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The Dragon King Phenomenon (Super-Extreme Outliers) in Cryptocurrency. Is Bitcoin the Riskier One?

(Fenomena Raja Naga (Pencilan Super-Ekstrem) dalam Mata Wang Kripto. Adakah Bitcoin Lebih Berisiko?)

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ABSTRACT

This study was conducted to identify the existence of the phenomenon of Dragon Kings (DKs) in five notable cryptocurrencies, namely Bitcoin, Dogecoin, Ethereum, Litecoin and Ripple. DKs are meaningful extreme outliers that occasionally fall outside the Pareto or power-law distribution. These examples have been statistically identified as extreme of extreme returns that occur more frequently than the power law distribution predicts. The study uses the Pareto distribution, usually associated with extreme data, to examine the upper and lower tails of returns. The result shows that the upper and lower tails of the returns of all the cryptocurrencies studied prove the existence of the Dragon Kings mechanism. Contrary to expectations, Bitcoin has seen the most unpreditable of extreme returns compared to other cryptocurrencies. This characteristic causes Bitcoin notably challenging to forecast. The results of this study are crucial for investors to evaluate and understand the Dragon King events, which represent returns that are exceptionally extreme even among other extreme values (super-extreme) observed in these financial assets.

Keywords: Cryptocurrency; Dragon Kings; extreme outliers

ABSTRAK

Kajian ini dijalankan untuk mengenal pasti kewujudan fenomena Raja Naga (DK) dalam lima mata wang kripto yang terkenal, iaitu Bitcoin, Dogecoin, Ethereum, Litecoin dan Ripple. DK adalah pencilan ekstrem yang bermakna yang adakalanya jatuh di luar taburan Pareto atau kuasa. Contoh ini telah dikenal pasti secara statistik sebagai pulangan ekstrem yang berlaku lebih kerap daripada yang diramalkan oleh taburan kuasa. Kajian ini menggunakan taburan Pareto yang biasanya dikaitkan dengan data ekstrem untuk meneliti ekor atas dan bawah pulangan. Keputusan menunjukkan bahawa ekor atas dan bawah pulangan semua mata wang kripto yang dikaji membuktikan kewujudan mekanisme Raja Naga. Bertentangan dengan jangkaan, Bitcoin telah melihat pulangan ekstrem yang paling tidak dapat diramalkan berbanding dengan mata wang kripto yang lain. Ciri ini menyebabkan Bitcoin sangat sukar untuk diramalkan. Keputusan kajian ini adalah kritikal bagi pelabur untuk menilai dan memahami secara ekstrem terhadap pulangan ekstrem yang boleh berlaku dalam aset kewangan ini.

Kata kunci: Mata wang kripto; pencilan ekstrem; Raja Naga

INTRODUCTION

Sornette (2009) first coined the term dragon kings to describe the presence of extreme events that are statistically different from the rest of the extreme data in the distribution. The term ‘dragon’ refers to the concept that the chimeric animal represented by a dragon possesses supernatural, mystical powers superior to those of other animals. It was added by Sornette to describe the unusual properties of matter. The term ‘king’ (Laherrère & Sornette 1998) describes in a concrete sense the fact that kings in some countries are apparently relatively wealthier than the wealthiest people in their country. It was added to describe the extreme outlier value that deviates from the total, such as the wealth of a king with his people. Leaving aside the royal household, the distribution of wealth across the population follows the Pareto distribution according to the power law. However, kings have wealth well above what is predicted by extrapolating the Pareto distribution, so they are considered outliers. This ‘king’ regime may be the result of cumulative historical events, such as certain geopolitical-cultural factors that have elevated the monarch’s special status in the distribution of wealth (with other additional characteristics that have contributed to the royal family’s accumulation of wealth).

The phenomenon of dragon kings is called an extreme outlier value or an event that coexists with the Pareto distribution. In general, the distribution of data for the extreme data can be studied using a Pareto model, and any presence of extreme values in the distribution of such data will affect the prediction of the Pareto model. In statistics, an outlier value means data that deviates from most other data points. When the data obtained have extreme outlier values that exceed the Pareto distribution model, they are called 'dragon kings'. The existence of dragon kings can be observed, for example, in disasters such as earthquakes, flash floods, typhoons, and landslides. The mechanism of dragon kings can also be observed in income distribution. Dragon kings in income include David Koch, Michael Bloomberg, Warren Buffet, Larry Ellison, Bill Gates, Jeff Bezos, and Mark Zuckerberg. DKs can sometimes be more catastrophic than black swans, particularly in the case of negative DKs such as market crashes. However, DKs can also represent positive outliers - such as sudden, extreme gains - that are not necessarily harmful but still deviate significantly from what the power law distribution predicts. In this study, we analyze both positive (upper tail) and negative (lower tail) DKs. According to Sornette (2009), Dragon King events exhibit identifiable patterns and can be predictable within certain temporal and structural conditions. This predictability has been shown to be effective in anticipating events such as material failures and stock market crashes.

To understand the concept of the dragon kings, we must first understand power law distributions. The distribution of power law represents the idea that extreme events are not considered unique events because they are similarly distributed. Events from the 'dragon kings' show the presence of self-organizing processes that go beyond the distribution of power law of their smaller siblings. Stock market crashes (Johansen & Sornette 2001, 1998) and several capitals in the agglomeration size distributions (Pisarenko & Sornette 2012) are examples of empirical Dragon Kings in natural and socioeconomic systems that have been previously documented in the literature. These outliers occur statistically more often than the distribution of power law calibrated to the rest of the population would predict (Sornette 2009).

Recently, the cryptocurrency market has expanded rapidly. Cryptocurrencies are a subset of digital currency classes and are emerging as a major digital currency. They have become a worldwide phenomenon that is often a hot topic in the mass media, government institutions, and the financial system. Among the functions of cryptocurrencies is that without a trusted central authority, users can make payments for goods or services virtually. A substantial body of literature has been published addressing all major cryptocurrencies, especially Bitcoin, in terms of bubble formation (Bouri, Shahzad & Roubaud 2020; Chaim & Laurini 2019; Ismail, Hussain & Noorani 2020), safe-haven capability (Bouri, Shahzad & Roubaud 2020; Das et al. 2020; Dutta et al. 2020; Hatemi-J. et al. 2020), herding (Yousaf et al. 2021), interconnectedness (Ji et al. 2019, Hussain et al. 2020), and market efficiency (Noda 2021; López-Martín, Benito Muela & Arguedas 2021).

Longin (2005) and Dyhrberg (2016) state that assets that exhibit extreme price fluctuations and violate normality assumptions pose challenges to risk management and asset returns. Cryptocurrencies, especially Bitcoin, usually show extreme and erratic time series behavior in the financial market (James, Menzies & Chan 2021). According to Smith & Kumar (2017), Bitcoin is the most traded cryptocurrency and has a high volatility value. When the supply of Bitcoin approaches its fixed limit, it means that extreme price fluctuations can be caused by high demand. Bakar, Rosbi and Uzaki (2017) examined the volatility of Bitcoin using statistical measures such as standard deviation and Value-at-Risk (VaR) and came to the conclusion that Bitcoin poses a high-risk investment due to its extreme price behavior. The volatility and extreme price fluctuations became apparent during the sharp market expansion in 2017, when the price of Bitcoin surged from USD 1,000 to USD 20,000 before plunging to approximately USD 6,000 within a few months (Manahov 2021).

