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The Inefficiency of Bitcoin and the COVID-19 Pandemic

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Abstract. *From the perspectives of asset pricing, market outreach, regulatory framework, and investor ethos, crypto markets differ substantially from traditional financial markets. Given these fundamental differences, it is interesting to examine how the notions of market efficiency apply to crypto markets, especially because the arguments of the efficient market hypothesis (Fama, 1970) and the adaptive market hypothesis (Lo, 2004, and Lo, 2008) were originally developed in the context of traditional financial markets. Research on the informational efficiency of crypto markets has attracted increasing attention in recent years. This paper examines the evolving efficiency of Bitcoin, the leading cryptocurrency, especially during the period when economies around the world were devastated by the COVID-19 pandemic. For a newly-emerged cryptocurrency with a market that is essentially global, a global shock like the COVID-19 pandemic presents ideal conditions for assessing how efficiency evolves as the market faces a series of shocks. Employing a fixed-length rolling window approach, this paper carries out the following tests: the automatic portmanteau test of Escanciano and Lobato (2009), the wild bootstrap automatic variance ratio test proposed by Kim (2009), the generalized spectral test of Escaciano and Valesco (2006), and the test proposed by Dominguez and Lobato (2003). The results provide evidence of episodes of inefficiency in a market that is efficient over extended periods. The inefficiency index constructed in this study shows that the Bitcoin market went through proportionately longer and more frequent episodes of inefficiency during the COVID-19 period. This is in line with the adaptive market hypothesis and has practical significance for investors and regulators.*

Keywords: Adaptive Market Hypothesis, Bitcoin, Cryptocurrency, COVID-19 Pandemic, Market Efficiency.

JEL Codes: G01, G12, G14

1. Introduction

Academic interest in crypto assets and markets has been increasing exponentially. Crypto assets provide a particularly fertile ground for academic research in economics and finance because they emerged as a new asset class trading in essentially global markets. Crypto markets differ from traditional stock, currency, or commodity markets in several fundamental ways. Firstly, as compared to traditional assets, the pricing of crypto assets is far less understood. The opinion of experts varies from one extreme dismissing it as an outright scam to the other extreme passionately holding the vision that it is the beginning of a revolution. Secondly, crypto markets transcend national boundaries and can be construed as representing global conditions. In comparison to traditional asset markets, crypto markets are less influenced by the local conditions of a particular country. The third factor that differentiates crypto markets from traditional markets is the lack of regulation, making them open to unhindered use of various prohibited practices like insider trading, pump and dump schemes, and other scams. Finally, the most remarkable distinguishing feature of the crypto markets has been the all-for-one ethos (see e.g. Nicolle and Kharif, 2022) that runs across the communities of crypto investors. This is in sharp contrast with the behavior of investors and traders in the stock markets.

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Given these fundamental differences in asset pricing, market outreach, regulatory framework, and investor ethos, it is interesting to see how the notion of market efficiency applies to crypto markets, especially because the arguments of the Efficient Market Hypothesis (Fama, 1970) and Adaptive Market Hypothesis (see e.g. Lo, 2004, and Lo, 2008) were originally developed in the context of traditional financial markets.

As argued by Damodaran (2017), cryptocurrencies cannot be valued like stocks because they do not generate cash flows. However, like fiat currencies, they can be priced in terms of other currencies. What determines the price of cryptocurrencies is far from clear and has emerged as an active field of research. The emerging body of literature on the identification of the determinants of cryptocurrencies' prices has proceeded along several interesting themes. An incomplete list of such themes would include ongoing research on adoption and usage of cryptocurrencies (e.g. Polasik et al. 2015, Athey et al. 2016, Tasca et al. 2018, and Foley et al. 2019), transactional and speculative motives for holding cryptocurrencies (e.g. Yermack, 2013, and Bolt and Van Oordt, 2020), impact of the media coverage on the price of cryptocurrencies (e.g. Garcia et al. 2014, and Wang and Vergne, 2017), impact of network factors, production factors, equity factors, macroeconomic factors, and other factors on cryptocurrency returns (Liu and Tsyvinski, 2021 and Liu et al. 2022), etc. Needless to say, the issue of identification of the determinants of cryptocurrencies' prices remains far from settled and continues to draw the attention of researchers.

