sciendo

Cryptocurrency Trading Pairs and Benford's Law: Investigating Market Irregularities

Petre-Cornel GRIGORESCU*
Bucharest University of Economics Studies, Bucharest, Romania
**Corresponding author, grigorescupetre19@stud.ase.ro*

Antoaneta AMZA
Bucharest University of Economics Studies, Bucharest, Romania
amzaantoaneta10@stud.ase.ro

Abstract. *In the context of MiCAR implementation, we propose a simple and effective approach that national competent authorities can use in their supervisory role to detect potential market manipulation. Our method is based on Benford's Law as a quantitative tool to assess the conformity of crypto-asset transactions with expected numerical distributions, helping supervisors identify anomalies that may indicate market manipulation. From a practical perspective, we have evaluated the conformity of various cryptocurrency trading pairs with Benford's Law by applying two well-established metrics: Mean Absolute Deviation and Sum of Squared Deviations. These metrics were used to assess how closely each pair's transaction distribution aligns with the theoretical expectations of Benford's Law, using literature-recommended thresholds as a benchmark. The analysis highlights a distinct separation between the transaction patterns of major cryptocurrencies paired with fiat currencies and those of less established or more volatile assets. BTC, ETH, and even LUNA exhibit strong conformity with Benford's Law, suggesting greater market stability, transparency, and organic trading behavior, while exotic pairs and assets like DOT deviate significantly, pointing to potential irregularities, inefficiencies, or unique market characteristics. Such deviations can sometimes be associated with market manipulation, wash trading, or other fraudulent activities commonly observed in less regulated, lower-liquidity, or highly speculative markets. These findings highlight the potential of Benford's Law as a diagnostic tool for detecting abnormal transaction patterns, identifying markets susceptible to manipulation, and improving overall market surveillance and security. Our study contributes to a deeper understanding of cryptocurrency market dynamics and offers a foundation for further research into fraud detection, regulatory oversight, and market integrity within the rapidly evolving cryptocurrency environment.*

Keywords: Markets in Crypto-Assets Regulation (MiCAR), Crypto-Asset Service Providers (CASPs), Benford's law, cryptocurrency, market manipulation.

Introduction

Cryptocurrencies, virtual and decentralized forms of currencies that have sprung up starting with Satoshi Nakamoto's Bitcoin Whitepaper (2008) have taken a hold of orthodox and unorthodox investors' portfolios by storm, especially among new, young investors who are more prone to invest in higher risk, higher reward methods of wealth accumulation.

With any new method of investment, however, there is the possibility, risk or some degree of fraud that comes associated – cryptocurrencies have been no exception. With the popularisation of low-code or no-code platforms that enable less technically mature "developers" to establish cryptocurrencies, the number of options to invest in increased exponentially, many of which with the sole goal of profiting from less-informed investors or taking advantage of good-willed

DOI: 10.2478/picbe-2025-0041
© 2025 P.-C. Grigorescu; A. Amza, published by Sciendo.
This work is licensed under the Creative Commons Attribution 4.0 License.

interested parties. However, its largely unregulated nature has raised significant concerns regarding market integrity, transparency, and vulnerability to manipulation and illicit activities. Unlike traditional financial markets, the absence of comprehensive regulatory oversight in the cryptocurrency sector creates opportunities for practices such as wash trading, market manipulation, and fraudulent transactions.

Recognizing these risks, recent global regulatory initiatives have emerged to address the need for stricter compliance and transparency. Notably, the European Union's Markets in Crypto-Assets (MiCAR) framework and ongoing efforts by the U.S. Securities and Exchange Commission (SEC) aim to establish clearer guidelines and enforce regulatory standards within the crypto market. The implementation of these regulatory frameworks seeks to mitigate systemic risks, reduce market abuse, and enhance overall market stability.

