved had a value of 1.31, showing the excess returns over a risk-free rate per unit of the taken risk. The Sharpe ratio above one is considered to be "good" by investors. The results for the optimized Sharpe ratio for cryptocurrencies show that the performance is considered to be good.

We then analyzed the different asset portfolios considered in the study. For this, we initially develop a portfolio of five stocks that were taken from technological companies, namely Microsoft, Google, Apple Inc., Amazon, and Facebook. The efficient frontier for the stocks only portfolio has been plotted in Fig. 2. A diversified portfolio of the same assets, with the cryptocurrencies incorporated therein, is also plotted in the same figure. It can be seen that for the same levels of risk, a diversified portfolio provides a higher level of returns. In other words, this provides a better Sharpe ratio results, as compared to a portfolio consisting of technological firms' stocks only. Table 5 provides the results for different portfolios. The results of the naïve portfolio show that the Sharpe ratio decreases when the cryptocurrencies are incorporated, with equal proportions of investments in the assets. However, the results for the optimized Sharpe ratio portfolio show a slight improvement in the returns. An approximate decrease of 0.94% is observed in the risk, as measured by the standard deviation. Therefore, the diversification of portfolios in order to reduce risk and improve the Sharpe ratio is achieved when cryptocurrencies are incorporated into the portfolio. Interestingly, when selling is allowed in the assets of the portfolio, better results are achieved. The return of the diversified portfolio increased to 75.28% from 29% of the 'stocks only' portfolio. It was further observed that when the selling is allowed in the underlying assets, there is a tendency to decrease the risk by manifold. Hence, providing an improved and higher Sharpe ratio.

Table 4
Descriptive statistics for cryptocurrencies' portfolios.

Cryptocurrencies	*Naïve portfolio (1/5)*	*Optimized Sharpe ratio*
Mean	75.17%	132.21%
Standard deviation	92.21%	115.98%
Sharpe ratio	0.80	1.31

Next, we study a portfolio of the top-performing assets, namely the assets of Berkshire Hathaway Inc. (BRKa), JPMorgan Chase & Co., Johnson & Johnson (JNJ), Procter & Gamble Company (PG) and Visa Inc Class A. As practiced before, the efficient frontiers for the 'stocks only' portfolio, and cryptocurrencies diversified stock portfolios, are plotted in Fig. 3. It was again observed that for the same level of risk, a diversified portfolio provides higher returns, and hence a better Sharpe ratio. Table 6 provides the results of the different portfolios against the mean, standard deviation, and the Sharpe ratio. The results for the naïve portfolio show that the Sharpe ratio decreases when cryptocurrencies have been included, due to the equal proportions of investments in all the assets. The same was observed for a similar portfolio of the stocks of technology companies as well. The results for an optimized Sharpe ratio portfolio provide a significant increase of more than 14% in return, along with an increased risk of about 2.9%. An increase in the Sharpe ratio is realized after the diversification with cryptocurrencies.

The results of the portfolio diversification, in which the cryptocurrencies were used, on the next two asset classes, were quite intriguing. We applied the same methodology on a portfolio of five foreign currencies: Euros, Japanese Yen, Canadian dollar, British pounds, and the Australian dollar. It was observed that the returns from the crypto-diversified portfolio were better than the returns from the portfolio consisting of the five currencies, for the same risk level. The results were then plotted in Fig. 4. Table 7 shows that the naïve portfolio did not perform well when the cryptocurrencies were included in the currency portfolio. The Sharpe ratio, in this case, came out to be negative, since the returns on the portfolio were lower than the risk-free rates of 1.58%.

It is interesting to note that the portfolio diversification that is put into practice by optimizing the Sharpe ratio provides no better results when the cryptocurrencies are being included in the existing portfolio of currencies. However, when allowed for short sales, it was observed that the returns increased by around 80%. Moreover, the short sales simultaneously decreased the volatility to 0.02%, which is a 12% reduction in the risk of the portfolio. Hence, a well-diversified portfolio was achieved by including the riskier, yet rewarding cryptocurrencies.