Despite this lack of understanding of the determinants of cryptocurrency prices, it is possible to test the weak-form informational efficiency of crypto markets. If a market is informationally efficient, it essentially implies that the price reflects all the information relevant to the determination of price. As explained by Halaburda et al. (2022), weak-form informational efficiency can be tested by checking whether the data-generating process exhibits predictability. Based on statistical tests, market can be considered inefficient if the data-generating process exhibits predictability. This has been utilized by various studies to assess the weak-form informational efficiency of cryptocurrency markets. Urquhart (2016) tested the weak form efficiency for the Bitcoin market and concluded that the Bitcoin returns do not satisfy the efficient market hypothesis but it may be in the process of moving towards efficiency. Nadarajah and Chu (2016) show that an odd integer power transformation of Bitcoin returns is largely weakly efficient. Wei (2018) examines 456 cryptocurrencies and concludes that efficiency is stronger in liquid cryptocurrency markets. Other studies on this theme include Bariviera (2017), Tiwari et al. (2017), Zheng and Kaizoji (2019), and Sensoy (2019).

The COVID-19 pandemic, being the most prominent global shock experienced by the crypto markets in their brief history of existence, provides an appropriate setting to study the evolution of market efficiency of crypto markets. This conclusion is supported by both empirical evidence and theoretical arguments. Historically, it has been observed that global shocks tend to have an impact on the informational efficiency of markets. Several empirical studies have been conducted to investigate this phenomenon. For example, Lazar et al. (2012) studied the impact of the 2008 global financial crisis on the informational efficiency of currency markets. Similarly, Jiang et al. (2014) have examined the weak-form efficiency of the WTI (West Texas Intermediate) crude oil futures market and found that the Gulf War reduced its efficiency. More closely related to our paper is the study by Okorie and Lin (2021) who examine the impact of the COVID-19 pandemic on the informational efficiency of stock markets. Intuitively, it is not difficult to see how a global shock like the COVID-19 pandemic can have an impact on the informational efficiency of markets, including the crypto markets. The pandemic induced widespread distress conditions such as health emergencies, lockdown, severely-constrained resources, and unanticipated loss of income, which can interfere with the decision-making process of market participants. For example, the criteria and objectives of

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trading decisions under these circumstances may differ radically from those under normal conditions. Similarly, these extraordinary conditions can also affect the way information is distributed and processed by the market participants. Issues like panic, rumours, misinformation, slower distribution of information, and price manipulations may become more prominent. As a result, these mechanisms can lead to a noticeable impact on the informational efficiency of the markets, including the crypto markets.

This paper contributes to the literature in several ways. Firstly, it employs a fixed-length rolling window approach to assess the efficiency of the Bitcoin market every day with different sizes of the window to identify changes in the informational efficiency of the market as it endures various shocks, including the three waves of the COVID-19 pandemic. For a newly-emerged asset with a market that is essentially global, a global shock like the COVID-19 pandemic presents well-suited conditions for assessing how efficiency evolves as the market faces a series of shocks. Secondly, an efficiency index has been constructed for the periods of interest even though the rolling window approach makes a continuous assessment of efficiency. Thirdly, the efficiency tests employed in this paper are based on both linear and non-linear measures of dependence. This is intended to give a comprehensive assessment of the evolution of market efficiency. Finally, the empirical findings may have important policy implications from the perspectives of investment and regulation.

Following this introductory section, the remainder of this paper is organized as follows. Section 2 describes the methodology and data. Section 3 reports the empirical results and their interpretation. Section 4 concludes with a discussion of the main empirical findings and their implications.