The Markets in Crypto-Assets Regulation (MiCAR, 2023), which became fully applicable on December 30, 2024, establishes clear rules to prevent market manipulation in the crypto-asset sector. By introducing a comprehensive regulatory framework, MiCAR seeks to enhance transparency, protect investors, and ensure fair market conditions across the European Union. However, effective enforcement of these provisions requires supervisory authorities to develop practical tools for identifying suspicious activities and potential instances of market manipulation.

In this context, Benford's Law can emerge as a valuable analytical tool, offering a systematic approach for detecting anomalies in crypto-asset transactions. Widely recognized as a state-of-the-art method in financial auditing, Benford's Law is particularly effective in identifying unnatural distortions in numerical datasets. Given that legitimate financial transactions typically follow predictable statistical patterns, deviations from Benford's expected distribution can serve as early warning signals for fraudulent behavior, artificial trading volumes, or potential price manipulation. By leveraging this method, regulators can conduct a preliminary assessment of crypto-market transactions, flagging irregularities that may warrant further investigation. While Benford's Law alone does not constitute direct evidence of misconduct, its integration into a broader market surveillance framework can significantly enhance the detection of illicit activities.

From an empirical perspective, with the rising popularity of crypto pump-and-dump schemes, we aim to determine for some of the most popular cryptocurrencies, as well as for some of the most recent issued if the trading volumes (purchased quantities of the currency) tend to conform to Benford's law when analyzed for special channels: BTC-EUR, BTC-USD, etc. Due to the large number of transactions used, we apply the mean absolute deviation and squared sum of deviation thresholds as elaborated in the literature review.

Literature review

Alternative methods of investment have become one of the hallmark traits of the post 2000s global economy. Ranging from virtual (crypto) currencies made by private individuals, attempts at digitalizing traditional currencies, video game currencies obtainable with physical fiat and up to digital images claiming to sell sole ownership through URLs, even the most casual of investors is spoiled for choices at the time of this article's writing. Of them all, cryptocurrencies have shown a stunning level of resilience in the face of many scandals, attempts at regulation, scams, and more, becoming more and more prevalent across today's investment portfolios and recently even crossing, for the first time of any cryptocurrency, the 100,000 $US per unit of Bitcoin (Giudici, 2020).

Attempting to follow in Bitcoin's footsteps and have a piece of this success, cryptocurrencies have seemingly started to appear out of nowhere and everywhere, in video games, NGOs, various projects that required financing, and more, being a sort of "layman's proof of faith", a method through which any interested could invest into an idea, project or even person in which they believe, hold a stake, or otherwise want to profit from (Russell Belk, 2022).

Through the development and popularization of low-code and no-code platforms for launching cryptocurrencies at low cost, many fraudulent schemes have started to appear and the number of scandals from pump-and-dump schemes have skyrocketed in recent years. In light of this, traditional methods for fraud conformity such as Benford's law may come into play for investors to be able to determine, among other means, the trustworthiness of the cryptocurrency and potentially avoid fraud.

Benford's law is the colloquially used term for what was written as "The Law of Anomalous Numbers" by Frank Benford, which essentially established that naturally occurring numbers will have the first digits of these numbers follow a distribution expressed as $log_{10}(1+\frac{1}{d})$ for $d \in \{1, \dots, 9\}$ (Benford, 1938). A similar distribution is determined for the 2nd digit, however it will not be used for the purposes of this article. This theoretical property of naturally-occurring numbers has been repeatedly tested and proven as an anomaly detection method, often-times in the fraud prevention and auditing domains, noting that manipulated or otherwise unnatural numbers can be effectively detected using Benford's law testing (Nigrini, 1999). Benford's law is traditionally tested using chi-square statistical tests. However, as experiments pointed out, the chi-square test faces the issue of excessive statistical power, meaning that as the dataset size increases (more than 5,000 records), the calculated chi-square value almost always exceeds the critical threshold (Nigrini, 2012)(Druică et al., 2018). This will lead to the incorrect conclusion that the data does not conform to Benford's Law. Due to this limitation for large volumes of data, other methods have been found to be more exact, such as Mean Absolute Deviation (MAD), expressed as $\frac{1}{9}\sum_{d=1}^{9}|F(d) - F_B(d)|$ and the Sum of Squared Deviations (SSD) expressed as $\sum_{d=1}^{9}(F(d) - F_B(d))^2$, for F and F_B being the empirical, respectively theoretical Benford distribution for digit d. For comparisons we utilize the thresholds defined by (Cerqueti & Maggi, 2021) to divide the Benford conformity results in the [Close, Acceptable, Marginal, None] categories.

