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Cryptocurrencies and portfolio diversification in an emerging market

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Abstract

Purpose – This paper examines the effect of cryptocurrencies on the portfolio risk-adjusted returns of traditional and alternative investments within an emerging market economy.
Design/methodology/approach – The paper employs daily arithmetic returns from August 2015 to October 2018 of traditional assets (stocks, bonds, currencies), alternative assets (commodities, real estate) and cryptocurrencies. Using the mean-variance analysis, the Sharpe ratio, the conditional value-at-risk and the mean-variance spanning tests.
Findings – The paper documents evidence to support the diversification benefits of cryptocurrencies by utilising the mean-variance tests, improving the efficient frontier and the risk-adjusted returns of the emerging market economy portfolio of investments.
Practical implications – This paper firmly broadens the Modern Portfolio Theory by authenticating cryptocurrencies as assets with diversification benefits in an emerging market economy investment portfolio.
Originality/value – As far as the authors are concerned, this paper presents the first evidence of the effect of diversification benefits of cryptocurrencies on emerging market asset portfolios constructed using traditional and alternative assets.

Keywords Alternative assets, Cryptocurrencies, Portfolio optimisation
Paper type Research paper

1. Background of the study

"Some succeeded, many failed dismally. All while the price of Bitcoin skyrocketed to $20,000 . . . then fell back down to the $3,000 in less than a year. But what does the future hold? There are hundreds of outlandish predictions of where Bitcoin will be in the next year, five, or 10 years, but rather than making price predictions; it is interesting to hear the thoughts of an early investor" (Pollock, 2019, online). Cryptocurrency is a form of digital currency (Dandapani, 2017) that is based on cryptography. Digital currency is "electronic money that serves as an alternative currency in digital or online transactions" (Dandapani, 2017, p. 614) while cryptography is "the art of solving codes" (Hornsby, 2010, p. 355). Essentially, cryptography is the use of encryption and decryption of data and information. One can view cryptocurrency as digital currency that is built using encryption and decryption. Therefore, cryptocurrency is currency secured in its own vault using electronic puzzles and codes. Nonetheless, the concept of cryptocurrency and cryptography has been around for several years. Chaum (1983) suggested the use of cryptography within payment systems. This was to

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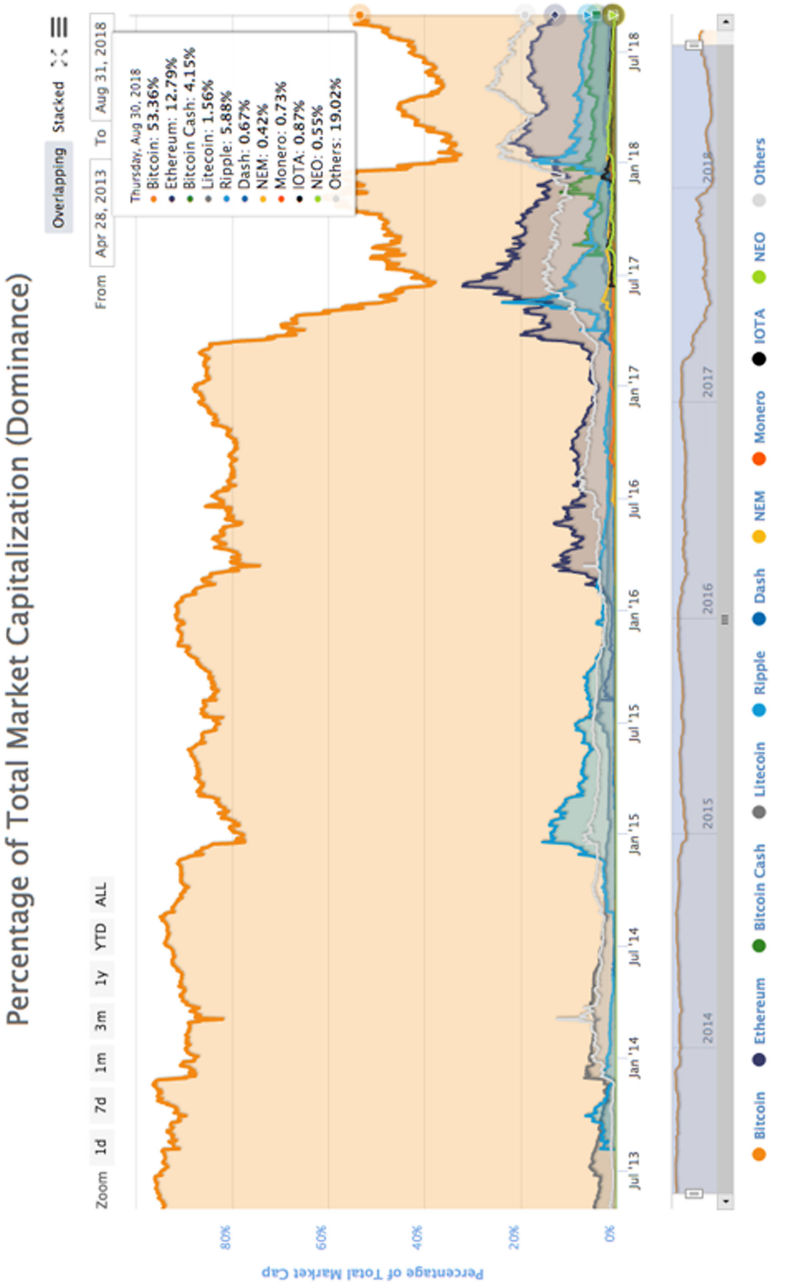
protect the user of electronic payment systems from their payment data being used by third parties. He proposed an untraceable payment system using blind signature systems. The object of these untraceable payment systems was to prohibit third parties from tracking the payment details, including the time, payee and number of payments made. This was done to enable the disclosure of the payee and proof of payment only if necessary and to stop the theft of payment information while blind signatures refer to the use of passwords to encrypt and decrypt information so that the information is never compromised between the creation, transportation and delivery of the information between two parties (Chaum, 1983). This led to the creation of Digicash on 21 April 1990. Digicash was a combination of untraceable payment systems and digital currency. However, due to bad management, the entity that built Digicash went bankrupt in 1998. This resulted in the demise of Digicash (Abrar, 2014; How DigiCash Blew Everything, 1999).

Satoshi Nakamoto created Bitcoin (BTC) in 2009 (Brière *et al.*, 2015; Osterrieder and Lorenz, 2017; Taylor, 2018) that has become one of the more widely used forms of cryptocurrencies (Dandapani, 2017). As on 30 August 2018 (Figure 1), BTC formed 53.36% of the total market capitalisation for cryptocurrencies (CoinMarketCap, 2018).

As on 1 October 2018 (Table 1), BTC constituted 64.51% of the top 10 cryptocurrencies market capitalisations. Figure 1 also reveals that, on 1 August 2017, the market capitalisation of BTC decreased due to the creation of Bitcoin Cash from BTC and the entrance of other cryptocurrencies into the market. Cryptocurrencies allow for a payment system that is based on encryption rather than trust (Kim *et al.*, 2018). This means that cryptocurrency transactions are fully encrypted and cannot be breached unlike conventional financial transactions that can be hacked and breached [1].

The Modern Portfolio Theory (MPT) of Markowitz (1952, 1991) suggests that investors must ensure that they diversify their portfolio investment in securities by investing across multiple economically diverse industries. The Capital Asset Pricing Model (CAPM), efficient market hypothesis (EMH) and behavioural finance theory (BFT) are other theories that are also related to investments. The CAPM infers that an investor prefers a higher future value, rather than a lower future value of an investment (Sharpe, 1964). Moreover, the CAPM notes that there is a linear relationship between risk and return (Karceski, 2002). Fama (1970) analysed the EMH that mentions three categories of information in the market, the weak form, semi-strong form and the strong form. The BFT assesses the capital markets and the investors from a psychological and sociological perspective (Lo, 2004; Malkiel, 2015; Subrahmanyam, 2007).

The empirical studies (Brière *et al.*, 2015; Lee *et al.*, 2017; Osterrieder and Lorenz, 2017; Brauneis and Mestel, 2019; Trucíos *et al.*, 2020) on cryptocurrencies have some similarities and differences in their findings. The similarities found within the studies are that BTC is very risky and that it is riskier than G10 currencies. Cryptocurrencies were also found to be more volatile than traditional and alternative investments. Other similarities found were that there was a low correlation between cryptocurrencies, including BTC and traditional and alternative investments, including G10 currencies. Cryptocurrencies, including Cryptocurrency Index (CRIX) and BTC had better returns than traditional and alternative investments, including G10 and emerging market currencies (Brière *et al.*, 2015; Lee *et al.*, 2017; Osterrieder and Lorenz, 2017; Rohrbach *et al.*, 2017). Cryptocurrencies were found to be a good diversifier of investments (Brauneis and Mestel, 2019; Brière *et al.*, 2015; Lee *et al.*, 2017) and reasonable investment (Brière *et al.*, 2015; Lee *et al.*, 2017). The differences within the studies varied. Brière *et al.* (2015) discovered that Bitcoin returns differed greatly from those of hedge funds, gold and oil. The empirical studies also found that cryptocurrencies were more volatile than the annual inflation of Japan, US, Britain, South Africa and Mexico (Kim *et al.*, 2018). Equally weighted portfolios performed better than optimal portfolios for cryptocurrency investment portfolios (Brauneis and Mestel, 2019). The Fully-Connected



Source(s): Data from CoinMarketCap Global Charts (2018)

Figure 1.
Percentage of total market capitalisation from April 2013 to August 2018

Number	Name	Symbol	Market capitalisation	Percentage of market capitalisation[a]	Circulating supply
1	Bitcoin	BTC	R1,619,344,831,706	64.51	17,298,562
2	Ethereum	ETH	R333,297,114,307	13.28	102,295,813
3	XRP	XRP	R327,427,298,382	13.04	39,870,907,279
4	Stellar	XLM	R68,876,842,252	2.74	18,789,957,655
5	Litecoin	LTC	R50,263,838,354	2.00	58,530,852
6	Tether	USDT	R39,705,678,904	1.58	2,806,421,736
7	Monero	XMR	R26,962,499,811	1.07	16,452,054
8	Dash	DASH	R22,064,326,921	0.88	8,350,590
9	NEM	XEM	R12,349,926,054	0.49	8,999,999,999
10	Dogecoin	DODG	R9,879,132,427	0.39	116,363,737,525

Source(s): Data from CoinMarketCap market capitalizations (2018). [a]Authors' own calculation, percentage of market capitalisation = (market capitalisation of the cryptocurrency divided by the sum of the total market capitalisation of the 10 cryptocurrencies included in CRIX) × 100

Table 1. 10 Cryptocurrencies included in CRIX on 1 October 2018

Neural Networks (CNN) outperformed three other portfolio management algorithms and three benchmarks and they had significantly less risk and a larger Sharpe ratio than the Passive Aggressive Mean Reversion (PAMR) (Jiang and Liang, 2017). The univariate volatility and vine copula models all estimated the value-at-risk (VaR) and Expected Shortfall (ES) well. However, the combination of the vine copula and robust GARCH models was the best estimator of VaR and ES (Trucíos *et al.*, 2020).