Thazhungal (2022) state that the distribution of returns of cryptocurrencies is abnormal and has a leptokurtic structure, indicating a high-risk value, especially when the market is in a phase of decline. Moreover, the cryptocurrency market shows signs of overreaction. Institutional investors and corporations have paid close attention to large cryptocurrencies such as Dogecoin, Ethereum, Litecoin, and Ripple. Moreover, they are relevant candidates for the study of outliers and time-varying jumps, as their return volatility tends to be higher than that of Bitcoin (Dutta & Bouri 2022). Omari and Ngunyi (2021) studied the behavior of the upper and lower tails of the return distributions of the four most popular cryptocurrencies using high-frequency data. The results showed that Ripple cryptocurrencies are the riskiest cryptocurrencies, with extreme potential gains or losses, while Bitcoin cryptocurrency is the least risky cryptocurrency. Begušić et al. (2018) reported that extreme prices of cryptocurrencies are more frequent and have a stronger tail behaviour compared to stock returns. Barkai et al. (2024) introduced a co-movement aware tail risk measure for crypto assets, outperforming traditional VaR/ES in forecasting extreme losses. In summary, most literature showed that returns on cryptocurrencies are susceptible to speculative bubbles. The behavior described leads to large gains, but can also lead to surprise declines and extreme losses, increasing the likelihood of a market collapse. This suggests that investing in the cryptocurrency market carries a high level of risk, as cryptocurrencies are highly volatile. This leads to an imbalance in the trading price with the price and return of cryptocurrencies, as well as volatility at the end of the distribution.

The novelty of this paper is to identify the presence of the phenomenon of dragon kings in the upper and

lower tails of the returns of the main cryptocurrencies. Although various extreme studies have been conducted on cryptocurrencies, there is still room, especially in relation to very extreme data, namely dragon kings. Liu, Dashti Moghaddam and Serota (2024) identified dragon king volatility events in S&P500 history by statistically testing for deviations from power-law tails. The concept of dragon kings can also explain the cryptocurrency bubble, which can be used to identify highs and lows in cryptocurrencies. This study can serve as a foundation and guide for future researchers conducting deeper studies to understand cryptocurrencies. Based on the asymptotic properties of the empirical cumulative distribution function (ECDF), the confidence interval (CI) technique of Janczura and Weron (2012) is used to identify dragon kings. In contrast to previous studies, our findings indicate that Bitcoin exhibits a higher level of risk compared to other cryptocurrencies. This is mainly due to the inability to accurately predict Bitcoin's extreme returns using the Pareto model, which is commonly employed for extreme data. Conventional statistical approaches, particularly the recognised discipline of Extreme Value Theory have proven their effectiveness in illustrating the predictability of changes in cryptocurrency prices under certain thresholds of increased volatility. The previously recognized concepts have proven to be extremely beneficial in assessing risk and formulating investment strategies in the bitcoin market space.

However, our research differs from traditional approaches in that we explore the domain of highly volatile returns, which have inherent unpredictability. Unlike previous academic research, our investigation shows a distinctive and intellectually stimulating discovery: Bitcoin exhibits the highest degree of unpredictability in its extreme returns compared to other cryptocurrencies. This revelation presents a novel and thought-provoking viewpoint that challenges the widely held belief that Bitcoin is a comparatively safe and reliable investment in cryptocurrencies.

Our empirical analysis suggests that forecasting Bitcoin's extreme returns is a complex undertaking, adding an additional layer of perceived risk beyond what conventional assessments indicate. This study thus expands the boundaries of cryptocurrency research by shedding light on the intricate dynamics of extreme returns, ultimately contributing to a deeper understanding of cryptocurrency behavior. The results can contribute to a deeper understanding of the risks associated with the aspect of cryptocurrencies as an investment platform. Overall, this research can provide a more comprehensive picture of the existence of bubble phenomena and extreme values in cryptocurrencies, which will benefit investors and other stakeholders when dealing with cryptocurrencies.

The remainder of this paper is organised as follows. Next section is about the method employed. Subsequent section shows the empirical results and delivers some discussions. The conclusion is drawn in the last section.

METHODS

DATA

Data on the daily price of the five major cryptocurrencies Bitcoin, Dogecoin, Ethereum, Litecoin, and Ripple were used for this study. The daily return was used in this study because it provides more information than the weekly and monthly data models. Daily closing price data for all cryptocurrencies studied from January 1, 2017 to June 30, 2021 was obtained from Investing.com. These digital assets - Bitcoin, Dogecoin, Ethereum, Litecoin, and Ripple - stood out for their exceptional market capitalization during the study's observation period, which spans from January 1, 2017, to June 30, 2021. More specifically, these cryptocurrencies consistently ranked among the highest market capitalizations throughout the duration of the study.

PARETO QUANTILE PLOT

The Pareto model for the upper and lower tails of the distribution can be evaluated using the Pareto quantile plot to see if it is appropriate (Hussain, Nur-Firyal & Ruza 2022). When the data set follows a Pareto distribution, the points in the plot form a fairly straight line. Also, one of the advantages of the Pareto quantile plot is that it clearly identifies the outliers in the upper and lower tail ranges that deviate from the Pareto model. Thus, the Pareto-Quantile chart can be used to identify the outliers in the upper and lower tails of the distribution.

DRAGON KINGS MECHANISMS

Janczura and Weron (2012) proposed a 95% confidence interval calculation based on the asymptotic property of the empirical cumulative distribution function as a method to investigate the existence of dragon kings. The existence of dragon kings in cryptocurrencies can be determined by constructing the shape of the Pareto distribution using the statistical estimation method of the integral probability transformation (PITSE) and the confidence interval of the empirical cumulative distribution function (ECDF) on a graph using the obtained data. Then, the data that fall outside the two shapes of these distributions are identified as dragon kings. The proposed CI for the upper and lower tail with probability 1-θ:

$$P\left(1 - F_\alpha(X) + \sqrt{\frac{F_\alpha(x)[1-F_\alpha(x)]}{n}} z_{\frac{\theta}{2}} < 1 - F_\alpha(x) + \sqrt{\frac{F_\alpha(x)[1-F_\alpha(x)]}{n}} z_{1-\frac{\theta}{2}}\right) \approx 1 - \theta \quad (1)$$

When the upper tail data are fitted by the Pareto model, as indicated in Equation (1), the upper and lower tails of the cryptocurrency return distribution should lie in the following interval:

$$\left(\left(\frac{x_0}{x}\right)^{\alpha}+\sqrt{\frac{\left[1-\left(\frac{x_0}{x}\right)^{\alpha}\right]\left[\left(\frac{x_0}{x}\right)^{\alpha}\right]}{n}}z_{\frac{\theta}{2}}\ \left(\frac{x_0}{x}\right)^{\alpha}+\sqrt{\frac{\left[1-\left(\frac{x_0}{x}\right)^{\alpha}\right]\left[\left(\frac{x_0}{x}\right)^{\alpha}\right]}{n}}z_{1-\frac{\theta}{2}}\right) \quad (2)$$