Benford's law has been tested before as a method of detecting potential cryptocurrency trading (market) fraud, specifically focusing on the potentially anomalous prices (Peterson, 2011), traded fiat values (Vičič, 2022) or returns (Iskenderoglu, 2021). Our analysis aims to complete the picture in two ways – by focusing on cryptocurrency trade size, in terms of amounts of a particular "coin", as well as looking at the various counter assets, such as USD/EUR/other cryptocurrency. Usually, literature deals with aggregated values. A similar approach in terms of inspecting the distribution of each trade size whose first significant digit should follow Benford's law was taken by Cong et al. who found evidences that most analyzed exchanges perform Wash trading (simultaneously selling and buying the same financial assets to create artificial activity in the marketplace). However, two key distinctions in our work lie in incorporation of several trading pairs into our experiment and in the way we compare the empirical distribution with Benford's distribution.

Methodology

Before delving into the application of Benford on our selected cryptocurrencies (top 2 by transaction volumes and 3 by pump-and-dump indicators as noted in the literature review), we split the transacted volumes (per minute) into the smaller ecosystems denoted by the fiat currency or otherwise "paired" currency, such as BTC-EUR or BTC-JPY. The data is obtained through the Bitfinex exchange's API and published as comma-separated (CSV) value files at 1-minute trading resolutions, including open, close and adjusted closing prices for each resolution. (Klein, 2023) For this analysis we strictly use the traded volume, aggregated at 1-minute intervals, which for the biggest cryptocurrencies may represent hundreds of transactions, while for less known ones fewer than 10 per minute.

Due to the period extracted and the API used, certain limits apply to datasets extracted. The maximum extracted sample size differs by pairing due to the time trading was opened to the public or due to currency-specific downtimes, but at its maximum spans from 2013-04-01 to 2023-10-08. The exact number of observations for each pairing is specified in the results table of the following section.

The practical methodology is typical for Benford analyses, starting by extracting the 1st digit of the traded volume of each transaction as we have observation-level data, taking note to scale these beforehand to ensure sub-unitary numbers become unitary. Using pandas pivot-tables to calculate the frequency of these digits we then compute their weight out of the total and compare these empirical frequencies to the theoretical Benford's law distribution. For the statistical analysis of deviations, we use thresholds as defined by (Cerqueti & Maggi, 2021) for the MAD and SSD values, respectively. We additionally test the traditional chi-square test for distributions as well, but due to the inflationary nature of its formula for high-volume datasets, none of the pairings adhere to the theoretical benford distribution with this test. The thresholds used for the conformity tests are [<0.006 < 0.012 < 0.015 < inf] and [0.0002 < 0.0025 < 0.0101 < inf] for MAD and SSD respectively, conforming to the Close/Acceptable/Marginal/None gradings.

Ultimately, using these calculated values, we apply the MAD and SSD formulas as well as the thresholds for Benford conformity as close/acceptable/none and extract the results in the table attached in the following pages, for all cryptocurrency pairings, and discuss on the results against the expected behaviour.