The empirical studies comparing cryptocurrencies [2] to traditional and alternative assets revealed that BTC is highly volatile and risky; it has high average returns and a very low correlation to both traditional and alternative assets; cryptocurrencies are a potentially decent investment; cryptocurrencies and emerging market currencies performed better than G10 currencies; and Bitcoin is riskier that G10 currencies (Brière *et al.*, 2015; Kim *et al.*, 2018; Lee *et al.*, 2017; Osterrieder and Lorenz, 2017; Rohrbach *et al.*, 2017). Nonetheless, very few of these empirical studies focused on emerging economies, l*et al*one Africa. Some of the empirical studies included the Rand as a currency however, they did not focus on comparing the performance of African or South African listed shares to cryptocurrencies. Furthermore, these studies did not assess whether cryptocurrencies are good portfolio diversification assets, in terms of an African or South African listed shares investment portfolio. The empirical literature has not compared the performance of South African listed shares to cryptocurrencies. Herein lies a gap to study South African assets. This study seeks to address this gap in knowledge.

Against this background, this paper examines the performance of cryptocurrencies in relation to traditional and alternative investments in South Africa. Therefore, this study expands on the Modern Portfolio Theory (MPT) in terms of utilising economically diverse securities to improve the expected return in relation to the risk. It also contributes towards this theory in attesting towards using low correlating assets to diversify an investment portfolio. It underscores the expansion of the pool of knowledge and data being contributed towards assets with diversification benefits within an investment portfolio. Therefore, this research seeks to assess whether the incorporation of cryptocurrencies into the pool of available South African investments would be beneficial to investors and determine whether cryptocurrencies will improve the portfolio of traditional and alternative assets. It also seeks to assess the diversification benefits of cryptocurrencies in a portfolio of traditional and alternative investments in an emerging economy and the performance of cryptocurrencies in relation to traditional and alternative assets within an emerging economy.

This paper focuses on the South African stock exchange for the following reasons. First, the Johannesburg Stock Exchange (JSE) is the most developed stock market in Africa (Demirgüç-Kunt and Klapper, 2012). Since the market crash of 2008, investors have sought out investments, such as alternative assets, that are not correlated to the stock market, to further diversify their portfolio investments. However, most of these alternative investments have underperformed (Srilakshmi and Karpagam, 2017). Listed equities in South Africa have also been underperforming on the JSE, which is the largest African exchange and the 19th largest exchange globally (JSE, 2019). The JSE's Top 40 index and the JSE's All Share index had a return of −5.40 and −4.93% for the 12-month period ended 5 October 2018, respectively (Trading Economics, 2018). This reflects the underperformance of listed shares in South Africa. Second, the market capitalisation of Bitcoin and over 1,000 cryptocurrencies was more than US$400 billion in January 2018. The market capitalisation of over 1,000 cryptocurrencies excluding Bitcoin in January 2018 was more than US$250 billion. Various cryptocurrency exchanges have daily volumes of US$50 billion and Bitcoin futures have been created in places like Chicago so that institutional investors can hedge and trade Bitcoin. Additionally, between January 2009 and April 2017, 606 million transactions of US$1 trillion were performed (Taylor, 2018). The question is whether cryptocurrencies can assist in alleviating the illiquidity of many African financial markets as the cryptocurrency market has had good returns in the past, even though these returns have declined in recent times. Perhaps cryptocurrencies can tackle the problem resulting from the underperformance of listed shares in South Africa. Finally, the JSE is one of two emerging stock markets in the 20 largest stock exchanges that trades in cryptocurrencies. Although South Africa is ranked as the second in the cryptocurrency adoption index countries in Africa (behind Kenya and ahead of Nigeria), it has the largest trade volumes in Peer-to-peer (P2P) cryptocurrency compared to the second emerging stock market (China) that trades cryptocurrencies (Chainalysis, 2020; Euronext, 2021; Haqqi, 2020).

The rest of the paper is organized as follows; Section 2 outlines the hypothesis development; Section 3 outlines the methodology employed in the study; Section 4 discusses the results while Section 5 presents a conclusion and policy recommendations of the findings.

2. Hypotheses development

2.1 Portfolio diversification and the modern portfolio theory

The Modern Portfolio Theory (MPT) of Markowitz (1952) suggests that investors should maximise their discounted estimated future returns and minimise their risk on securities (Fama and French, 2004; Litterman, 2003b; Malkiel, 2015; Markowitz, 1991). Markowitz (1952, 1991) further stated that, in doing so, the investors must diversify their portfolio investment in securities by investing across multiple and economically diverse industries, particularly in entities which have smaller covariances or correlations in those industries being invested in. Therefore, securities should be selected while bearing in mind how the fluctuations of other securities within the portfolio impact the chosen securities (Elton and Gruber, 1997). Furthermore, an increased diversification of the portfolio decreases the risk of the investment, but it does not eliminate all the risk (Malkiel, 2015). Within the MPT, the expected returns-variance rule states that, the expected returns should be maximised for the variance or more than the variance, and the variance should be minimised for the expected returns or less than the expected returns (Markowitz, 1952). Consequently, the variance is the driver of the expected returns (Litterman, 2003c; Malkiel, 2015). The variance of the portfolio needs to be taken into consideration when assessing the expected returns for every investment made (Litterman, 2003c). Markowitz postulates that an optimal portfolio is one that lies on the efficient frontier (Harvey *et al.*, 2010). The efficient frontier is the amalgamation of securities

within a portfolio that maximises returns for a specific risk level of the portfolio (Mangram, 2013; Pfiffelmann *et al.*, 2016).

2.2 The impact of the inclusion of different asset classes in a portfolio

The inclusion of different asset classes impacts an investment portfolio, either by improving or reducing the portfolio's performance. A study performed by Lintner (1965) on mutual funds indicated that the investors' risk after diversification is significant. It also finds that diversification and cautiously selecting assets within a portfolio cannot significantly reduce the market and residual risk. Jensen (1969) performed a study on mutual funds, where the net returns of the mutual funds in relation to the risk-return amount was below that of the market. In an examination carried out by Karceski (2002) on the cash flows of equity funds for aggressive growth, growth, growth and income, equity income and income options, it showed that there is no quantitative indication that the ownership of larger mutual funds reduces the beta risk premium, however, it showed that market returns exceeded funds flowing from stocks. Brière *et al.* (2015) conducted a study on Bitcoin, the Euro, Japanese Yen, emerging and developing economies' government bonds, equities, corporate and globally linked inflation bonds, listed real estate, oil, hedge funds and gold indices. The study found Bitcoin to be very volatile and risky at 176% per annum, however, it had high average returns of 404% per annum. Moreover, Bitcoin had a very low correlation to both traditional and alternative assets returns. An investigation was conducted by Lee *et al.* (2017) indicated that traditional investments do not perform as well as cryptocurrencies on an average daily return. The investigation also found that there was a low correlation between cryptocurrencies' returns and traditional investments' returns. Therefore, cryptocurrencies are likely to generate greater returns in relation to risk than South African traditional and alternative assets.

H1. Cryptocurrencies generate higher returns in relation to risk than South African traditional and alternative assets.

The study by Brière *et al.* (2015) also discovered that Bitcoin is a good diversifier of investments and that the inclusion of Bitcoin in an investment portfolio, at a small level, greatly increases the risk-return utility of a well-diversified investment portfolio (Brière *et al.*, 2015). Moreover, the investigation by Lee *et al.* (2017) also found that a portfolio consisting of cryptocurrencies, traditional and alternative assets outperformed a portfolio consisting of only traditional and alternative assets (Lee *et al.*, 2017). Thus, cryptocurrencies are anticipated to have diversification advantages in South African investment portfolios.

H2. Cryptocurrencies have diversification advantages in South African investment portfolios.

3. Methodology

3.1 Data and sample

This quantitative study employs traditional financial assets (stocks, bonds, currencies), alternative assets (commodities, real estate) and cryptocurrencies as the units of analysis. The data are used to assess these units of analysis. The data sourced consisted of time series data being the daily historical closing prices of financial assets and cryptocurrencies from 10 August 2015 to 31 October 2018. The data were extracted from 10 August 2015, as this was the date that the daily historical closing price of Ethereum was available from the very beginning of the trading week of traditional assets. Ethereum was only released to the

public from 31 July 2015 (Coinmama, 2019). Referring to Table 1, Ethereum had to be included within the testing as it was the second largest cryptocurrency on 1 October 2018, and it formed 13.28% of the market capitalisation of 10 cryptocurrencies that were included in the CRIX on 1 October 2018. The data were sourced from the Iress Expert database for South African financial assets, the investing.com website for 3-Year South African government bonds, the CoinMarketCap website for cryptocurrencies and http://crix.hu-berlin.de website for the CRIX. Iress is an Australian company that houses an electronic financial asset database and it has footprints in South Africa, Australia, Canada, New Zealand, the United Kingdom, Hong Kong and Singapore (Iress, 2019). CoinMarketCap is a well-known online cryptocurrency trading database that provides access to trading data for 289 cryptocurrencies from numerous cryptocurrency exchanges from across the globe (Coinguides, 2019; CoinMarketCap, 2018). CRIX is a German based cryptocurrency index that was constructed and is maintained by various academics, technologists and economists from Humboldt University, Singapore Management University and CoinGecko (Härdle *et al.*, 2018b). CoinGecko is a financial trading web based database (CoinGecko, 2019). The data that were sourced was available for most periods under analysis, if not all, for most financial assets and cryptocurrencies. The following section will focus on sampling and the choice of data.