GENERALIZED BOXPLOT

The generalized boxplot developed by Bruffaerts, Verardi and Vermandele (2014) is used to examine the upper and lower ends of cryptocurrency returns. In addition, the generalized boxplot has also been used to identify the existence of extreme outliers in the data distribution of the major cryptocurrencies Bitcoin, Dogecoin, Ethereum, Litecoin, and Ripple.

$$B\pm=\left(\varphi\left(Q_2^*+\frac{IQR^*}{1.3426}L\pm\right)[min(r_i)+max(r_i)]+min(x_i^*)+0.1\right)IQR+Q_2 \quad (3)$$

RESULTS AND DISCUSSION

DESCRIPTIVE STATISTICS

Table 1 provides descriptive statistics of the daily returns of Bitcoin, Dogecoin, Ethereum, Litecoin, and Ripple and provides information about their volatility characteristics. Volatility is an important metric for evaluating the potential price fluctuations and associated risk of an asset. Bitcoin's lower tail has a mean of -8.0541, a standard deviation of 3.0374, and a variance of 9.2260, indicating that when Bitcoin's returns are negative, they tend to be volatile and can deviate significantly from the mean. The upper tail of Bitcoin returns, on the other hand, has a mean of 8.0777, a standard deviation of 4.3229, and a variance of 18.6878, suggesting that positive Bitcoin returns are associated with increased volatility. The greater dispersion of values around the mean in both tails indicates the possibility of extreme price movements and significant fluctuations in the value of Bitcoin. All return values reported in this study are based on daily gross returns and are not annualized or expressed as a percentage.

Lower tail returns for Dogecoin have a mean of -19.0467, indicating that negative returns for Dogecoin can be highly volatile and deviate significantly from the mean. The standard deviation and variance of the lower-tail returns are 35.8621 and 1286.0913, respectively, indicating the extreme volatility of Dogecoin's downside. Upper-tail returns have a mean of 14.9641, indicating that positive returns for Dogecoin are also associated with greater volatility. The upper-tail returns have a standard deviation and variance of 33.8082 and 1142.9970, respectively. The greater value dispersion at both tails illustrates the potential for extreme outcomes. The lower tail returns for Ethereum have a mean of -9.4207, indicating that negative returns for Ethereum are volatile and can deviate significantly from the mean. The standard deviation and variance of the lower tail returns are 3.5936 and 12.9142, respectively, highlighting the volatility of Ethereum's downside. The upper tail of Ethereum returns has a mean of 10.2693, indicating that positive returns for Ethereum may be associated with increased volatility. The top tail returns have a standard deviation of 6.1327 and a variance of 37.6101, indicating the potential for significant price swings in Ethereum's upside.

The lower- tail returns for Litecoin are characterized by a mean of -11.0060, a standard deviation of 14.6490, and a variance of 214.5939. These statistics show that Litecoin's negative returns can be highly volatile and show significant deviations from the mean. Upper-tail returns, on the other hand, have a mean of 10.8114, indicating that positive returns for Litecoin are associated with increased volatility. Upper-tail returns have a standard deviation and variance of 6.8458 and 46.8647, respectively. The greater dispersion of values at both extremes indicates the potential for volatility in the Litecoin price.

The returns for Ripple in the lower range have a mean of -11.6184, a standard deviation of 7.0667, and a variance of 49.9385. According to these statistics, negative returns for Ripple are relatively volatile and can deviate significantly from the mean. With a mean of 11.2299, the upper tail of Ripple returns has a slightly higher standard deviation of 7.1161 and variance of 50.6383. This indicates that Ripple's positive returns are accompanied by significant volatility. The greater dispersion of values at both ends indicates the possibility of significant price fluctuations in Ripple.

In summary, the descriptive statistics of daily returns for the leading cryptocurrencies provide important insights into their volatility characteristics. The returns of Bitcoin, Dogecoin, Ethereum, Litecoin, and Ripple are all extremely volatile. Both the low and high ends of Bitcoin returns exhibit a significant amount of dispersion from the mean. Ethereum exhibits comparable volatility patterns, with significant divergence in both negative and positive returns. In addition, Ripple exhibits significant volatility in both tails, indicating the possibility of extreme price fluctuations. Similar to other cryptocurrencies, Litecoin's returns also exhibit significant volatility, especially in the tails. Dogecoin is the most volatile cryptocurrency, with both tails showing significant dispersion from the mean.

These results highlight the inherent risk and price volatility of cryptocurrency investing. As evidenced by the wide dispersion of returns and the significant standard deviations and variances at the low and high ends, investors should be aware of the potential for extreme price volatility. Understanding and effectively managing the volatility of cryptocurrencies is essential to making informed investment decisions and effectively managing risk.

PARETO QUANTILE PLOT

Figures 1-5 show the Pareto-quantile diagram created based on the obtained data. The Pareto-quantile chart was created to determine if the Pareto model fits the data well and to identify extreme outliers. The observations in the figure should practically form a straight line if the data set follows the Pareto distribution, while the extreme outliers in the Pareto-quantile plot deviate from the Pareto model. From these figures, it can be seen that the distribution of returns for all cryptocurrencies (Bitcoin, Dogecoin, Ethereum, Litecoin, and Ripple) almost forms a straight line at the top and bottom ends, which means that the data follows the Pareto distribution. However, the figures also show that there are several data points that deviate from the lines formed, indicating the presence of outliers in the distribution of the upper and lower tail data of returns for all cryptocurrencies. This indicates that all major cryptocurrencies studied have the possibility of dragon kings, which will be analyzed in the next section.

DRAGON KINGS MECHANISMS

Figures 6-10 show the 95% confidence interval for the empirical cumulative distribution function for the top and bottom tails of five cryptocurrencies to test for the presence of dragon kings. The presence of dragon kings in cryptocurrencies can be determined by constructing the Pareto distribution shape with the statistical estimation method of integral probability transformation (PITSE) and the confidence interval of empirical cumulative distribution function (ECDF) on a graph using the obtained data. If the data fall outside the line of the confidence interval, the data are identified as dragon kings. From these figures, it can be seen that for all five cryptocurrencies, only a few data points fall outside the 95% confidence interval. So this proves that the dragon kings phenomenon occurs in all major cryptocurrencies.

GENERALIZED BOXPLOT

Figures 11-15 show the generalized boxplot for the upper and lower tails of the returns of major cryptocurrencies namely Bitcoin, Dogecoin, Ethereum, Litecoin, and Ripple. Generalized boxplot is used to study the upper and lower tails of cryptocurrency returns as well as to identify the existence of extreme outliers in the return data distribution. Based on these figures, all cryptocurrencies contain extreme outliers. Next, the estimated number and percentage of extreme outliers in the upper and lower tails of all five cryptocurrencies returns will be disclosed in Table 2.

Table 2 summarizes the number of extreme outliers and the percentage of extreme outliers in the returns of the top and bottom tails of the five major cryptocurrencies, Bitcoin, Dogecoin, Ethereum, Litecoin, and Ripple. From the table, we can see that the lower tail of Bitcoin returns has 12 extreme outliers with a percentage of 7.36%. The top tail of the Bitcoin return has 4 extreme outliers resulting in a percentage of 2.45%. The lower tail of the Bitcoin return has a higher percentage of extreme outliers than the upper tail of the Bitcoin return. The bottom tail of the Ethereum return has 7 extreme outliers, yielding a percentage of 5.60%. The lower tail of the Dogecoin return has 5 extreme outliers with a percentage of 3.36%, while the upper tail of the Dogecoin return has 7 extreme outliers with a percentage of 4.70%. In terms of the Dogecoin return, the upper tail of the return has a higher percentage of extreme outliers than the lower tail of the return.