2. Research Elaboration: Methodology and Data

To assess the market efficiency of Bitcoin markets, this study employs martingale difference hypothesis (MDH) tests based on both linear and non-linear measures of dependence because it is not clear whether the nature of dependency is linear or nonlinear. This is also in line with the recommendation of Charles et al. (2012).

It has been employed the following four tests:

- Automatic Portmanteau (AP) Test of Escanciano and Lobato (2009): This is a robustified version of the Ljung-Box test (1978)
- Wild Bootstrap Automatic Variance Ratio (WBAVR) Test proposed by Kim (2009): This is essentially a wild bootstrap version of Choi's (1999) automatic variance ratio (AVR) test which is based on the variance ratio test of Lo and MacKinlay (1988)
- Generalized Spectral (GS) Test of Escaciano and Valesco (2006): It has generalized the spectral test of Durlauf (1991) to take into account both linear and nonlinear dependence in asset returns. The test is implemented by employing the wild bootstrap.
- Test proposed by Dominguez and Lobato (2003) based on Cramer-von Mises (CvM) and Kolmogorov-Smirnov (KS) statistics. The p-values for the test can be calculated from the wild bootstrap distribution.

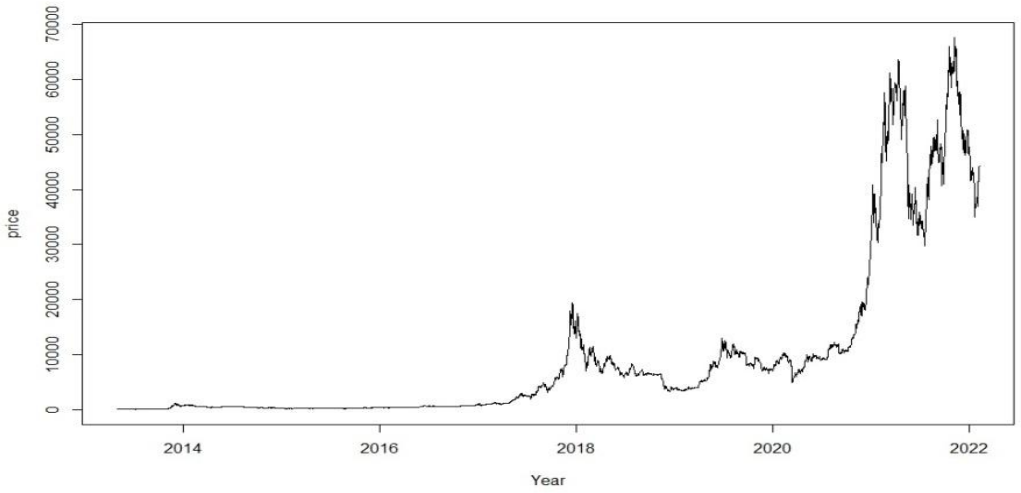
Bitcoin price data has been taken from www.coinmarketcap.com, which represents an average of the prices in various crypto exchanges around the world. This kind of global averaging is justified because the Bitcoin market and the COVID-19 pandemic are essentially global. Daily prices from April 28, 2013, to February 9, 2022, with a total of 3210 observations, as shown in Figure 1, were used in the study.

The origin of the COVID-19 pandemic remains unclear. It started in December 2019 or earlier and the World Health Organization declared it a public health emergency of international concern on January 30, 2020. The exact date on which the pandemic started is not crucial to this study as it is based on rolling

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estimation windows. However, for the purposes of basic statistics and calculation of the inefficiency index (described later), the beginning date of the COVID-19 period has been taken as January 9, 2020, which is the date of the first confirmed COVID-19 death.

Figure 1: Time-series graph of the daily price of Bitcoin



Efficiency tests were carried out on continuously compounded returns (R_t) calculated as follows:

$R_t = 100 * \ln(P_t / P_{t-1})$, where P_t is the price of Bitcoin at time t.