The two sets of populations that were studied were cryptocurrencies and financial assets from a South African investors' perspective. Traditional and alternative assets have been categorised under one unit of analysis, as financial assets, similar to the categorisation of the studies carried out by Brière *et al.* (2015) and Lee *et al.* (2017). The period of study was in days from 11 August 2015 to 31 October 2018. However, weekends and South African public holidays during this period were excluded, as trading of traditional assets does not occur during this period (JSE, 2018a, b, c). A non-probability sampling technique, being purposive sampling, was used. This technique allows for the selection of specific samples in order to test the constructs of the study (Gay *et al.*, 2012; Leacock *et al.*, 2015). The financial assets selected consisted of both traditional and alternative assets that would realistically be included in an investment portfolio. The traditional assets consisted of South African listed shares and government bonds while the alternative assets selected were gold, oil, platinum and South African listed property and resources. These alternative and traditional assets were classified in a similar manner and in line with studies by Brière *et al.* (2015) and Lee *et al.* (2017). Gay *et al.* (2012) posit that, with a large population, a 400 sample size would suffice, but a 500 sample size would add credence (Leacock *et al.*, 2015). However, Lee *et al.* (2017) had a sample size that spanned the daily prices from 11 August 2014 to 27 March 2017, which is far greater than 500. Therefore, the sample size for this study was 800.

3.2 Description and measurement of variables

3.2.1 Returns. This paper employs the arithmetic returns, rather than geometric returns, because they balance out the downward bias with their upward bias (Levy and Sarnat, 1970). The computation of the arithmetic returns is defined as follows:

$$r_{i(t)} = \frac{P_{i(t)} - P_{i(t-1)}}{P_{i(t-1)}} \tag{1}$$

where r_{it} is the arithmetic rate of return for the period for ith financial asset or cryptocurrency, P_t is the price of the ith financial asset or cryptocurrency for period t and P_{t-1} is the price of the ith financial asset or cryptocurrency for period $t-1$. These returns were calculated after the US dollar denominated financial asset and cryptocurrency prices were converted into South

African Rands. The daily arithmetic returns were computed for each of the three assets; namely cryptocurrency asset, alternative asset and traditional asset.

Brière *et al.* (2015) found that cryptocurrencies have different statistical characteristics from oil, gold and other assets. They have also been found to be more volatile but often result in greater returns than traditional assets (Brière *et al.*, 2015; Härdle *et al.*, 2018a; Srilakshmi and Karpagam, 2017).

This study seeks to determine whether cryptocurrencies will improve the portfolio of traditional and alternative assets and assess the diversification benefits of cryptocurrencies in a portfolio of traditional and alternative investments. Moreover, the study also assesses the performance of cryptocurrencies in relation to traditional and alternative assets. Similar investigations, performed by Brière *et al.* (2015), Kan and Zhou (2012) and Lee *et al.* (2017), classified independent and dependent variables, as well as benchmark and test assets based on the potential diversification benefits of either cryptocurrencies or international financial assets. The alternative, traditional and domestic assets were classified as independent variables and benchmark assets, while cryptocurrencies and international assets were classified as dependent variables and test assets. Therefore, this study followed the same mode of classification from a South African investor's perspective. Refer to Table 2 for more details as to how these assets are classified.

3.2.2 Estimation techniques. In line with Brière *et al.* (2015) and Lee *et al.* (2017), this study employs the mean-variance analysis and Sharpe ratio, conditional Value-at-risk analysis and Spanning test techniques in the analysis of the data described in Table 2. This section discusses each of the techniques as used in the study.

3.2.2.1 Mean-variance (MV) analysis and Sharpe ratio. The strength of the MV analysis is that it assesses the return in relation to the risk of each asset, while considering the risk and return of the other assets within the portfolio of investments. This is done to optimise the portfolio of investments (Litterman, 2003c; Malkiel, 2015). Its weaknesses are that it is restricted as it does not account for high moments risks due to skewness and kurtosis, and it results in large asset weights for unconstrained mean-variance optimal portfolios (Lee *et al.*, 2017; Litterman, 2003a). The approach used for the MV analysis was the expected utility function that was utilised to construct the mean-variance efficient frontier, which is represented as follows:

$$E[u(r_p(\omega))] = E[r_p(\omega)] - \lambda E[(r_p(\omega) - E[r_p(\omega)])^2] \tag{2}$$

and the MV was optimised using:

$$\max_{\omega \epsilon \Omega} \Phi(\omega) := \omega_{p(\omega)} - \lambda \sigma_p^2(\omega) = \alpha^T \omega - \lambda \omega^T \Sigma \omega \tag{3}$$

where ω is the weight of the funds invested in asset i, r_p is the total return of the portfolio, $u(r_p(\omega))$ is the utility function that measures $r_p(\omega)$, λ is the risk-aversion coefficient that

Asset types	Asset names	Variables descriptions
Traditional assets	JSE All Share, JSE Top 40, JSE Alternative Exchange and South African government bond	Daily returns of the assets
Alternative assets	JSE SA Listed Property, JSE SA Resources, gold, Platinum, Brent Crude oil and South African Rand	Daily returns of the assets
Cryptocurrencies	CRIX, Bitcoin, Ethereum, XRP, Dash, NEM, Stellar, Litecoin, Dogecoin, Tether and Monero	Daily returns of the assets

Table 2. Variable description, asset names and types

accounts for the deviation of the returns from the mean, Φ is the risk-adjusted expected return function and σ_p^2 is the standard deviation of the portfolio (Tutuncu, 2012). During the analysis, either the Sharpe ratio was maximised or a particular risk rate was targeted (Jorion, 1992; Kan and Zhou, 2012). The MV analysis was computed using Matlab and there was no shorting of investments.

The Sharpe ratio (SR) is a performance measurement technique that is represented using the following formula:

$$\mathrm{SR}_i = \frac{\mu_i - R_f}{\sigma_i} \tag{4}$$

where μ_i is the mean or the return of the investment or portfolio, R_f is the risk-free rate of return and σ_i is the investment or portfolio volatility (Cowell, 2013; Howard and Lax, 2003).

The Sharpe ratio determines how much excess return an investment provides above the risk-free rate for each unit of volatility. Although the Sharpe ratio is a performance measurement technique that is often used, it does have some weaknesses. The first weakness is that it only considers asset risks and returns and it does not account for liabilities. It does not differentiate between downside and upside volatility. Another weakness is that extremely high returns result in a greater increase of σ_i than of $\mu_i - R_i$. It does not perform well for returns that have non-normal distributions (Howard and Lax, 2003; Rollinger and Hoffman, 2013).

3.2.2.2 Conditional value-at-risk (CVaR) analysis. The auxiliary function used to construct the CVaR efficient frontier is as follows:

$$F_\alpha(\omega, \gamma) \;:=\; \gamma + \frac{1}{1-\alpha}\int_{f(\omega,r)\geq\gamma} (f(\omega, r) - \gamma)p(r)\mathrm{d}r \tag{5}$$

which allowed the study to set a target risk for the efficient frontier for a portfolio of investments with n-dimensional vector below:

$$\min_{\omega_t \epsilon R^P} CVaR_\alpha(\omega_t) = \min_{\omega_t \epsilon R^P, \gamma} F_\alpha(\omega, \gamma) \tag{6}$$

$$\min_{\omega_t \epsilon R^P} CVaR_\alpha(\omega_t) \tag{7}$$

$$s.t. u_{p,t}(\omega_t) = r_{\text{Target}} \tag{8}$$

$$\omega_t \; 1_p = 1 \tag{9}$$

$$\omega_{i,t} \geq 0 \tag{10}$$

where r is the returns of the assets, $p(r)$ is the probability density function of r, $\varphi(\omega, \gamma) \;:=\; \int_{f(\omega,r)\geq\gamma}(f(\omega, r) - \gamma)p(r)\mathrm{d}r$ is the cumulative distribution function of $\int$, α is the probability level, r_{Target} is the target risk or significance level, R^P is the constraints of the portfolio, α is the probability level, $\omega_{i,t} \geq 0$ represents no shorting of assets and $\omega_t \; 1_p = 1$ represents investing 100% of the funds in the portfolio. CVaR allows this study to account for the expected amount of loss that exceeds the VaR loss (Lee *et al.*, 2017; Tutuncu, 2012). CVaR was computed using Matlab.

Measures of risk are helpful in optimising portfolios where there is uncertainty and potential losses. The CVaR and VaR are measures of risk. However, the VaR is not stable and it is not easy to utilise when there is extreme risk and when losses are non-normal. Another weakness of VaR is that it does not provide for losses that can be made beyond the amount specified by VaR. VaR is more geared towards the optimisation of portfolios than allowing for conservative risk management of a portfolio. The CVaR overcomes the weaknesses of the

VaR (Rockafellar and Uryasev, 2002). The CVaR's advantages are that it can be utilised to measure large amounts of risk, estimate the chances of the target return being fulfilled and the CVaR, which is also known as the Expected Shortfall (ES) and Expected Tail Loss (ETL), shows the expected extreme loss of an investment (Cowell, 2013). In portfolio optimisation, the CVaR allows for the minimization of the risk, while targeting a specific return. It also allows for the minimization of the return based on a constraint of the CVaR and it permits the maximization of the CVaR in relation to the return (Rockafellar and Uryasev, 2002). Its disadvantage is that it does not naturally account for the higher moments, being skewness and kurtosis (Amédée-Manesme *et al.*, 2019; Lee *et al.*, 2017). If a specific return is the targeted return for both the MV and CVaR analysis, the composition of the portfolio will be the same using both research designs. However, the weights within the portfolios will differ between the MV and CVaR analysis (Miskolczi, 2016).

3.2.2.3 Spanning test. To assess the performance of cryptocurrencies in relation to alternative and traditional assets within a portfolio of investments, the regression test below was used.

$$R_{2t} = \alpha + \beta R_{1t} + \varepsilon_t \quad t = 1, 2, \ldots T \tag{11}$$

where R_{2t} is the N-vector returns on N test assets (being the respective cryptocurrencies), R_{1t} is the K-vector returns on the K benchmark assets (being the alternative and traditional assets), ε_t is the error term, α is a coefficient and t represents time which is in days (Brière *et al.*, 2015; Kan and Zhou, 2012).

The expected returns of N test + K benchmark assets are:

$$\mu = E[R_t] = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix} \tag{12}$$

and the covariance matrix of N test + K benchmark assets is:

$$V = \mathrm{Var}[R_t] = \begin{bmatrix} V_{11} & V_{12} \\ V_{21} & V_{22} \end{bmatrix} \tag{13}$$

and

$$\Sigma = V_{22} - V_{21} V_{11}^{-1} V_{12} \tag{14}$$

In obtaining the "exact distributions of the test statistics" that are assumed "conditional on R_{1t}, the disturbances ε_t are independent and identically distributed as multivariate normal with mean zero and variance Σ" (Kan and Zhou, 2012, p. 144). The regression model is based on the CAPM and MPT (Cowell, 2013). The cryptocurrencies, alternative assets and traditional assets form part of the test and benchmark assets.