In addition, the top tail of the Ethereum return, on the other hand, has 2 extreme outliers, which is a percentage of 1.60%. Thus, the lower tail of Ethereum cryptocurrency return has more extreme outliers than the upper tail of Ethereum return because the lower tail of Ethereum has a higher percentage of extreme outliers. The lower tail of Litecoin returns has 7 extreme outliers with a percentage of

TABLE 1. Descriptive statistics of daily returns for cryptocurrency tail distributions

	Mean	Standard Deviation	Variance	Maximum	Minimum
Lower tail of Bitcoin	-8.0541	3.0374	9.2260	-4.8799	-23.7220
Upper tail of Bitcoin	8.0777	4.3229	18.6878	48.0904	4.7261
Lower tail of Dogecoin	-19.0467	35.8621	1286.0913	-6.8511	-414.1786
Upper tail of Dogecoin	14.9641	33.8082	1142.9970	415.5892	6.2474
Lower tail of Ethereum	-9.4207	3.5936	12.9142	-6.0403	-23.4784
Upper tail of Ethereum	10.2693	6.1327	37.6101	59.2454	5.7084
Lower tail of Litecoin	-11.0060	14.6490	214.5939	-5.7601	-158.3256
Upper tail of Litecoin	10.8114	6.8458	46.8647	48.7803	6.2234
Lower tail of Ripple	-11.6184	7.0667	49.9385	-5.8481	-45.1438
Upper tail of Ripple	11.2299	7.1161	50.6383	54.2163	6.4861