The final case study provides diversification of a commodity portfolio with the inclusion of cryptocurrencies. The commodities used in the study are Copper, Gold, and Coffee. The efficient frontier

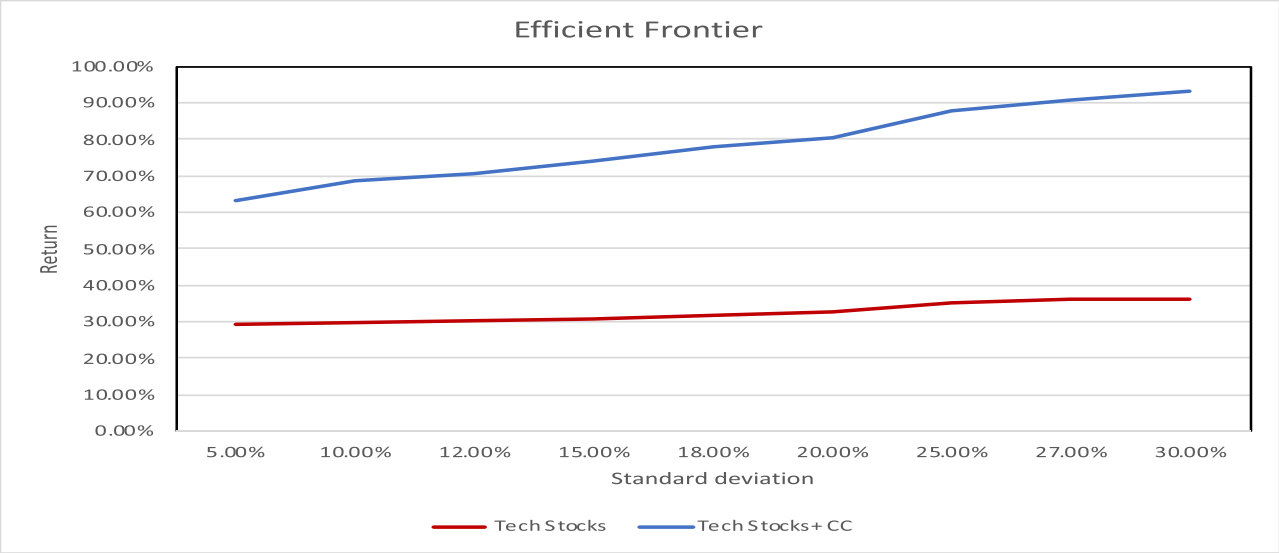

Fig. 2. Efficient frontier of a portfolio of Technological companies' stocks along with a cryptocurrency based diversified portfolio.

representing the returns for the different levels of risk is plotted in Fig. 5. The efficient frontier of the portfolio with the cryptocurrencies is slightly above by a few points. The results match in both cases when the risk level is above 18%. Table 8 shows that the optimized Sharpe ratio does not provide any better results, unless, selling of the entities is allowed in the portfolio. It is also observed that the risk factor in the diversified portfolio can be reduced significantly, and a higher Sharpe ratio is achieved.

4. Discussion

The study provides empirical results for the diversification of different asset portfolios by including cryptocurrencies. As discussed above, the results in the previous section were substantially conclusive. It was observed, in all the cases presented above, that a cryptocurrency diversified portfolio provides better returns as compared to a portfolio of assets (without cryptocurrencies), for the same level of risk, as measured by the standard deviation of the portfolios. The cryptocurrency diversified portfolios outperformed the traditional portfolios of not only the technology companies but also of the other stocks in both the long and the short asset portfolios. Moreover, the diversification through cryptocurrencies also reduced the risk significantly while achieving higher returns. In cases where the selling of assets is allowed, even better results can be achieved by reducing the risk even further. For the portfolios that are consisted of currencies and commodities, the diversification with the inclusion of cryptocurrencies provided better results when the sale of assets was allowed. The results were improved due to a reduction in the risk that existed in these portfolios. It is noteworthy that better results may be achieved when no additional conditions are applied to a commodity portfolio. Therefore, we can conclude that adding cryptocurrencies to the existing portfolios may significantly increase the returns, and provide a better diversification by reducing the risk of the portfolio.