The spanning test that was used is the Huberman and Kandel (1987) multivariate OLS regression Wald test, which was computed using SAS. The strength of Huberman and Kandel's (1987) multivariate OLS regression Wald test is that it is easier to perform than its counterparts, the Lagrange Multiplier test and the Likelihood Ratio test. The Lagrange Multiplier (LM) or the Likelihood Ratio (LR) test are not completely equivalent in rejecting or accepting the null hypothesis. The Lagrange Multiplier (LM) test performs better under asymptotic spanning tests but only when T is not tiny and the Wald test performs better for finite samples in testing. However, its disadvantage is that it sometimes results in a Type I error. T is the amount of time in a time series (Kan and Zhou, 2012). Therefore, the Wald test was chosen due to the statistical software capabilities of this test.

"The necessary and sufficient conditions for spanning in terms of restrictions" (Brière *et al.*, 2015, p. 368; Kan and Zhou, 2012, p. 142) are:

$$H_0 : \alpha = 0 \text{ and } \beta 1_k = 1_N \tag{15}$$

where (15) suggests the mean-variance spanning and implies that, for each N test asset, there is a portfolio of the K benchmark assets that has the same mean but smaller variance than the test assets (Brière *et al.*, 2015; Kan and Zhou, 2012). The Wald statistic test has the asymptotic distribution:

$$W = T(\lambda_1 + \lambda_2) \sim \chi^2_{2N} \tag{16}$$

where:

$$\lambda_1 = \max_r \frac{1 + \theta_2^2(r)}{1 + \theta_1^2(r)} - 1 \tag{17}$$

$$\lambda_2 = \max_r \frac{1 + \theta_2^2(r)}{1 + \theta_1^2(r)} - 1 \tag{18}$$

and $\theta_2^2(r)$ and $\theta_1^2(r)$ are the Sharpe ratios for the risk-free rate, while the portfolio consists of K benchmark assets and N test assets (Brière *et al.*, 2015; Kan and Zhou, 2012).

$N = 1$ and thus the F-test is:

$$\left(\frac{1}{U} - 1\right)\left(\frac{T - K - 1}{2}\right) \sim F_{2,T-K-1} \tag{19}$$

The regression test is run multiple times with $N = 1$. This is done by running the regression multiple times with different cryptocurrencies and CRIX, to assess whether each cryptocurrency has diversification advantages. This was done as CRIX is overwhelmed by Bitcoin, with Bitcoin making up 64.51% of CRIX (Table 1).

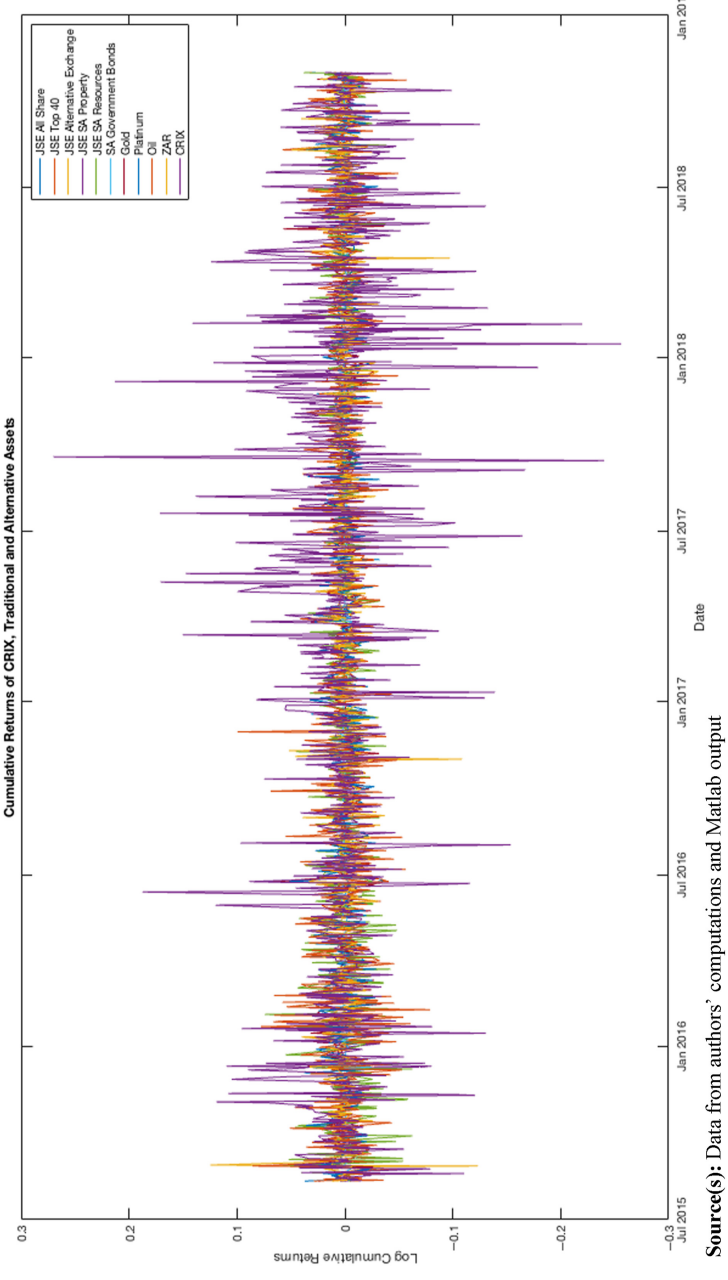
3.3 Research reliability and validity

There is validity confidence that other researchers performing similar tests with the same data will obtain the same results as this study. The data sourced were verified using the author's reputation, the reputation of the source, the period over which the data related, the plausibility of this time collection period and the location from which it was sourced. Additionally, the data were consistent with the data used in the studies performed by Brière *et al.* (2015) and Lee *et al.* (2017). This study is reliable as it is based on two rigorous studies performed and published by Brière *et al.* (2015) and Lee *et al.* (2017). The study performed by Brière *et al.* (2015) was on BTC, traditional and alternative assets from an American perspective. While the study performed by Lee *et al.* (2017) was on CRIX, 10 of the most frequently used cryptocurrencies within CRIX, traditional and alternative assets. The aforementioned studies performed were consistent. The reliability of this study is further supported by using CRIX, 10 cryptocurrencies used within CRIX, traditional and alternative assets from a South African perspective within this study, which is consistent with the two previous rigorous studies performed.

4. Results

4.1 Trend analysis

In Figure 2, log cumulative returns are used for the trend analysis similar to studies by Brière *et al.* (2015) and Lee *et al.* (2017), these studies used weekly returns and average daily returns



Source(s): Data from authors' computations and Matlab output

Figure 2.
Cumulative returns of CRIX, traditional and alternative assets

for all the testing performed other than for the trend analysis respectively. This directed the use of log cumulative returns in the trend analysis and arithmetic rate of return based on the daily historical closing prices being used for all the other tests performed in this study. Cumulative returns are calculated over days, weeks, months or years. Similar to the study conducted by Brière *et al.* (2015) that used the same period for the trend analysis and the testing performed for all the other tests conducted in the study, this study uses same period for the trend analysis and the testing performed for all the other tests conducted in the study.

In Figure 2, the daily log cumulative returns graph of CRIX and the traditional and alternative assets from 11 August 2015 to 31 October 2018 was created to analyse the trend of the various financial assets over time. As per Figure 2, the returns of the assets oscillate and are symmetric around zero. The returns of bonds, property and JSE Alternative Exchange index (AtlX) move mainly between 0.05 and −0.05, very close to zero, below 0.05 and −0.05 and 0.02 and −0.02 respectively. These also show that the returns of bonds, property and AtlX are less volatile and lower on average than those of the other assets. The returns of JSE All Share index (ALSI), gold, platinum, oil, resources, Top 40 and ZAR move between 0.08 and −0.06 and they were more volatile and higher on average than bonds, property and AltX. The CRIX returns moved between 0.2 and −0.2 for most of the period and 0.3 and −0.3 between late 2017 and early 2018 and then moved back to between 0.2 and −0.2 after early 2018, after significant price adjustments in cryptocurrencies. Thus, CRIX has the highest volatility and returns in comparison to the other assets. As found by Kim *et al.* (2018), there was an upswing in the BTC and ETH price that was caused by BTC and ETH being used to buy other cryptocurrencies in 2017. As per a study by Lee *et al.* (2017), cryptocurrencies average daily returns exceeded those of traditional assets, while a study by Brière *et al.* (2015) found that BTC cumulative weekly returns exceed those of other assets on average. Therefore, based on current and prior studies, the cumulative log returns and volatility of CRIX and cryptocurrencies, on average, exceed those of traditional and alternative assets. Descriptive statistics will now be discussed below.

4.2 Descriptive statistics

Tables 3 and 4 show the descriptive statistics of the different asset classes. The annual mean of traditional and alternative assets is low, with most of the annual means being positive or negative single digit returns on assets whereas the annual mean of CRIX and cryptocurrencies are all positive triple digits, except for Usdt. Therefore, the annual means of CRIX and cryptocurrencies are high and far exceed those of the relatively low means of alternative and traditional assets. This suggests that the annual returns of cryptocurrencies are very high in relation to traditional and alternative assets. These results are supported by the studies carried out by Brière *et al.* (2015) and Lee *et al.* (2017). The very high annual returns of CRIX and cryptocurrencies supports the maximisation of the returns by the investor as per the MPT. The standard deviations and variances of the alternative and traditional assets are low in comparison to those of CRIX and cryptocurrencies, which are high. Therefore, the risk of cryptocurrencies largely exceeds that of alternative and traditional assets. The high risk of CRIX and cryptocurrencies increases instead of minimising the risk of the assets held by the investor. This increased risk contests the minimisation of risk on securities as postulated by the MPT. Most traditional and alternative assets have a skewness of between 0.5 and −0.5, with the exception being bonds with a skewness of −2.23. This means that most of these assets are relatively symmetric. Most cryptocurrencies have skewnesses of above 0.5, which means that the data is heavily skewed (McNeese, 2016). This positive skewness also illustrates that returns increase rapidly and drop at a slow pace. Similar results were found in the studies performed by Brière *et al.* (2015) and Lee *et al.* (2017). Kurtosis of most traditional and alternative assets is lower than three, with AltX, Prop and bonds being exceptions, with kurtosis exceeding 11.42. The lower than three kurtosis suggests that most of these assets' returns are platykurtic. Moreover, the