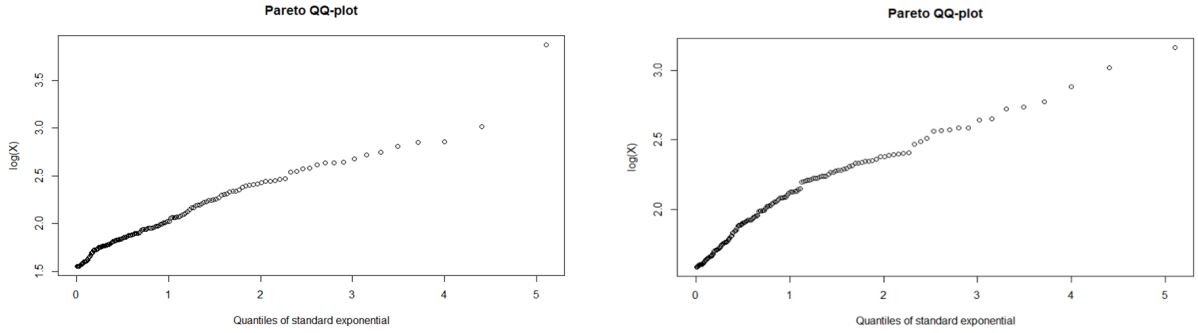

FIGURE 1. Pareto quantile plot for lower and upper tail of Bitcoin return

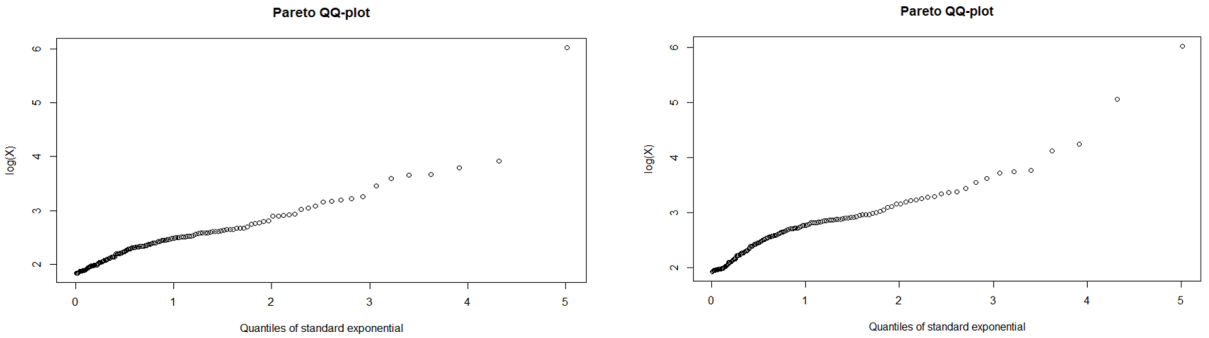

FIGURE 2. Pareto quantile plot for lower and upper tail of Dogecoin return

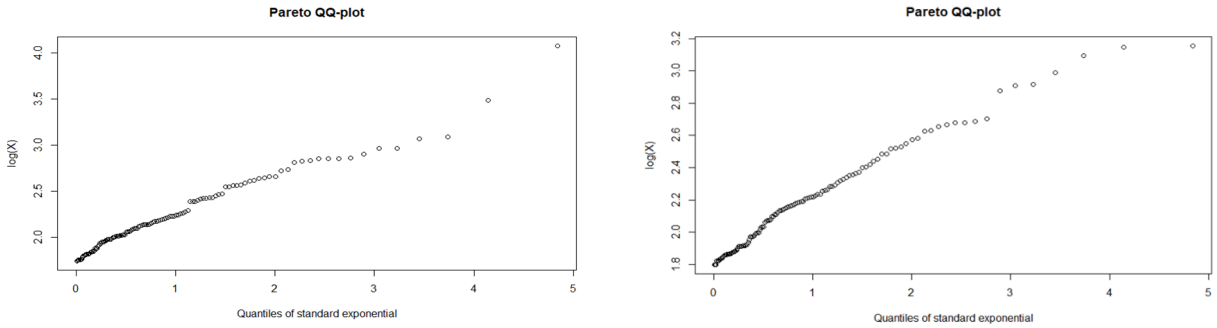

FIGURE 3. Pareto quantile plot for lower and upper tail of Ethereum return

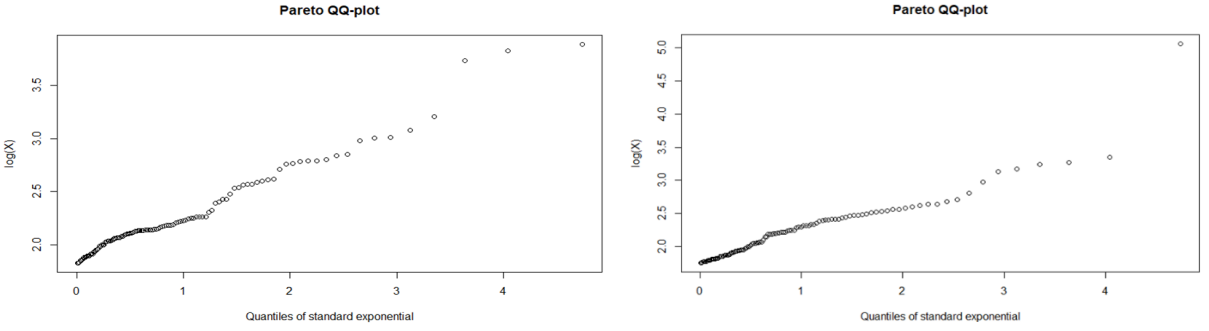

FIGURE 4. Pareto quantile plot for lower and upper tail of Litecoin return

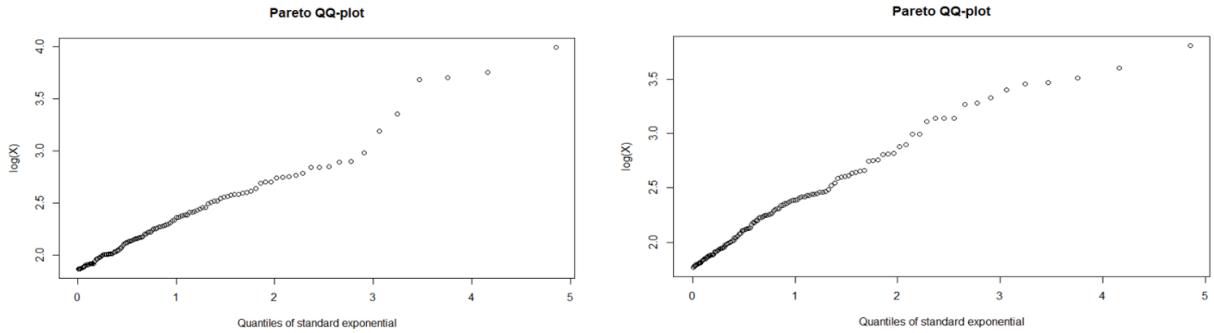

FIGURE 5. Pareto quantile plot for lower and upper tail of Ripple return

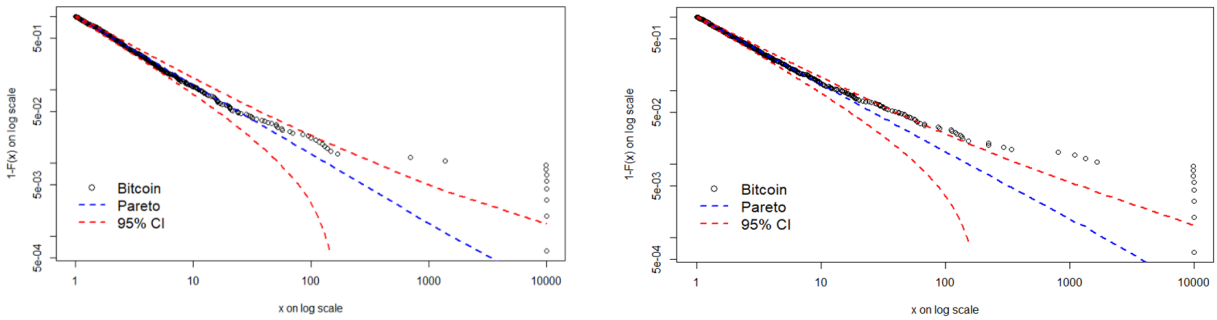

FIGURE 6. The fitted Pareto tails with 95% confidence interval for lower and upper tail of Bitcoin return

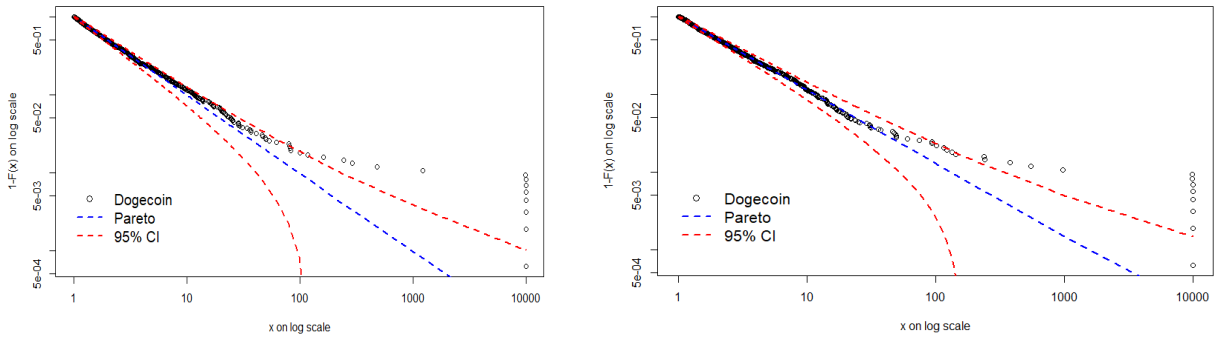

FIGURE 7. The fitted Pareto tails with 95% onfidence interval for lower and upper tail of Dogecoin return

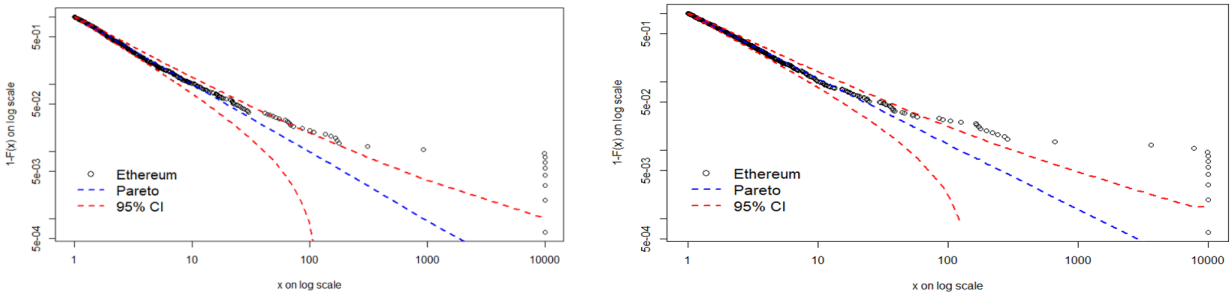

FIGURE 8. The fitted Pareto tails with 95% confidence interval for lower and upper tail of Ethereum return

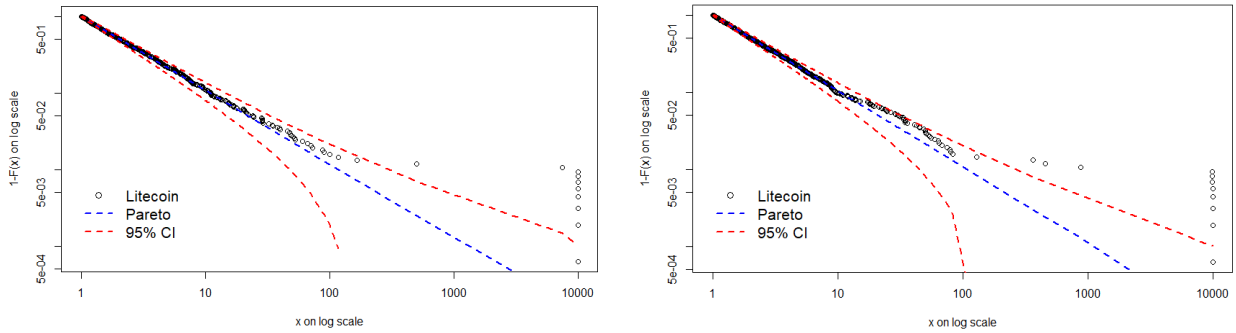

FIGURE 9. The fitted Pareto tails with 95% confidence interval for lower and upper tail of Litecoin return