From the empirical analysis, it was also observed that Ethereum provides better diversification as compared to Bitcoin. The previous studies have mostly focused on diversification of the traditional portfolio by using Bitcoin only (Kajtazi and Moro, 2019; Guesmi et al., 2019; Symitsi and Chalvatzis, 2019). In our study, specifically from Table 9, we observe that Ethereum provides a better diversification by significantly decreasing the portfolio risk as compared to Bitcoin, in most of the portfolios. Two out of the four portfolios analyzed did not show any improvement when Bitcoin was included, despite allowing short-selling of the entities. The stock portfolio showed a slight improvement, and the commodity portfolio increased the returns, but also increased the risk of the overall portfolio, providing a lower value of the Sharpe ratio. In comparison to this, Ethereum improved the diversification by either decreasing the risk in the portfolio or by significantly increasing the returns. The commodity portfolio diversification through Ethereum, however, did not improve the results. Our results in the previous section showed that a combination of cryptocurrencies provides better diversification as compared to the diversification using individual cryptocurrencies.

In the literature, many studies have investigated the performance of cryptocurrency inclusive portfolios (Platanakis et al., 2018; Platanakis and Urquhart, 2019; Borri, 2019; Liu, 2019; Brauneis and Mestel, 2019). Most of these studies have discussed the portfolio diversification using only Bitcoin as a benchmark. So much so, that we could only find two papers in which Trimborn et al. (2017) and Petukhina et al. (2018) had shed light on portfolios that achieved diversification with multiple cryptocurrencies. Trimborn et al. provided results for liquidity bounded risk-return optimization on the S&P100 stocks, bonds index, and the commodity index on a data that spanned between April 2014 and October 2017. The focus of their paper had been on the low liquidity of the cryptocurrencies market. Interestingly, our results concur with the results of Trimborn et al., because the cryptocurrencies provide better diversification avenues for the

Table 5
Descriptive statistics for different stock and cryptocurrencies' portfolios.

Technological Firm Stocks	Tech Stocks only *Naïve portfolio (1/5)*	Tech stocks + Cryptocurrencies *Naïve portfolio (1/10)*	Tech Stocks only *Optimized Sharpe ratio*	Tech Stocks + Cryptocurrencies *Optimized Sharpe ratio*	Tech Stocks + Cryptocurrencies *Optimized Sharpe ratio Selling allowed*
Mean	28.40%	51.78%	29%	29.55%	75.28%
Standard deviation	24.39%	47.37%	1.55%	1.46%	0.01%
Sharpe ratio	1.10	1.06	17.68	19.08	8938

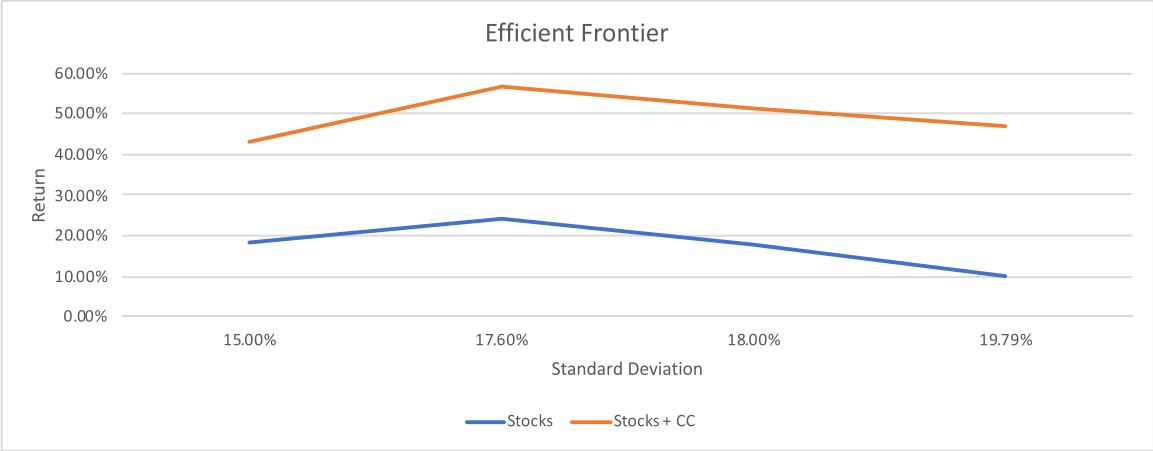

Fig. 3. Efficient frontier of a portfolio of five companies' stocks along with a cryptocurrency based diversified portfolio.