Results and discussions

We take 2 of the most traded and randomly select 3 of the pump and dump-flagged cryptocurrencies, in order to ensure we have some number of transactions. Based on trading volume, market cap, number of transactions in the 2013-2023 period and a "pump and dump flag" where we detect whether patterns of rapid price increase/decrease of over 10% happen within 5 successive transactions, we ended up by selecting the following 5 cryptocurrencies:

Table 1. Summary of cryptocurrencies analyzed

Cryptocurrency	Ticker	Market Cap 2024	Data Volume	Consideration
Bitcoin	BTC	>1 trillion	>1 million	Popularity by Market Cap, # of transactions
Ethereum	ETH	>400 billion	>1 million	
LUNA	LUNA	>300 million	>20 thousand	Possible Pump and Dumps (any 10% price change in less than 5 transactions)
TRON	TRX	>22 billion	>600 thousand	
Polkadot	DOT	>10 billion	>400 thousand	

Source: Authors' own elaboration.

Additionally, due to the nature of cryptocurrency exchanges, a few versions for each of the above coins is analyzed separately – for instance, BTC-USD and BTC-EUR can be considered two different cryptocurrencies from a trading point of view, and while these may be very close in terms of price, trading volumes are often different due to the investor profile, and also more volatile or potentially dangerous cryptocurrencies as TERRA/LUNA proved to be. Data for each individual transaction value was collected from the Bitfinex exchange.

As an initial hint, the visual inspection of data shows some different behavior of samples between well-established cryptocurrencies and those with lower market capitalization. For exemplification purposes we present the charts for two cryptocurrency pairs.

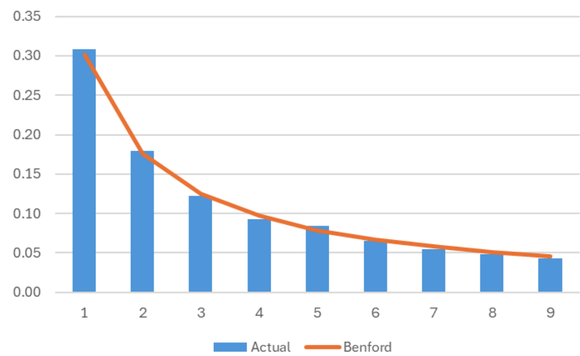

Fig. 1. The distribution of the first digit, actual and expected, for ETH/USD
Source: authors' own elaboration.

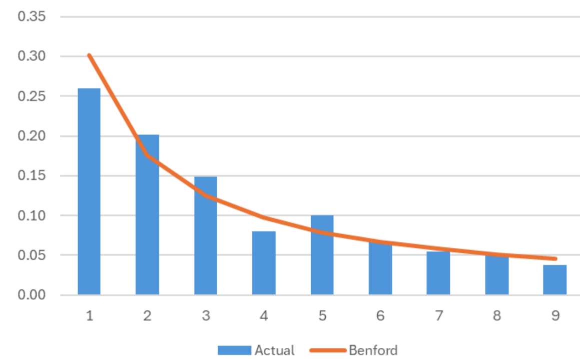

Fig. 2. The distribution of the first digit, actual and expected, for DOT/USD
Source: authors' own elaboration.

The results for all selected cryptocurrency pairings can be examined in the table below, with each pair's respective conformity level according to the MAD and SSD calculations. The thresholds we set are "Close", "Acceptable", "Marginal" and "None" in terms of Benford's law conformity.

Table 2. Benford conformity results for different cryptocurrency pairs's traded volume at 1-minute resolutions

Pair	MAD	SSD	Conformity	CHISQ Test	Sample Size
BTC-EUR	0.010183	0.001385	Acceptable	Non-conform	2133859
BTC-USD	0.006778	0.000506	Acceptable		4527148
BTC-JPY	0.016415	0.003577	None/Marginal		1433019
BTC-GBP	0.006772	0.000654	Acceptable		1268711
BTC-CNY	0.158417	0.594740	None		3399
BTC-UST	0.005805	0.000484	Close/Acceptable		1674371
BTC-MXNT	0.151920	0.539699	None		805
BTC-XAUT	0.130642	0.303691	None		729
BTC-EUT	0.023850	0.012499	None		432131
BTC-MIM	0.073009	0.057856	None		146967
BTC-TRY	0.124956	0.359647	None		60155
ETH-USD	0.004906	0.000501	Close/Acceptable		3248946
ETH-EUR	0.014526	0.002428	Marginal/Acceptable		1507913
ETH-BTC	0.004814	0.000327	Close/Acceptable		2295177
ETH-EUT	0.041545	0.041307	None		578714
ETH-UST	0.007577	0.000947	Acceptable		1547002
ETH-GBP	0.024597	0.006221	None/Marginal		998039
ETH-JPY	0.023076	0.006249	None/Marginal		1118564
ETH-MXNT	0.154782	0.559359	None		806
ETH-XAUT	0.151548	0.344076	None		587
LUNA-USD	0.008946	0.000857	Acceptable		19932