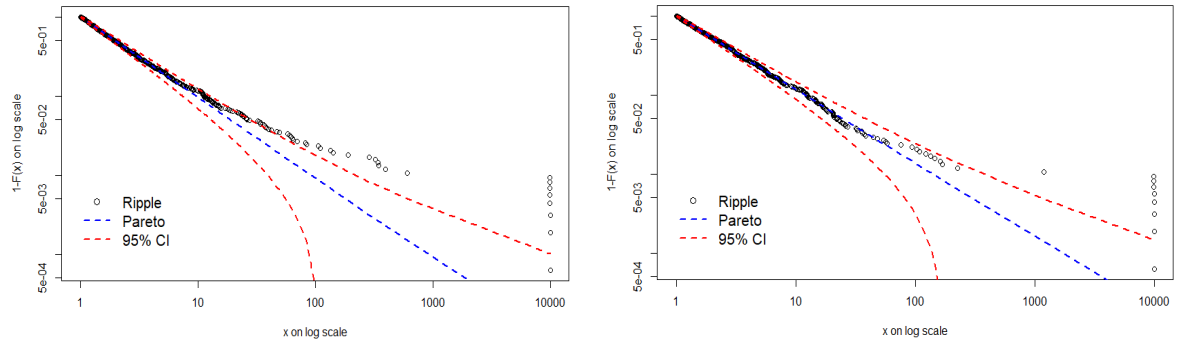

FIGURE 10. The fitted Pareto tails with 95% confidence interval for lower and upper tail of Ripple return