Table 6
Descriptive statistics for different stock and cryptocurrencies' portfolios.

Stocks	Stocks only *Naïve portfolio (1/5)*	Stocks + Cryptocurrencies *Naïve portfolio (1/10)*	Stocks only *Optimized Sharpe ratio*	Stocks + Cryptocurrencies *Optimized Sharpe ratio*	Stocks + Cryptocurrencies *Optimized Sharpe ratio Selling allowed**
Mean	19.52%	47.34%	24.06%	38.31%	103.2%
Standard deviation	15.78%	46.37%	17.63%	20.53%	0.025%
Sharpe ratio	1.14	0.99	1.27	1.79	4087

* additional condition applied on weights to be $<= 1$.

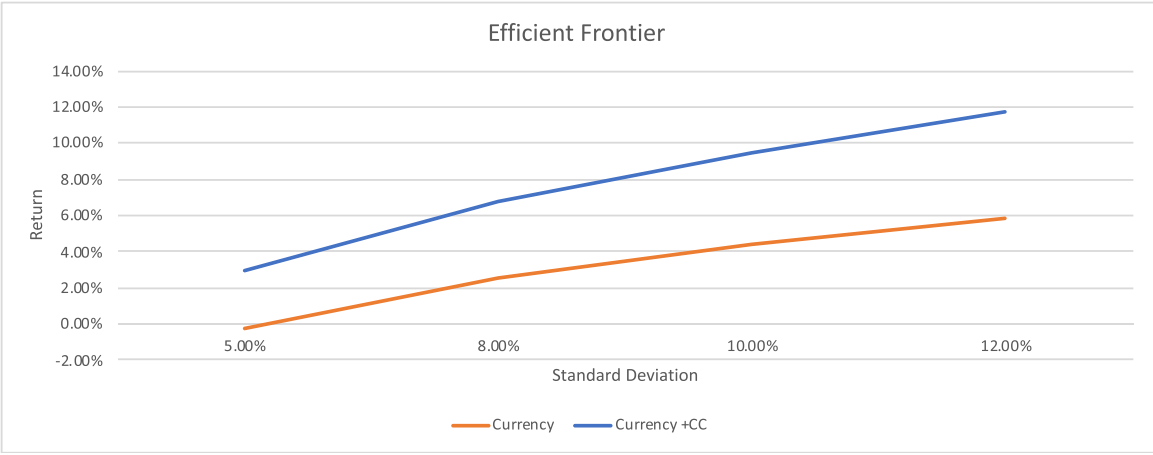

Fig. 4. Efficient frontier of a currency exchange portfolio along with a cryptocurrency based diversified portfolio.

Table 7
Descriptive statistics for different stock and cryptocurrencies' portfolios.

Currencies	Currencies *Naïve portfolio (1/5)*	Currencies + Cryptocurrencies *Naïve portfolio (1/10)*	Currencies *Optimized Sharpe ratio*	Currencies + Cryptocurrencies *Optimized Sharpe ratio*	Currencies + Cryptocurrencies *Optimized Sharpe ratio Selling allowed*
Mean	0.30%	0.15%	5.90%	5.90%	85.36%
Standard deviation	6.73%	3.60%	12.02%	12.02%	0.02%
Sharpe ratio	-0.19	-39.69	0.36	0.36	4218.53

investors. Moreover, by analyzing data from January 2015 to December 2017, Petukhina et al. (2018), concluded that cryptocurrencies could improve the risk and return profiles of a portfolio, especially for a high-targeted return strategy.

We have added to this literature by performing an empirical analysis on a recent set of data that spans from November 2015 to November 2019, making and comparing the mean-variance efficient frontiers of different asset portfolios, with the addition of cryptocurrencies. Our results resonate with the findings of both Trimborn et al. and Petukhina et al. in a way that cryptocurrencies provide better diversification opportunities for the existing portfolios. Furthermore, our results also show that when short selling is allowed, the diversification is achieved by a significant reduction in the volatility. We also provide analysis for diversification in the technological companies'