Pair	MAD	SSD	Conformity	CHISQ Test	Sample Size
LUNA-BTC	0.008431	0.001203	Acceptable		14869
LUNA-UST	0.008632	0.000880	Acceptable		18641
TRX-USD	0.013286	0.004272	Marginal		1132958
TRX-EUR	0.011919	0.002523	Acceptable/Marginal		458876
TRX-BTC	0.035760	0.025025	None		638328
TRX-UST	0.011028	0.001998	Acceptable		357463
TRX-ETH	0.030602	0.016538	None		435876
DOT-USD	0.015579	0.003730	None/Marginal		898556
DOT-BTC	0.044636	0.045059	None		408560
DOT-UST	0.027778	0.016235	None		761500

Source: Authors' own analysis.

The analysis revealed distinct patterns of conformity to Benford's Law among the examined cryptocurrency trading pairs, highlighting notable differences between major assets and less common ones. Trading pairs involving BTC and ETH, particularly those denominated in well-established fiat currencies such as USD and EUR, demonstrated a stronger tendency to adhere to Benford's Law. This may suggest that these markets are relatively stable and mature, characterized by consistent and predictable transaction behaviors. These findings reinforce the idea that flagship cryptocurrencies paired with widely used fiat currencies operate within more orderly market environments. Similarly, USDT (Tether – USD) has shown a particularly strong adherence to Benford's law, at times more than the /USD pair itself.

Interestingly, LUNA also showed significant conformity to Benford's Law across the analyzed pairs during the considered timespan. This result is particularly notable given the dramatic collapse of the Terra ecosystem in 2022, which led to extreme volatility and market instability. The initial conformity may reflect a period of market confidence prior to the collapse, highlighting how sudden structural failures and loss of trust can rapidly disrupt even seemingly stable markets.

On the other hand, more exotic pairs or those involving lesser-known stablecoins, such as XAUT and MXNT, exhibited weaker or no conformity to Benford's Law. These deviations could be explained by irregular transaction patterns, lower trading volumes, or the potential influence of market manipulation. Among the analyzed cryptocurrencies, DOT stood out as particularly anomalous. None of its trading pairs adhered to Benford's Law, making it the only asset to consistently fail the conformity hypothesis across all pairs studied, with a noted "marginal" conformity for the sum of squared deviations when purchased with USD.

Conclusion

The implementation of the Markets in Crypto-Assets Regulation (MiCAR) marks a significant step towards ensuring transparency and integrity in the crypto-asset market. By establishing clear rules to prevent market manipulation, MiCAR imposes strict oversight obligations on crypto-asset service providers (CASPs) and other market participants. However, effective enforcement of these regulations requires robust tools to detect potential irregularities in transaction patterns.

In this paper, we propose a methodology based on Benford's Law as a practical approach for identifying anomalies in crypto-asset transactions. Given its well-established application in auditing, this method can support supervisory authorities in detecting suspicious market behaviors. While not a definitive proof of manipulation, Benford's Law provides an efficient initial screening tool that can guide further regulatory investigations.

The results of our analysis provide valuable insights into the conformity of cryptocurrency trading pairs with Benford's Law, offering a nuanced understanding of market behavior across various assets. Notably, major cryptocurrencies such as BTC and ETH paired with well-established fiat currencies (e.g., USD and EUR) demonstrated strong adherence to Benford's Law. This suggests a high degree of market maturity, transparency, and stability in these trading pairs, as their transaction distributions closely align with theoretical expectations. Interestingly, our methodology revealed no signs of irregularities in LUNA trades during the examined period, a result that stands out given the controversies surrounding its broader ecosystem. This finding underscores the importance of granular transaction-level analysis when evaluating market integrity.