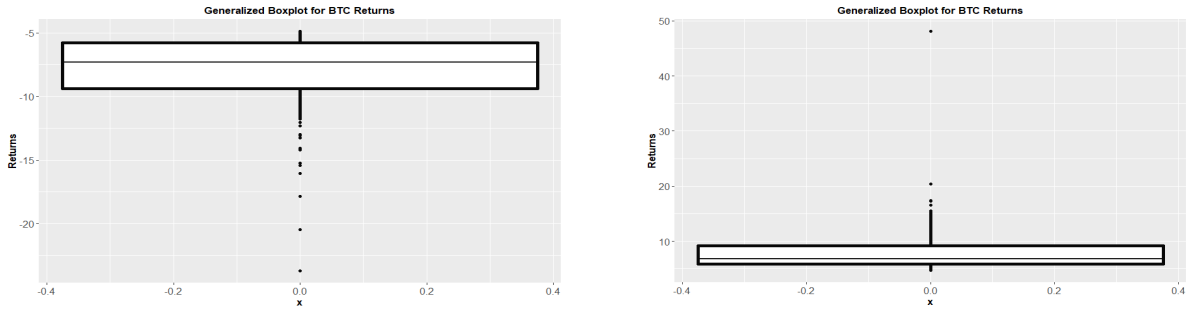

FIGURE 11. Generalized boxplot for lower and upper tail for Bitcoin return

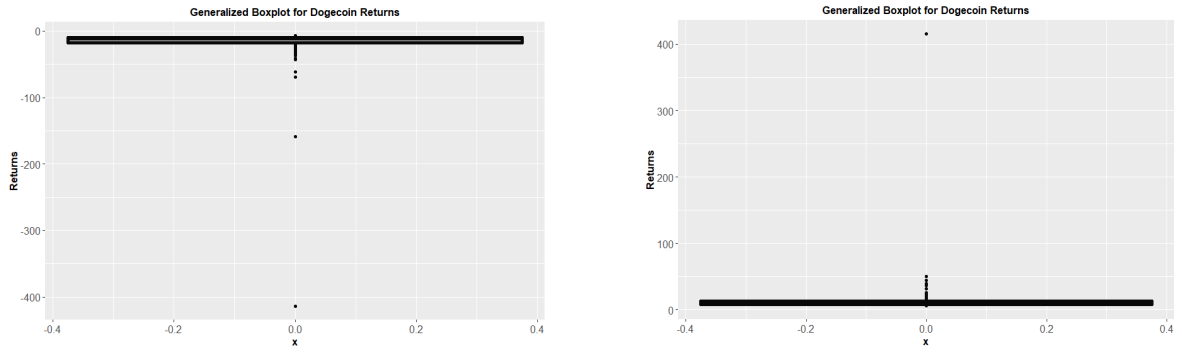

FIGURE 12. Generalized boxplot for lower and upper tail for Dogecoin return

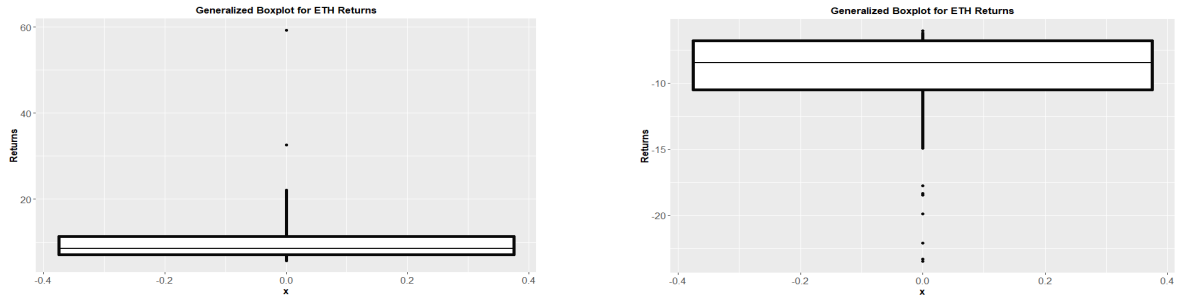

FIGURE 13. Generalized boxplot for lower and upper tail for Ethereum return

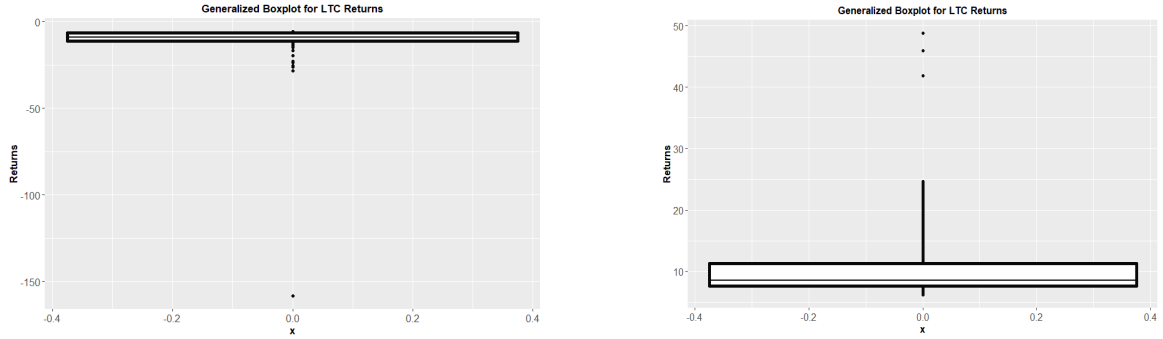

FIGURE 14. Generalized boxplot for lower and upper tail for Litecoin return

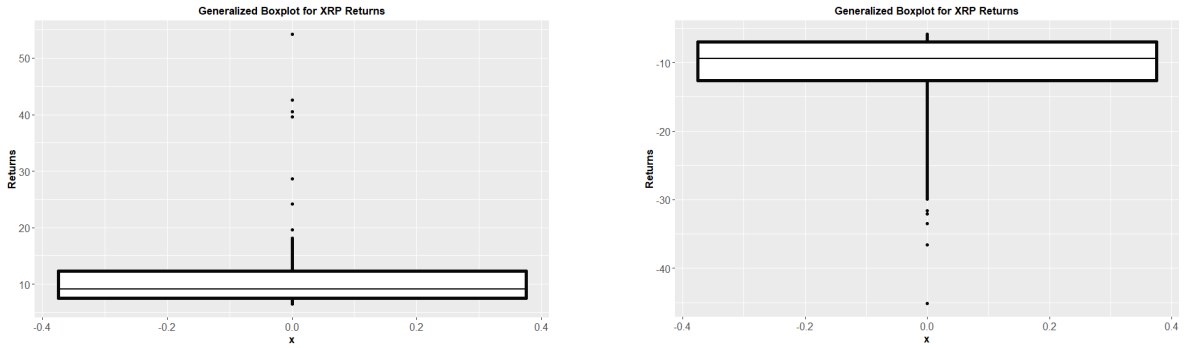

FIGURE 15. Generalized boxplot for lower and upper tail for Ripple return

6.19%. The upper tail of the Litecoin return has 3 extreme outliers with a percentage of 2.65%. The lower tail of the Litecoin return has a higher percentage of extreme outliers than the upper tail of the Litecoin return. Finally, the upper tail of the Ripple return has a higher percentage of extreme outliers than the lower tail of the Ripple return. This is because the lower tail of the Ripple returns has 4 extreme outliers with a percentage of 3.15%, while the upper tails of the Ripple returns have 7 extreme outliers with a percentage of 5.51%.

The table also shows that the lower tail of Bitcoin returns has the highest number of extreme outliers, while the upper tail of Ripple returns has the highest number of extreme outliers. The lower-tails returns of most major cryptocurrencies had a higher number of extreme outliers, as well as a higher percentage of extreme outliers, than the upper-tails returns of major cryptocurrencies. This fact implies that the task of anticipating negative risk is significantly more complex than to forecasting positive risk. In further explication, Bitcoin exhibits notable complexities in forecasting its potential for negative outcomes, whereas Ripple poses challenges in anticipating its potential for positive outcomes.

In summary, Bitcoin has the most extreme outliers and Ethereum has the fewest extreme outliers. Our results differ from those of previous research in that we found that

TABLE 2. Summary of extreme outliers in the lower and upper tail data of cryptocurrencies return

Cryptocurrencies	$N_{tails}(x \geq \widetilde{x_0})$	Number of extreme outliers	Percentage of extreme outlier (%)
Lower tail of Bitcoin	163	12	7.36
Upper tail of Bitcoin	163	4	2.45
Lower tail of Dogecoin	149	5	3.36
Upper tail of Dogecoin	149	7	4.70
Lower tail of Ethereum	125	7	5.60
Upper tail of Ethereum	125	2	1.60
Lower tail of Litecoin	113	7	6.19
Upper tail of Litecoin	113	3	2.65
Lower tail of Ripple	127	4	3.15
Upper tail of Ripple	127	7	5.51

Bitcoin poses more risk than other cryptocurrencies due to its extreme returns that cannot be adequately captured by the Pareto distribution. While statistical tools such as the Extreme Value Theory coupled with the Pareto distribution have traditionally been effective in predicting extreme events, our study has unveiled an interestingy scenario. In this instance, the extremeness of the data transcends the confines of conventional statistical analysis. This revelation distinguishes our findings from prior research, which had implied that Bitcoin was relatively safer compared to other cryptocurrencies.

Our research marks a departure from the conventional approach as we venture into extreme returns; characterized by inherent unpredictability. In stark contrast to earlier studies, our investigation has unearthed a distinctive and thought-provoking observation: Bitcoin exhibits the highest degree of unpredictability in its extreme returns when contrasted with other cryptocurrencies. This discovery introduces a fresh and compelling perspective, challenging the prevailing notion that Bitcoin represents a relatively secure and stable investment within the cryptocurrency domain. Our empirical analysis underscores the intricacies involved in forecasting Bitcoin's extreme returns, thereby introducing an additional layer of perceived risk beyond the scope of conventional assessments. Consequently, this study extends the frontiers of cryptocurrency research by illuminating the complex dynamics underlying extreme returns, ultimately contributing to a more profound comprehension of cryptocurrency behavior.

This finding is relevant to investors, portfolio managers, and risk managers who seek to predict price movements, diversify portfolios, mitigate risk, and engage in cross-speculation. By shedding light on the tail behavior of Bitcoin and other cryptocurrencies, this study improves our understanding of their extreme outliers and contributes to a more thorough analysis of their behavior.

CONCLUSIONS

Dragon kings are an extreme outlier that exceeds the expected threshold of heavy-tailed distributions such as Pareto's law, and they can also be classified as extreme values or extreme events in other populations with other events. This insight paves the way for a methodological theory of catastrophe prediction, especially in financial investments. The term 'Dragon Kings' is used to refer to a group of severe events, but research on cryptocurrencies is currently sparse. We emphasize the importance of understanding dragon kings as events that often occur near a phase transition, tipping point, catastrophe or bifurcation. The fact that rare, massive events often dominate financial investments and lead to huge losses is one of the most amazing phenomena in science and social science. To quantify this statement, in most cases heavy-tailed distributions of event sizes are assumed. The phenomenon of dragon kings has not yet been studied in the context of cryptocurrencies, and knowledge and awareness of cryptocurrencies is also limited in society and among economists.

This study has highlighted two important objectives for understanding the returns of cryptocurrencies in general, namely the existence of dragon kings in the upper and lower tails of the five major cryptocurrencies: Bitcoin, Dogecoin, Ethereum, Litecoin, and Ripple. Based on the analysis and the results of the study, the existence of the phenomenon of dragon kings can be proven in all the cryptocurrencies mentioned. In addition, this study has led to a deeper understanding of the upper and lower tails of the returns of cryptocurrencies. Furthermore, this study has also shown that all cryptocurrencies studied have an extreme outlier in the distribution of cryptocurrency return data.

This study further explores the complexity of Bitcoin's risk behavior and offers new insights into this

important topic. To date, Bitcoin has been viewed as a cryptocurrency with a lower risk compared to other similar cryptocurrencies. However, our research contradicts this commonly accepted view. Extreme data can be accurately represented by applying EVT. The Pareto distribution is often used to characterize the behavior of extreme data in this framework. However, our study shows occasions when certain exceptional points of information exist beyond the bounds of this distribution, an anomaly known as dragon kings. The dragon kings symbolize phenomena that challenge conventional forecasting frameworks.

In particular, our research highlights scenarios in which the extreme returns of Bitcoin cannot be correctly described, even when using the Pareto distribution. This highlights the existence of a significant portion of Bitcoin's extraordinary gains that are not accounted for by models specifically designed to measure less risky situations. Furthermore, our analysis shows that Litecoin has the potential to generate even greater gains than originally expected under extreme circumstances. This discovery highlights the intricate and complex risk patterns within the cryptocurrency market and contradicts the assumption that Bitcoin is always lower risk compared to other cryptocurrencies.