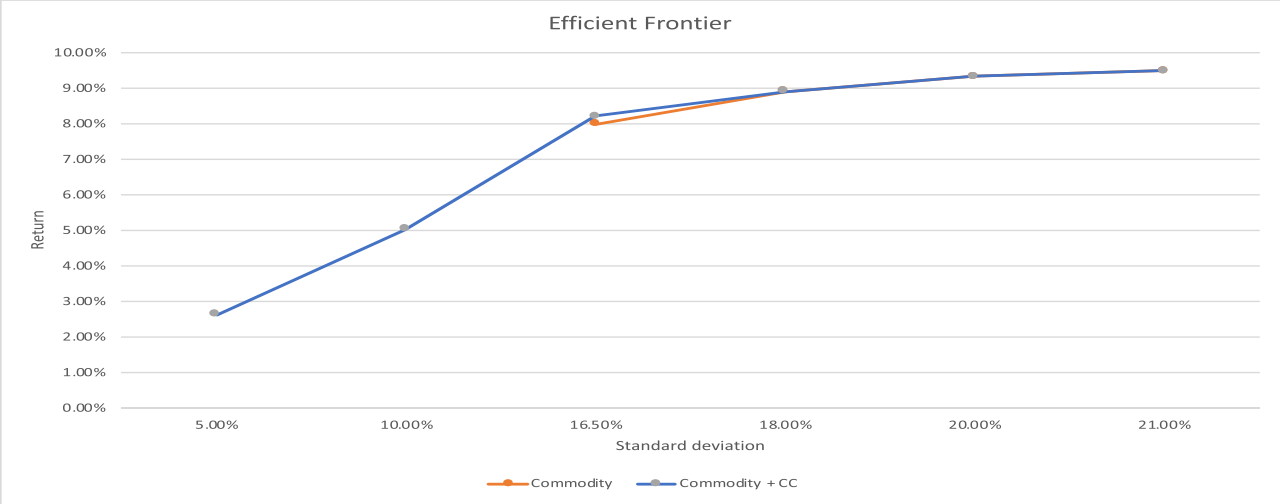

Fig. 5. Efficient frontier of a commodity portfolio along with a cryptocurrency based diversified portfolio.

Table 8
Descriptive statistics for different stock and cryptocurrencies' portfolios.

Commodities	Commodities *Naïve portfolio (1/3)*	Commodities + Cryptocurrencies *Naïve portfolio (1/8)*	Commodities *Optimized Sharpe ratio*	Commodities + Cryptocurrencies *Optimized Sharpe ratio*	Commodities + Cryptocurrencies *Optimized Sharpe ratio Selling allowed**
Mean	4.75%	1.78%	8.76%	8.76%	5.67%
Standard deviation	16.43%	6.67%	17.64%	17.64%	0.01%
Sharpe ratio	0.19	0.03	0.50	0.50	432

* additional condition applied on weights to be $<= 1$

Table 9
Portfolio diversification with optimized Sharpe ratio using Bitcoin (only) and Ethereum (only).

Portfolios	Without cryptocurrency	With Bitcoin	With Ethereum
Technological companies' stock	Mean: 29% SD: 1.55% SR: 17.68	Mean: 29% SD: 1.55% SR: 17.68	Mean: 28% SD: 0.00001% SR: 4835472.43
Stocks	Mean: 24.06% SD: 17.63% SR: 1.27	Mean: 34% SD: 19.23% SR: 1.68	Mean: 38.94% SD: 21.34% SR: 1.75
Currency	Mean: 5.90% SD: 12.02% SR: 0.36	Mean: 5.90% SD: 12.02% SR: 0.36	Mean: 22.14% SD: 24.8% SR: 0.83
Commodity	Mean: 8.76% SD: 17.64% SR: 0.50	Mean: 13.58% SD: 27% SR: 0.443	Mean: 13.19% SD: 26.22% SR: 0.44

stocks, and the currencies portfolios, along with other stocks and commodity portfolios. We further made a comparison of the naïve portfolios, and the efficient frontiers of the portfolios, in terms of a 'with and without cryptocurrencies' comparison of the diversification. The results reveal that the portfolios with cryptocurrencies generally performed better.