On the other hand, exotic pairs and those involving lesser-known or less liquid stablecoins, such as XAUT and MXNT, displayed weaker or no conformity to Benford's Law. These deviations could reflect irregular transaction patterns, lower trading volumes, or other structural factors that introduce noise or inefficiency into the market. On the other hand, such discrepancies can sometimes be associated with market manipulation, wash trading, or other fraudulent activities commonly observed in less regulated, lower-liquidity, or highly speculative markets. These findings are particularly relevant given the largely unregulated nature of the cryptocurrency market, which makes it more vulnerable to manipulation and illicit activities.

These findings are particularly relevant given the largely unregulated nature of the cryptocurrency market, which makes it more vulnerable to manipulation and illicit activities. Our work validates the utility of Benford's Law as a diagnostic tool for market behavior and highlights potential areas of interest for further investigation, particularly in understanding why certain pairs diverge from expected distributions and whether these divergences point to structural anomalies in the market.

References

Benford, F. (1938). The law of anomalous numbers. *Proceedings of the American Philosophical Society, 78*(4), 551–572.

Belk, R., Humayun, M., & Brouard, M. (2022). Money, possessions, and ownership in the metaverse: NFTs, cryptocurrencies, Web3 and wild markets. *Journal of Business Research, 153*, 198–205.

Klein, C. (2023, October 8). Historical cryptocurrency data from the Bitfinex exchange including Bitcoin. *Medium & Kaggle*.

Cerqueti, R., & Maggi, M. (2021). Data validity and statistical conformity with Benford's law. *Chaos, Solitons & Fractals, 144*, 110740.

Cong, L. W., et al. (2022). Detecting and quantifying crypto wash trading. In *3rd International Conference on Blockchain Economics, Security and Protocols (Tokenomics 2021)*. Schloss Dagstuhl–Leibniz-Zentrum für Informatik.

Druică, E., Oancea, B., & Vâlsan, C. (2018). Benford's law and the limits of digit analysis. *International Journal of Accounting Information Systems, 31*, 75–82.

Giudici, G., Milne, A., & Vinogradov, D. (2020). Cryptocurrencies: Market analysis and perspectives. *Journal of Industrial and Business Economics, 47*, 1–18.

Herteliu, C., et al. (2015). Effect of religious rules on time of conception in Romania from 1905 to 2001. *Human Reproduction, 30*(9), 2202–2214.

Herteliu, C., et al. (2021). Testing Benford's law's (non)conformity within disclosed companies' financial statements among the hospitality industry in Romania. *Physica A: Statistical Mechanics and Its Applications, 582*, 126221.

Iskenderoglu, O., & Ayyıldız, N. (2021). The suspicion of manipulation in bitcoin returns: An investigation with Benford's law. *Journal of Economics, Finance and Accounting, 8*(2), 109–116.
Nigrini, M. J. (1999). I've got your number. *Journal of Accountancy, 187*(5), 79–83. Nigrini, M. J. (2012). *Benford's law: Applications for forensic accounting, auditing, and fraud detection*. John Wiley & Sons.
Peterson, T. (2021). To the moon: A history of bitcoin price manipulation. *Journal of Forensic and Investigative Accounting, 13*(2), 1–15. https://doi.org/10.2139/ssrn.3639431 Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. *Bitcoin.org*. https://bitcoin.org/bitcoin.pdf
Vičič, J., & Tošić, A. (2022). Application of Benford's law on cryptocurrencies. *Journal of Theoretical and Applied Electronic Commerce Research, 17*(1), 313–326.
Wist, H. (2019). *Assessing the conformity of cryptocurrency market data with Benford's law* [Master's thesis, University of Vaasa].