The results of this study can serve as a guide or insight for investors, economists, and the public to better understand the price movements and volatility of cryptocurrencies before deciding to invest. In addition, the government could use the results of this study to enact regulations on cryptocurrencies in the country. Finally, the results of this study provide the basis for future researchers to understand the price characteristics of the five major cryptocurrencies and determine the tail risk and extreme return behavior of cryptocurrencies more accurately than just the volatility rate.

Overall, this study has provided important insights and a better understanding of the price characteristics of the five major cryptocurrencies as well as the extreme outliers of the five major cryptocurrencies. In addition, this study can also serve as a guide to determine the relationship between the existence of dragon kings and extreme outliers in the top five cryptocurrencies. Future studies can conduct further research to identify factors that play a role in the existence of dragon kings and extreme outliers among the top five cryptocurrencies. In contrast to previous research, we concluded that Bitcoin is riskier than other cryptocurrencies because Bitcoin's extreme returns cannot be represented by the Pareto distribution. This information is important for investors, portfolio managers, and risk managers to forecast price movements, portfolio diversification, hedging and cross-speculation.

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REFERENCES

Bakar, N.A., Rosbi, S. & Uzaki, K. 2017. Cryptocurrency framework diagnostics from Islamic finance perspective: a new insight of Bitcoin system transaction. *International Journal of Management Science and Business Administration* 4(1): 19-28.

Barkai, I., Hadad, E., Shushi, T. & Yosef, R. 2024. Capturing tail risks in cryptomarkets: A new systemic risk approach. *Journal of Risk and Financial Management* 17(9): 397.

Begušić, S., Kostanjčar, Z., Stanley, H.E. & Podobnik, B. 2018. Scaling properties of extreme price fluctuations in Bitcoin markets. *Physica A: Statistical Mechanics and its Applications* 510: 400-406.

Bouri, E., Shahzad, S.J.H. & Roubaud, D. 2020. Cryptocurrencies as hedges and safe-havens for US equity sectors. *The Quarterly Review of Economics and Finance* 75: 294-307.

Bruffaerts, C., Verardi, V. & Vermandele, C. 2014. A generalized boxplot for skewed and heavy-tailed distributions. *Statistics and Probability Letter* 95: 110-117.

Chaim, P. & Laurini, M.P. 2019. Is Bitcoin a bubble? *Physica A: Statistical Mechanics and its Applications* 517: 222-232.

Das, D., Le Roux, C.L., Jana, R.K. & Dutta, A. 2020. Does Bitcoin hedge crude oil implied volatility and structural shocks? A comparison with gold, commodity and the US Dollar. *Finance Research Letters* 36: 101335.

Dutta, A. & Bouri, E. 2022. Outliers and time-varying jumps in the cryptocurrency markets. *Journal of Risk and Financial Management* 15(3): 128.

Dutta, A., Das, D., Jana, R.K. & Vo, X.V. 2020. COVID-19 and oil market crash: Revisiting the safe haven property of gold and Bitcoin. *Resources Policy* 69: 101816.

Dyhrberg, A.H. 2016. Bitcoin, gold and the dollar–A GARCH volatility analysis. *Finance Research Letters* 16: 85-92.

Hatemi-J., A., Hajji, M.A., Bouri, E. & Gupta, R. 2022. The benefits of diversification between bitcoin, bonds, equities and the US dollar: A matter of portfolio construction. *Asia-Pacific Journal of Operational Research* 39(04): 2040024.

Hussain, S.I., Nur-Firyal, R. & Ruza, N. 2022. Linkage transitions between oil and the stock markets of countries with the highest COVID-19 cases. *Journal of Commodity Markets* 28: 100236.

Hussain, S.I., Ruza, N., Masseran, N. & Safari, M.A.M. 2020. Dependence structure between index stock market and bitcoin using time-varying copula and extreme value theory. *AIP Conference Proceedings* 2266(1): 030002.

Ismail, M.S., Hussain, S.I. & Noorani, M.S.M. 2020. Detecting early warning signals of major financial crashes in bitcoin using persistent homology. *IEEE Access* 8: 202042-202057.

James, N., Menzies, M. & Chan, J. 2021. Changes to the extreme and erratic behaviour of cryptocurrencies during COVID-19. *Physica A: Statistical Mechanics and its Applications* 565: 125581.

Janczura, J. & Weron, R. 2012. Black swans or dragon-kings? A simple test for deviations from the power law. *The European Physical Journal Special Topics* 205(1): 79-93.

Ji, Q., Bouri, E., Lau, C.K.M. & Roubaud, D. 2019. Dynamic connectedness and integration in cryptocurrency markets. *International Review of Financial Analysis* 63: 257-272.

Johansen, A. & Sornette, D. 2001. Large stock market price drawdowns are outliers. *Journal of Risk* 4(2): 69-110.

Johansen, A. & Sornette, D. 1998. Stock market crashes are outliers. *The European Physical Journal B-Condensed Matter and Complex Systems* 1: 141-143.

Laherrère, J. & Sornette, D. 1998. Stretched exponential distributions in nature and economy: "fat tails" with characteristic scales. *Eur. Phys. J. B* 2: 525-539.

Liu, J., Dashti Moghaddam, M. & Serota, R.A. 2024. Are there Dragon Kings in the stock market? *Foundations* 4(1): 91-113.

Longin, F. 2005. The choice of the distribution of asset returns: How extreme value theory can help? *Journal of Banking & Finance* 29(4): 1017-1035.

López-Martín, C., Benito Muela, S. & Arguedas, R. 2021. Efficiency in cryptocurrency markets: New evidence. *Eurasian Economic Review* 11(3): 403-431.

Manahov, V. 2021. Cryptocurrency liquidity during extreme price movements: is there a problem with virtual money? *Quantitative Finance* 21(2): 341-360.

Noda, A. 2021. On the evolution of cryptocurrency market efficiency. *Applied Economics Letters* 28(6): 433-439.

Omari, C. & Ngunyi, A. 2021. The predictive performance of extreme value analysis based-models in forecasting the volatility of cryptocurrencies. *Journal of Financial Risk and Forecasting* 12(4): 245-260.

Pisarenko, V.F. & Sornette, D. 2012. Robust statistical tests of Dragon-Kings beyond power law distributions. *The European Physical Journal Special Topics* 205(1): 95-115.

Smith, C. & Kumar, A. 2017. *Crypto-Currencies–An Introduction to Not-So-Funny Moneys (No. AN2017/07).* Reserve Bank of New Zealand.

Sornette, D. 2009. Dragon-kings, black swans and the prediction of crises. *International Journal of Terraspace Science and Engineering* 2(1): 1-18.

Thazhungal Govindan Nair, S. 2022. On extreme value theory in the presence of technical trend: pre and post Covid-19 analysis of cryptocurrency markets. *Journal of Financial Economic Policy* 14(4): 533-561.

Yousaf, I., Ali, S., Bouri, E. & Dutta, A. 2021. Herding on fundamental/nonfundamental information during the COVID-19 outbreak and cyber-attacks: Evidence from the cryptocurrency market. *SAGE Open* 11(3): 21582440211029911.

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