Table 3. Descriptive statistics for daily returns of traditional and alternative assets

	All	Top40	AltX	Property	Resources	Bonds	Gold	Platinum	Oil	ZAR
Mean	0.01%	0.01%	−0.04%	−0.03%	0.04%	0.03%	0.04%	0.01%	0.10%	0.03%
Annualised mean	1.41%	1.27%	−9.82%	−7.68%	9.26%	8.13%	10.23%	2.77%	24.09%	6.55%
Median	0.04%	0.03%	−0.02%	0.01%	0.08%	0.04%	0.04%	0.02%	0.05%	−0.04%
Standard deviation	0.99%	1.07%	1.14%	1.07%	1.72%	0.21%	1.25%	1.29%	2.11%	1.15%
Variance	0.01%	0.01%	0.01%	0.01%	0.03%	0.00%	0.02%	0.02%	0.04%	0.01%
Minimum	−3.56%	−3.97%	−11.60%	−7.72%	−6.27%	−2.46%	−6.20%	−4.25%	−7.59%	−5.09%
Maximum	3.72%	3.97%	13.27%	7.61%	7.71%	1.44%	7.31%	5.30%	10.45%	5.09%
Skewness	−0.0809	−0.0550	−0.5111	−0.1653	0.0041	−2.2300	0.3946	0.2301	0.3559	0.2864
Kurtosis	1.0478	1.0898	50.1184	11.4181	1.4832	31.2595	2.8043	0.3803	1.7130	1.2491
One-lag autocorrelation	−0.0220	−0.0393	−0.2601	0.0459	0.0553	0.1140	−0.0188	−0.0549	0.0291	0.0369
Observations	800	800	800	800	800	800	800	800	800	800

Note(s): All = JSE All Share index, Top40 = JSE Top 40 index, AltX = JSE Alternative index, Property = JSE SA Property index, Resources = JSE SA Resources index, Bonds = SA Government Bonds, Oil = Brent Crude oil and ZAR = South African Rand
Source(s): Data from authors' computations

Table 4.
Descriptive statistics for daily returns of CRIX and cryptocurrencies

	CRIX	BTC	ETH	XRP	Dash	NEM	XLM	LTC	Doge	Usdt	XMR
Mean	0.57%	0.53%	0.96%	0.93%	0.74%	1.57%	1.25%	0.60%	0.81%	0.03%	1.05%
Annualised mean	142.82%	132.34%	242.70%	233.47%	186.51%	396.24%	315.49%	150.55%	203.99%	6.84%	263.65%
Median	0.52%	0.45%	0.12%	−0.28%	0.13%	−0.14%	−0.68%	−0.14%	−0.10%	−0.05%	0.00%
SD	4.81%	4.83%	9.14%	9.92%	7.10%	14.20%	14.34%	7.84%	9.82%	1.35%	9.65%
Variance	0.23%	0.23%	0.84%	0.98%	0.50%	2.02%	2.06%	0.61%	0.97%	0.02%	0.93%
Minimum	−22.60%	−20.98%	−60.90%	−29.96%	−22.83%	−29.88%	−30.62%	−32.77%	−39.02%	−7.36%	−25.55%
Maximum	31.01%	30.49%	67.50%	114.97%	47.51%	169.63%	272.00%	71.57%	124.43%	6.60%	104.18%
Skewness	0.1642	0.5174	1.0421	4.1632	1.2775	5.2624	9.6281	3.3969	4.4427	(0.0437)	3.0169
Kurtosis	5.3541	5.7265	9.4996	33.6579	6.2524	49.1036	164.4675	26.4026	44.0225	2.7714	24.3495
1LA	(0.0005)	0.0015	0.0766	0.1708	(0.0110)	(0.0755)	0.0961	0.0755	0.0379	(0.0309)	0.0085
N	800	800	800	800	800	800	800	800	800	800	800

Note(s): BTC = Bitcoin, ETH = Ethereum, XLM = Steller, LTC = Litecoin, Doge = Dogecoin, Usdt = Tether and XMR = Monero. 1LA = One-lag autocorrelation
Source(s): Data from authors' computations

kurtosis of CRIX and all the cryptocurrencies also exceeds three. This means that returns of these assets are leptokurtic and subject to fat-tailed or extreme cases of risk (Forsberg, 2019) while the low one-lag autocorrelation for all the assets reflects a lack of predictability of the returns. This finding is similar to that of Lee *et al.* (2017).

4.3 Correlation analysis

Table 5 that illustrates the Pearson correlation matrix will now be discussed. Most correlations between the cryptocurrencies and the alternative and traditional investments are below 0.1 and −0.1. This suggests that there are several weak positive and negative relationships and correlations of below 0.1, −0.1, 0.5 and −0.5 between cryptocurrencies and alternative and traditional assets. Similar results of low correlations between BTC and traditional and alternative assets, as well as CRIX and traditional and alternative assets, respectively were found in studies by Brière *et al.* (2015) and Lee *et al.* (2017). From 2011 to 2016 low correlations between BTC and traditional and alternative assets were also found in a study by Burniske and White (2017). This study found that BTC has on average a low correlation of −0.05 correlated to emerging market currencies. This study also revealed that gold had a low to moderate correlation to BTC. The low correlations between the cryptocurrencies and the alternative and traditional investments builds upon the MPT of assets and industries that can be used to diversify an investment portfolio. These results also show that cryptocurrencies are potentially good diversifiers of traditional and alternative assets. However, correlations are known to change over time and these results should be assessed with caution (Brière *et al.*, 2015). Moving forward below, the MV analysis findings are discussed.

4.4 Mean-variance results

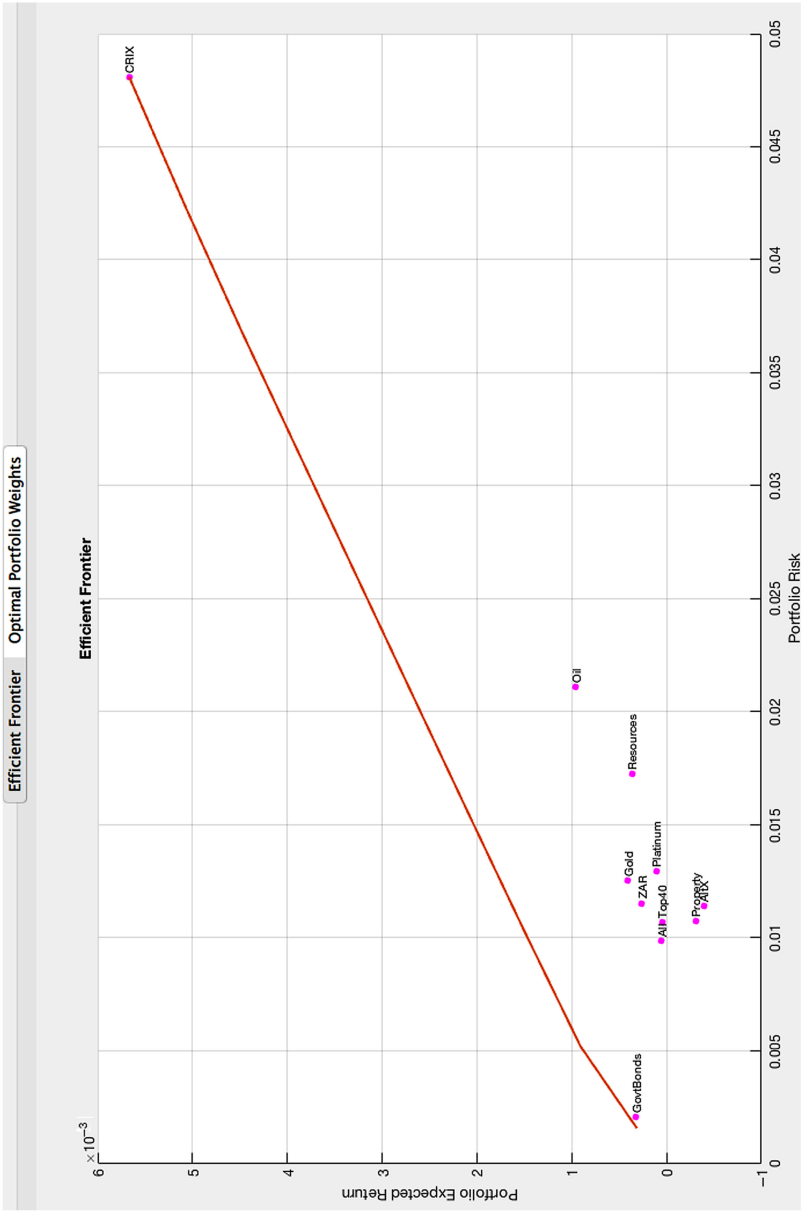
The results of the mean-variance analysis efficient frontier are presented in Figure 3. The figure indicates that cryptocurrencies generate higher returns in relation to risk than South African traditional and alternative assets, supporting H1. The only asset that lies on the efficient frontier is CRIX, while the bonds lie very close to the lower end of the efficient frontier. All the remaining assets, being: gold, oil, ALSI, Top 40, platinum, property, AltX, resources and ZAR, do not lie individually as assets on the efficient frontier. The assets that lie on the lowest point are property, which is followed by AltX. That means that AltX is the asset with the lowest return and with a respectively high level of risk. The efficient frontier is a line that consists of numerous optimised investment portfolios, which are a combination of the assets at different weights, risks and returns (Malkiel, 2015). Therefore, the efficient frontier is the point at which the investment portfolio return is maximised per unit of risk (Mangram, 2013; Pfiffelmann *et al.*, 2016; Watsham and Parramore, 1997).

In Figure 3, at the furthest point of the efficient frontier, CRIX is set to a portfolio investment of 100%. CRIX would be the only asset in the portfolio, that is, if the respective investor was willing to take the very high risk, for the high return at the top of the efficient frontier. If an investor were to hold the best investment to derive the highest return, it would have to be 100% CRIX, despite the high risk involved. This finding contests Markowitz (1952, 1991) who stated that investors should diversify their investment portfolios, as the above finding suggests 100% investment in CRIX. This study shows that CRIX results in a higher return per unit of risk than gold, oil, ALSI, Top 40, platinum, property, AltX, resources and ZAR. Similar results were derived by Lee *et al.* (2017) in their investigation, which also found that CRIX is on the top of the efficient frontier. However, their study was not from a South African investor's perspective. Their study found that the S&P 500, the Real Estate Investment Trusts (REITs), gold, oil, private equity and Goldman Sachs Commodity Index (GSCI) all lay below the efficient frontier, with oil being the asset with the smallest return for its respectively high level of risk.