5. Conclusion

The advancements in financial technology during the fourth industrial revolution have brought the cryptocurrencies and the blockchain technology to the front lines, especially in these times of highly competitive financial markets. Not only the underlying technology of the blockchain challenging the traditional financial systems but the investment opportunities in the cryptocurrencies are also changing the way investors are managing their portfolios. With the arrival of digital platforms and technology, investors are being compelled to upgrade their investment strategies for developing and managing their portfolios. This change is so rapid and natural that even conservative portfolio managers, who are managing endowment or retirement funds, are destined to change their strategies by exploring new avenues for investment and diversification.

This paper provides empirical evidence that validates the theory that the cryptocurrencies, in an existing portfolio of different asset classes, increases the potential gains from the portfolio. The rapid growth of cryptocurrencies makes these portfolios a promising investment asset by increasing the returns from the portfolio and diversifying the risks. Moreover, we have also provided a comparison of different portfolios with and without diversification through cryptocurrencies. Furthermore, the traditional Markowitz mean-variance framework is also applied in order to investigate the performances of the portfolios with and without diversification through the inclusion of cryptocurrencies. The results are provided in the form of the efficient frontiers of these portfolios, indicating higher returns for the same level of risk for a diversified portfolio with cryptocurrencies. In addition to this, we also made a comparison of the naïve portfolios and the optimized portfolios with the Sharpe ratios. Due to the equal distribution of weights in all the assets, the naïve portfolios, which were inclusive of the cryptocurrencies, resulted in lower Sharpe ratios, as compared to those naïve portfolios that were not inclusive of cryptocurrencies. The results show that because of varied risks and returns in the cryptocurrencies, it is not always optimal to go for a naïve diversification option.

The optimized Sharpe ratio shows the potential of the cryptocurrencies in diversifying portfolios. The diversified portfolios showed a tremendous growth of as much as 80% in the returns and reducing risk by as much as 20%. Better results may be achieved if we allow short

selling with higher weightage given to the cryptocurrencies. The study also investigated the diversification with only Bitcoin and Ethereum, and the results showed that as an individual diversification asset, Ethereum tends to perform better in the diversification of portfolios. The validity of these results under different matrics, and optimization techniques are open to future research.

The findings of the study indicate that cryptocurrencies have a high potential of diversifying the existing portfolios of stocks, currencies, and commodities. In addition to this, we also found that the inclusion of several cryptocurrencies in a portfolio provides better portfolio diversification results with an increase in the Sharpe ratio. Furthermore, the results also show that it is possible to improve the results when short sales of the assets are allowed in the portfolio. Therefore, based on our findings, we suggest that the investors further explore investment opportunities in cryptocurrencies as a viable diversification asset tool. This study is focused on a recent data set (November 10, 2015, to November 09, 2019) and establishes its findings on the current trends in the prices of the cryptocurrencies. From a policy point of view, the study also reveals that diversifying an existing portfolio, with several cryptocurrencies, has a comparative advantage when it comes to the diversification with one cryptocurrency in the volatile cryptocurrencies' market. It is also observed that when the short sale of the cryptocurrencies are allowed in a portfolio, it provides better diversification opportunities by reducing the volatility and increasing the return. This finding is fascinating because, in long-only portfolios, the increase in the Sharpe ratio might be driven by an increase in the returns coming from the portfolio, instead of a decrease in the volatility. If investors do not want to invest in multiple cryptocurrencies, in order to diversify their existing portfolios, it is observed that Ethereum provides better results compared to Bitcoin. This observation also implies that other cryptocurrencies may have better diversification capabilities, but due to the hype, Bitcoin has so far received more attention from both researchers and investors.

Thus, our findings suggest that cryptocurrencies provide reasonable investment avenues that most certainly require further exploration. The effects of transactional costs, liquidity, and optimal rebalancing on the performance of the portfolio and its diversification could interest future researchers in the field. Cryptocurrencies have performed reasonably well during the Covid-19 pandemic that cropped up earlier this year as well. Therefore, we recommend further investigation into the performance and diversification properties of the cryptocurrencies in such a situation.

CRediT authorship contribution statement

Yechi Ma: Conceptualization, Funding acquisition, Project administration, Resources, Writing - original draft. **Ferhana Ahmad:** Data curation, Formal analysis, Investigation, Methodology, Software, Writing - original draft. **Miao Liu:** Supervision, Visualization, Writing - review & editing. **Zilong Wang:** Validation, Writing - review & editing.

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