Table 5.
Pearson correlation matrix

	All	Top40	AltX	Prop	Res	Bonds	Gold	Plat	Oil	ZAR	CRIX	BTC	ETH	XRP	Dash	NEM	XLM	LTC	Doge	Usdt	XMR
All	1																				
Top40	0.994**	1																			
AltX	0.044	0.037	1																		
Prop	0.488**	0.441**	−0.002	1																	
Res	0.660**	0.651**	−0.013	0.110**	1																
Bonds	0.198**	0.156**	0.004	0.462**	−0.021	1															
Gold	−0.147**	−0.133**	−0.006	−0.296**	0.078*	−0.407**	1														
Plat	0.031	0.031	−0.010	−0.154**	0.253**	−0.227**	0.730**	1													
Oil	0.238**	0.248**	0.017	−0.038	0.342**	−0.128**	0.185**	0.239**	1												
ZAR	−0.109**	−0.078*	0.018	−0.296**	0.015	−0.524**	0.774**	0.508**	0.284**	1											
CRIX	0.010	0.013	−0.012	−0.062	0.016	−0.137**	0.153**	0.098**	0.089*	0.197**	1										
BTC	−0.014	−0.008	−0.015	−0.077*	0.003	−0.158**	0.164**	0.100**	0.082*	0.225**	0.711**	1									
ETH	−0.067	−0.068	0.018	−0.040	−0.042	−0.070*	0.086*	0.053	−0.022	0.097**	0.397**	0.370**	1								
XRP	0.020	0.023	−0.004	−0.028	−0.005	−0.068	0.101**	0.078*	0.045	0.117**	0.317**	0.309**	0.196**	1							
Dash	0.039	0.041	0.053	−0.035	0.030	−0.063	0.071*	0.034	0.100**	0.126**	0.401**	0.464**	0.423**	0.242**	1						
NEM	0.007	0.010	−0.036	−0.017	0.002	−0.033	0.083*	0.031	0.075*	0.091**	0.253**	0.278**	0.161**	0.295**	0.262**	1					
XLM	−0.027	−0.028	0.033	−0.017	−0.037	−0.034	0.083*	0.067	0.051	0.095**	0.311**	0.301**	0.169**	0.596**	0.218**	0.360**	1				
LTC	0.000	0.009	0.008	−0.041	0.016	−0.068	0.114**	0.072*	0.072*	0.166**	0.418**	0.521**	0.312**	0.330**	0.411**	0.271**	0.274**	1			
Doge	−0.018	−0.025	0.047	−0.021	−0.003	−0.046	0.095**	0.093**	0.050	0.093**	0.424**	0.443**	0.339**	0.401**	0.386**	0.317**	0.460**	0.372**	1		
Usdt	−0.112**	−0.087*	0.006	−0.253**	0.002	−0.450**	0.666**	0.437**	0.247**	0.865**	0.144**	0.173**	0.084*	0.094**	0.093**	0.053	0.094**	0.093**	0.063	1	
XMR	0.054	0.053	0.003	0.019	0.047	−0.023	0.055	0.037	0.045	0.079*	0.348**	0.413**	0.340**	0.234**	0.435**	0.196**	0.238**	0.315**	0.304**	0.041	1

Note(s): All = JE All Share index, Top40 = JSE Top 40 index, AltX = JSE Alternative index, Prop = JSE SA Property index, Res = JSE SA Resources index, Bonds = SA Government Bonds, Plat = Platinum, Oil = Brent Crude oil and ZAR = South African Rand, BTC = Bitcoin, ETH = Ethereum, XLM = Steller, LTC = Litecoin, Doge = Dogecoin, Usdt = Tether and XMR = Monero
*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed)
Source(s): Data from authors' computations



Note(s): All = ALSI = JSE All Share index, Top40 = JSE Top 40 index, AltX = JSE Alternative index, Property = JSE SA Property index, Resources = JSE SA Resources index, GovtBonds = SA Government Bonds, Oil = Brent Crude oil and ZAR = South African Rand

Source(s): From authors' computations

Figure 3.
Efficient frontier

The reason for CRIX resulting in better returns at a specified risk is due to it being an amalgamation of numerous cryptocurrencies which have high risks but also high returns. Cryptocurrencies are known to be volatile as their prices are susceptible to implosions or bubbles (Brière *et al.*, 2015; Hickey, 2017; Taylor, 2015).

JSE listed indices consist of various top performing listed entities on the JSE which is the 19th largest stock market globally that caters to various types of investors. The JSE has to ensure that the investments are regulated, efficient and that they are kept safe (JSE, 2019). Brière *et al.* (2015) found that gold, oil and hedge funds have different characteristics to Bitcoin. Therefore, it would be expected that the risk and return of traditional and alternative assets would be lower than those of CRIX and cryptocurrencies (see Table 6).

The Sharpe ratio measures the risk-adjusted return of an asset. From Table 6, the CRIX Sharpe ratio exceeds the Sharpe ratio of ALSI, Top 40, AltX, Prop, Res, gold, platinum, oil and ZAR. The CRIX Sharpe ratio is more than double the Sharpe ratio of ALSI, Top 40, AltX, Prop, Res, gold, platinum, oil and ZAR. However, the Sharpe ratio of the bonds exceeds that of CRIX. The risk-adjusted return of CRIX is better than that of ALSI, Top 40, AltX, Prop, Res, gold, platinum, oil and ZAR. While the risk-adjusted return of the bonds is better than that of the CRIX. In line with the research performed by Brière *et al.* (2015), the Sharpe ratio analysis shows that overall CRIX is a better investment than South African traditional and alternative assets. The CRIX results in a higher return per unit of risk than traditional and alternative assets which supports H1 and affirms the importance of analysing the variance (V) in relation to expected returns (E) for assets within a portfolio as stated by the MPT.

This study finds that, although CRIX lies on the highest point of the efficient frontier, the optimal point on the efficient frontier for an investor is known as the tangency portfolio, where the Sharpe ratio is maximised or where the investor gets the best return-risk ratio (Jorion, 1992; Kan and Zhou, 2012). This study also finds that overall CRIX has a better risk-adjusted return than traditional and alternative assets. As seen in Table 7, tangency portfolio weights are as follows: 88.42% for bonds, 2.46% for gold, 1.13% for oil, 5.54% for ZAR and 2.03% for CRIX. Therefore, due to the high-risk nature of cryptocurrencies, investors cannot invest 100% of their funds in cryptocurrencies but rather a lower portion, as per the tangency portfolio, in a portfolio that consists of cryptocurrencies, traditional and alternative assets. Due to CRIX being a cryptocurrency index, the testing of CRIX in a portfolio inadvertently tests a combination of cryptocurrencies in a portfolio. The weights of the aforementioned assets within an investment portfolio adds to the literature of the MPT and it further justifies the use of diversification of assets within an investment portfolio as postulated by Markowitz (1952, 1991) in the MPT. Additionally, unlike the studies performed by Brière *et al.* (2015) and

Table 6.
CRIX, traditional and alternative assets' Sharpe ratios

Names	Sharpe ratio
JSE All Share index (ALSI)	0.0901
JSE top 40 index (Top 40)	0.0747
JSE alternative index (AltX)	−0.5423
JSE SA property index (Prop)	−0.4507
JSE SA resources index (Res)	0.3381
SA government bonds (bonds)	2.4648
Gold	0.5148
Platinum	0.1346
Brent crude oil (oil)	0.7196
South Africa rand (ZAR)	0.3578
CRIX	1.8712

Source(s): Data from authors' computations

Names	Weights
JSE all share index (ALSI)	0.0000
JSE top 40 index (Top 40)	0.0000
JSE alternative index (AltX)	0.0000
JSE SA property index (Prop)	0.0000
JSE SA resources index (Res)	0.4231
SA government bonds (bonds)	88.4173
Gold	2.4589
Platinum	0.0000
Brent crude oil (oil)	1.1346
South Africa rand (ZAR)	5.5372
CRIX	2.0290

Source(s): Data from authors' computations

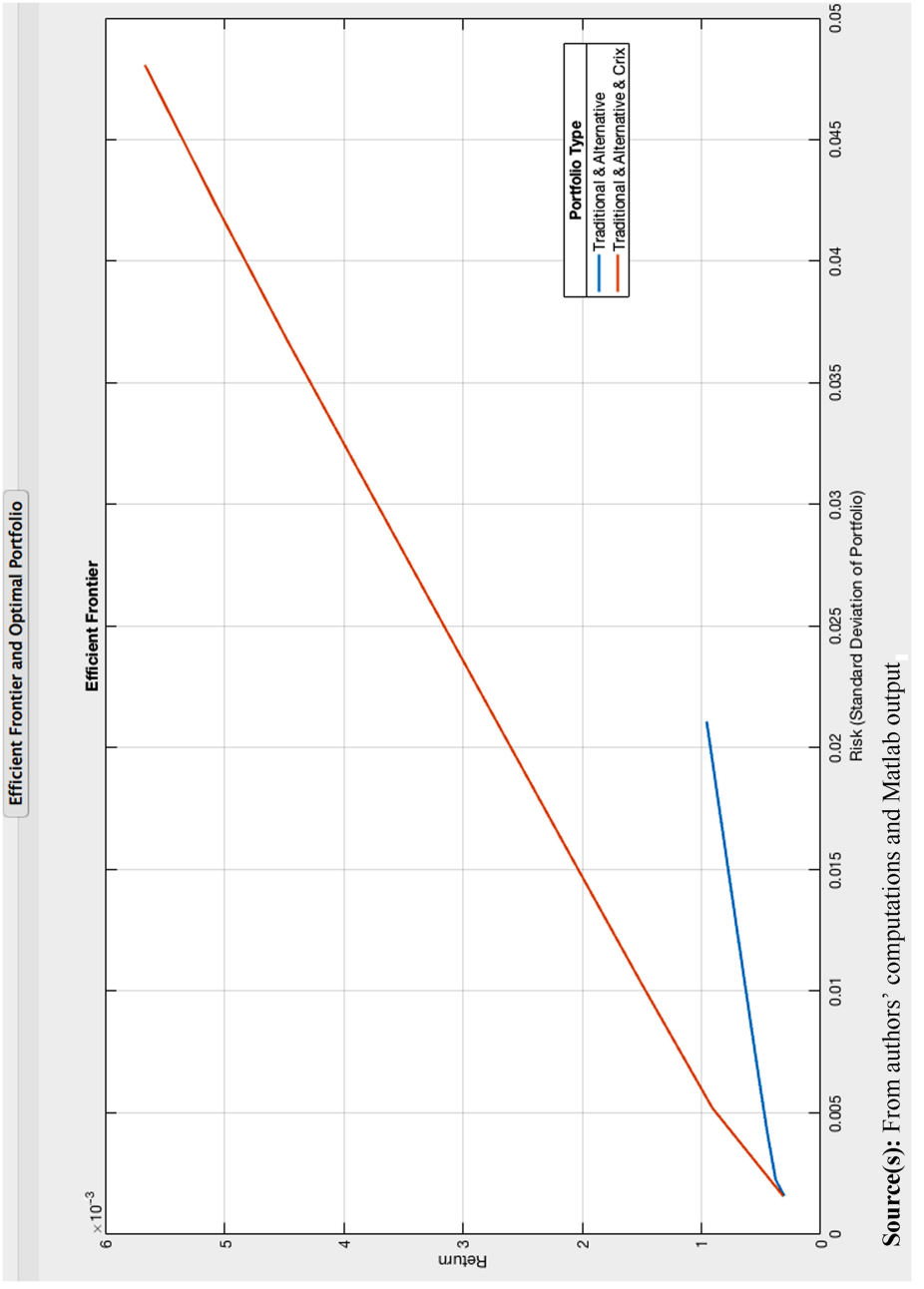
Table 7. Optimal portfolio asset weights

Lee *et al.* (2017), this study depicts and adds to the literature the weight at which cryptocurrencies should be included within an optimal investment portfolio.

Utilising the mean-variance analysis, the study tests H2 that cryptocurrencies have diversification advantages in South African investment portfolios. As per Figure 4, the efficient frontier of the optimised portfolio, consisting of traditional assets, alternative assets and CRIX is higher and larger than that consisting only of traditional and alternative assets.

The portfolio optimised using the Sharpe ratio within Figure 4 and Table 8 will now be discussed. Under the optimised portfolio, the annual mean of the portfolio without CRIX is 8.64% and with CRIX, it is 11.64%, while the standard deviation is 2.58% for the portfolio without CRIX and with CRIX, it is 2.93%. This means that the returns improved for a portfolio with CRIX rather than without, while the risk increased slightly. The Sharpe and Sortino ratios both increased from 3.21 to 3.76 and 5.37 to 6.47 respectively, for portfolios without CRIX to those with CRIX. The Sortino ratio that exceeds the Sharpe ratio shows that there are greater excess returns per unit of downside volatility in comparison to excess returns per unit of total volatility. Moreover, the results show that, by including CRIX within an optimised portfolio, utility can be slightly improved, although at a slightly increased risk level. A previous study performed by Lee *et al.* (2017) illustrated that a portfolio under the same risk level had higher returns with CRIX than without CRIX. However, unlike the investigation performed by Brière *et al.* (2015), this study reflects the optimal portfolio Sharpe and Sortino ratio, annual mean and standard deviation for an optimal investment portfolio with and without CRIX. This enhances the literature of the MPT and data relating to the investments pool of knowledge.

Referring to Table 8, volatility levels of 6 and 12% were used within the study similar to a study carried out by Brière *et al.* (2015). However, BTC was used by Brière *et al.* (2015) to represent cryptocurrencies, whereas this study used CRIX to represent cryptocurrencies. Although BTC constituted 64.51% of the top 10 cryptocurrencies market capitalisations as at 1 October 2018 (Table 1), CRIX is more representative of the cryptocurrency investment universe as it also consists of the bulk of other cryptocurrencies within the cryptocurrency investment universe. At a volatility of 6%, the annual mean of the portfolio without CRIX of 11.561% leaps to 20.727% for portfolios with CRIX. This means that the returns improved drastically for a portfolio with CRIX over one without CRIX. The Sharpe and Sortino ratios both increased from 1.82 to 3.08 and 2.83 to 5.11 respectively, for portfolios without CRIX to those with CRIX. This shows that, by including CRIX within a portfolio that targets a 6% volatility, utility is almost doubled. At double the volatility of 12%, the annual mean of the portfolio without CRIX of 14.93% jumps to 34.81% for portfolios with CRIX. This means that the returns improve drastically for a portfolio with CRIX over those without. The Sharpe and



Source(s): From authors' computations and Matlab output

Figure 4.
Efficient frontier with and without CRIX

Sortino ratios both increased from 1.16 to 2.49 and 1.74 to 4.01 respectively, for portfolios without CRIX to those with CRIX. The Sortino ratio that exceeds the Sharpe ratio shows that there are greater excess returns per unit of downside volatility in comparison to excess returns per unit of total volatility. Moreover, this shows that, by including CRIX within a portfolio that targets 12% volatility, utility is more than doubled. A previous study by Brière *et al.* (2015) that compared portfolios with and without Bitcoin overall also found that, for moderately risk-averse investors, including Bitcoin in their portfolios would drastically increase their portfolios' performance but at a greatly increased risk level. Therefore, the current study establishes that including CRIX and cryptocurrencies within a portfolio of investments results in a moderate to significant improvement in the South African investment portfolio, although at moderate to significantly increased risk levels. It reinforces H2 as it suggests that CRIX and cryptocurrencies have moderate to significant diversification advantages in South African investment portfolios and investment portfolios. These findings further validate the MPT in that diversifying across multiple economically diverse assets and maximising the E in relation to V strengthens the portfolio of investments.

The CVaR analysis will now be assessed.

4.5 Conditional value-at-risk analysis results

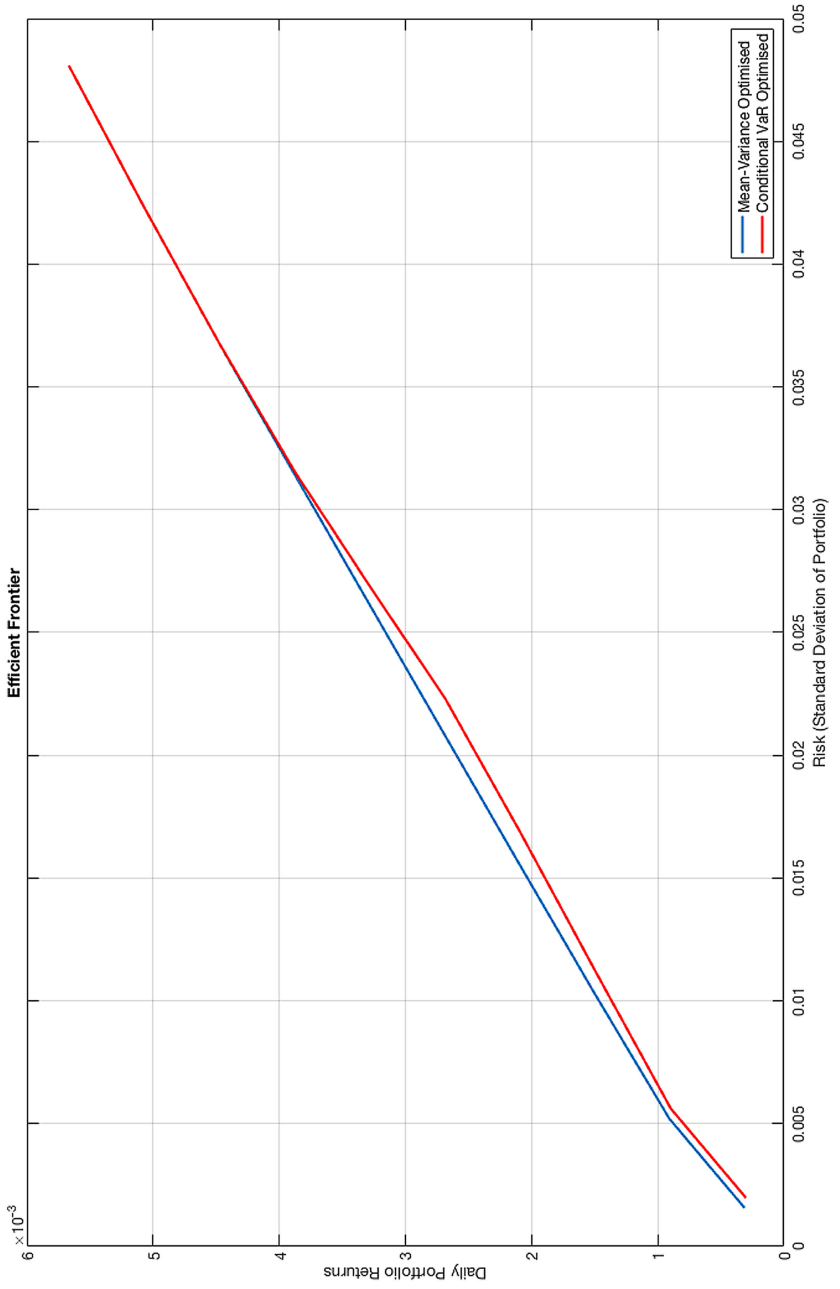
The results of the CVaR analysis efficient frontier are presented in Figure 5. The figure further validates H2, as it indicates that cryptocurrencies have diversification advantages in South African portfolios. At a given return, the mean-variance efficient frontier has lesser risk than the CVaR efficient frontier at a significance level of 0.01.

This is mainly due to more risk being accounted for by the CVaR than the mean-variance analysis. This shows that, under the CVaR analysis, cryptocurrencies have diversification benefits. During their study, Lee *et al.* (2017) found that the CVaR efficient frontier at a significance level of 0.01, which included higher risk and moments of skewness and kurtosis, performs slightly worse than the mean-variance frontier. Additionally, the asset allocation was similar under the CVaR analysis. This study did not account for higher moments, as per the Cornish–Fisher expansion, due to certain research limitations but the results were similar to those of a previous study. This investigation found that, under the CVaR analysis, the utilities under the CVaR and MV analyses are similar. Therefore, cryptocurrencies have diversification advantages under the CVaR analysis. The CVaR accounts for expected extreme loss of an investment (Cowell, 2013). The similarity between the CVaR and MV analyses results reveals that there is a similar expected extreme loss of an investment, when the South African investor includes and excludes cryptocurrencies in their investment portfolio. The results of the spanning test will now be discussed.

	Optimised		6% Volatility		12% Volatility	
	Without CRIX	With CRIX	Without CRIX	With CRIX	Without CRIX	With CRIX
Annual mean	8.641%	11.636%	11.561%	20.272%	14.934%	34.807%
Annual standard deviation	2.579%	2.931%	6.000%	6.000%	12.000%	12.000%
Sharpe ratio	3.2147	3.7563	1.8238	3.0775	1.1602	2.4904
Sortino ratio	5.3741	6.4663	2.8320	5.1069	1.7406	4.0053
CRIX (%)	0.000%	2.029%	0.000%	7.154%	0.000%	15.283%

Source(s): Data from authors' computations

Table 8. Efficient portfolio performance with and without CRIX



Source(s): From authors' computations and Matlab output

Figure 5.
Efficient frontier under CVaR and MV

4.6 Spanning test results

Although the MV and CVaR analysis studies performed above illustrate that cryptocurrencies have diversification gains, the studies were performed using CRIX. At 64.51%, Bitcoin forms an overwhelming part of CRIX. As a result, at this stage, it is uncertain whether only CRIX, Bitcoin or the individual cryptocurrencies result in diversification benefits. This prompted the testing of whether the individual cryptocurrencies have diversification advantages in South African investment portfolios. Using the Huberman and Kandel (1987) multivariate OLS regression Wald test at a level of significance or alpha of 0.05, the results of the spanning test were derived. As per Table 9, the research shows that the *p*-values of CRIX, Bitcoin, XRP, Ethereum, Dash, NEM, Stellar and Monero were all below 0.05, as 0.0025, 0.0045, 0.0352, 0.0089, 0.0178, 0.0143, 0.0461 and 0.0106 respectively while, the *p*-values of Litecoin, Dogecoin and Tether were greater than 0.05 at 0.0826, 0.0678 and 0.9997 respectively. This means that, since the *p*-value of CRIX, Bitcoin, XRP, Ethereum, Dash, NEM, Stellar and Monero is less than an alpha of 0.05, we reject the H_0 or null hypothesis. Therefore, there is significant evidence to support the fact that CRIX, Bitcoin, XRP, Ethereum, Dash, NEM, Stellar and Monero have diversification advantages in South African investment portfolios. However, since the *p*-value of Litecoin, Dogecoin and Tether is greater than an alpha of 0.05, we do not reject the H_0 or null hypothesis. There is significant evidence showing that Litecoin, Dogecoin and Tether do not have diversification advantages. Therefore, seven out of ten cryptocurrencies and CRIX have diversification benefits in South African investment portfolios, strengthening H2.

An investigation of a similar nature was performed by Brière *et al.* (2015) and Lee *et al.* (2017). Brière *et al.* (2015) discovered that Bitcoin spans traditional and alternative assets. Therefore, Bitcoin was found to have diversification benefits in a portfolio. While, Lee *et al.* (2017) found that most cryptocurrencies and CRIX improve the performance of a portfolio, with six out of ten cryptocurrencies and CRIX that span and diversify portfolios constructed of traditional and alternative assets but not tangency portfolios. Although it utilised the MV analysis on each cryptocurrency and portfolio, another study carried out by Ketelaars (2018) illustrated that the inclusion of Bitcoin, Steller, XRP, Litecoin and Monero in a portfolio increased the efficient frontier and the Sharpe ratio. As a result, they each have diversification benefits. From the current and previous studies, we can conclude that CRIX and most cryptocurrencies span the traditional and alternative investment portfolios. We can also conclude that CRIX and most cryptocurrencies have diversification advantages in these portfolios, excluding tangency portfolios. These findings illustrate the importance of diversifying an investment portfolio across various economically diverse assets as per the

Asset	Alpha	*F*-test	*p*-value
CRIX	0.0058	6.0200	0.0025
Bitcoin	0.0054	5.4500	0.0045
XRP	0.0093	3.3600	0.0352
Ethereum	0.0102	4.7500	0.0089
Dash	0.0071	4.0500	0.0178
NEM	0.0142	4.2700	0.0143
Stellar	0.0121	3.0900	0.0461
Litecoin	0.0052	2.5000	0.0826
Dogecoin	0.0082	2.7000	0.0678
Tether	0.0000	–	0.9997
Monero	0.0101	4.5700	0.0106

Source(s): Data from authors' computations

Table 9. Spanning test for cryptocurrencies' effect on portfolio constructed of alternative and traditional assets

MPT. Furthermore, it illustrates the gravity of selecting securities while noting the fluctuations of other securities as stated by the MPT (Elton and Gruber, 1997).

5. Conclusion and recommendations

Traditional and alternative South African investments have been performing poorly and returning less than satisfactory returns to their investors. This study sought to assist these investors by investigating alternative assets into which they can invest. In doing so, this investigation sought to compare the return relative to risk derived from cryptocurrencies and South African traditional and alternative assets. This was achieved using the mean-variance analysis and the Sharpe ratio that found that CRIX has a higher return per unit of risk than traditional and alternative assets. This demonstrated that cryptocurrencies are a better investment than South African traditional and alternative assets. A comparison of the performance of South African investment portfolios with cryptocurrencies to portfolios without cryptocurrencies was also performed. This was achieved by comparing mean-variance with and without CRIX. It was found that including cryptocurrencies within the portfolio increases the financial gains of the portfolio. This also means that including cryptocurrencies in a portfolio leads to diversification benefits. The CVaR analysis was then performed and it illustrated that risk-return under CVaR and MV analyses are similar and that diversification advantages are still derived under the CVaR efficient frontier. Lastly, the spanning test which used the multivariate OLS regression Wald test was performed. This showed that, individually, not only CRIX but most cryptocurrencies tested spanned traditional and alternative assets.

There were various findings that were made during the study performed from 11 August 2015 to 31 October 2018. The first finding is that the cumulative log returns and volatility of cryptocurrencies exceeded those of South African traditional and alternative assets. The cryptocurrency return variables observed are CRIX, Bitcoin, Ethereum, Monero, Stellar, XRP, Litecoin, Tether, Dash, NEM and Dogecoin. The traditional asset returns variables observed were the JSE All Share index, JSE Top 40 index, JSE Alternative Exchange index and South African government bonds while the alternative asset return variables consisted of JSE SA Listed Property, JSE SA Resources, gold, platinum, Brent Crude oil and South African Rand. The second finding is that the mean and risk of cryptocurrency returns is far greater than that of traditional asset returns. The risk related to cryptocurrencies was not only high but is considered extreme. Moreover, cryptocurrencies are heavily skewed, meaning that their risks increase quickly and decrease gradually. The returns of all the assets were found to be unpredictable. It was also found that most of the relationships were weak negative and positive relationships between cryptocurrencies, South African traditional and alternative assets.

In addition, CRIX, which was the representative asset of cryptocurrencies, was the only asset on the efficient frontier constructed of traditional and alternative assets that lay on the furthest top point of the efficient frontier. No alternative or traditional assets lay on the efficient frontier. The Sharpe ratio of CRIX was greater than all traditional and alternative investments, except for bonds. This revealed that overall CRIX has a better risk-adjusted return than traditional and alternative assets. The efficient frontier of South African investment portfolios including CRIX performed better than those that did not include CRIX. The Sharpe and Sortino ratios illustrated that investment portfolios with CRIX had greater utility, though at greater risk, than those without CRIX. It also showed that investment portfolios with risk targets of both 6 and 12% had better utility than that of an optimised portfolio, although at far greater risk. The mean-variance efficient frontier has less risk than the CVaR efficient frontier at a given return. This is mainly due to more risk being accounted for by the CVaR than the mean-variance analysis. This study's spanning test illustrated that

CRIX, Bitcoin, XRP, Ethereum, Dash, NEM, Stellar and Monero all individually improved the South African traditional and alternative investment portfolios whereas Litecoin, Dogecoin and Tether did not. Therefore, seven out of the ten cryptocurrencies and CRIX improved the South African traditional and alternative portfolios.

Although there is a pool of knowledge on diversification, not much knowledge exists in the literature with regards to cryptocurrencies and their diversification benefits, particularly in relation to the diversification advantages of cryptocurrencies in relation to African investments. This study contributes to the MPT, by enhancing this theory by illustrating that expected returns in relation to risks need to be considered when investing assets in an investment portfolio by assessing the expected returns and risks of cryptocurrencies, alternative and traditional assets. Furthermore, this study contributes towards the MPT's need by an investor in assessing diversification of an investment portfolio using economically diverse assets, while maximising the expected return in relation to the risk of the portfolio by showing that cryptocurrencies improve the risk-adjusted returns of an investment portfolio. The study contributes towards the MPT as it validates the use of low correlation assets, being cryptocurrencies to diversify an investment portfolio. This study firmly expands on the MPT by further validating cryptocurrencies as assets with diversification advantages in a portfolio of investments. This study enhances the data on investment portfolios, cryptocurrencies and diversification of investments. Moreover, this study has financial institution and investment company implications as it reflects the need for the consideration of cryptocurrencies as diversification assets within investment portfolios of financial institutions and investment companies.

Subsequent to the period of assessment of 31 October 2018, there was a 35% decline in the cryptocurrency prices on average in November 2018 (Ouimet, 2018). This large decrease in the price of cryptocurrencies could have altered the results of the investigation performed within this study. As this period was beyond that of the study, only the possible implications and not the actual implications of the price decrease are discussed. The large price decline could have resulted in cryptocurrencies not being a better investment than South African traditional and alternative assets and it may have resulted in the inclusion of cryptocurrencies within an investment portfolio causing financial loss rather than financial gain. Another possible result of the large price decline could have been that the CRIX and individual cryptocurrencies do not result in diversification benefits within the South African investment portfolios. These are a few of the many possibilities that could have arisen from the 35% decline in the cryptocurrency prices in November 2018. Only future research can reveal the outcome of cryptocurrency price decreases on traditional and alternative assets within South African portfolios.

Notes

1. Please refer to studies Brière *et al.* (2015), Hickey (2017), Taylor (2015), Foley *et al.* (2018), Kim (2017), Kim *et al.* (2018) expansive discussion on the disadvantages of cryptocurrencies.

2. In addition, similar studies by Corbet *et al.* (2018), Kurka (2019), Liu (2019), Platanakis and Urquhart (2019), Demiralay and Bayrac (2021), Akyildirim *et al.* (2020), Bouri *et al.* (2020), Kumah and Odei-Mensah (2021) and Karim *et al.* (2021) have also focused on the frequency, time domains and connection between cryptocurrencies and traditional and other financial assets, transmission shocks to volatility; the diversification and risk management of cryptocurrencies within cryptocurrency markets; the diversification benefits of cryptocurrencies in developed economies and emerging economies; stock investment portfolio and diversification capabilities of cryptocurrencies over time within equity portfolios. While this paper is closely related to Demiralay and Bayrac (2021) and Akyildirim *et al.* (2020), this paper extends these studies by providing the first empirical evidence of the effect of diversification benefits of cryptocurrencies on emerging market asset portfolios constructed using traditional and alternative assets.

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