The basic statistics of the Bitcoin returns series are shown in Table 1:

Table 1: Descriptive statistics of Bitcoin returns series

	Full sample	Pre-Covid	Covid period
Mean	0.1807	0.1675	0.2231
Standard deviation	4.2214	4.267	4.0739
Skewness	-0.5287	-0.1538	-1.9046
Kurtosis	10.9456	7.7144	23.3473
Jarque-Bera statistic	16194^{***}	6089^{***}	17896^{***}
Ljung-Box Q(10) statistic	33.22^{***}	25.64^{***}	26.22^{***}
Ljung-Box Q^2(10) statistic	296.88^{***}	515.62^{***}	14.8
ARCH-LM (10) statistic	193.41^{***}	316.17^{***}	14.79

*** indicates 0.1% level of significance

As expected, the Jarque-Bera test rejects the null hypothesis of normality and the Ljung-Box test rejects the null hypothesis of no autocorrelation. ARCH-LM test shows that the null hypothesis of no autoregressive conditional heteroscedasticity (ARCH) effects can be rejected.Applying the Bai-Perron test on the Bitcoin price series, the optimal 4-segment partition reveals the following break dates: August 11, 2017, May 25, 2019, and October 16, 2020. The last breakpoint falls within the COVID-19 phase.

3. Results and Discussions

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To study the evolution of market efficiency over time, this paper employs the rolling window approach. The four efficiency tests are performed for a fixed-length subsample starting at the beginning and moving it by one observation to create the next subsample. This process is continued till the end of the sample. Three sizes of fixed-length rolling windows are used: 100, 300, and 500.
Time-varying p-values are plotted in Figure 2 for the four tests for different sizes of fixed-length rolling windows.

Figure 2: Time-varying p-values of the efficiency tests for different sizes of rolling window

Figure 2a: Time-varying p-values of the Automatic Portmanteau Test with rolling window of size 100

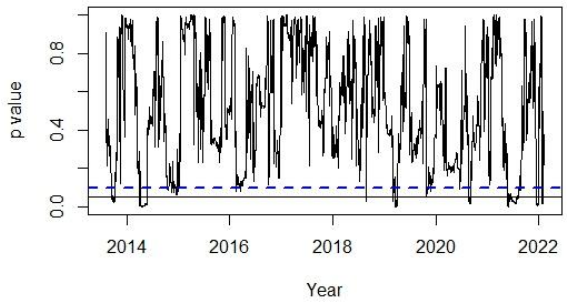


Figure 2b: Time-varying p-values of the Automatic Portmanteau Test with rolling window of size 300

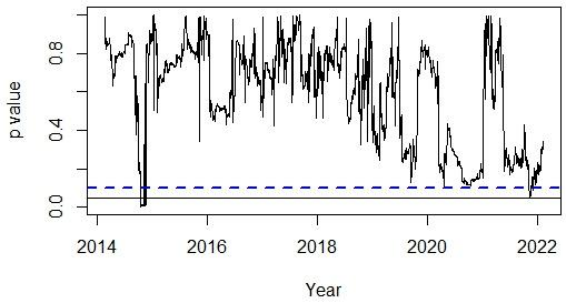


Figure 2c: Time-varying p-values of the Automatic Pormanteau Test with rolling window of size 500

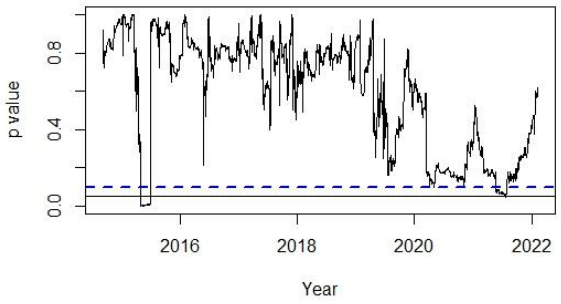
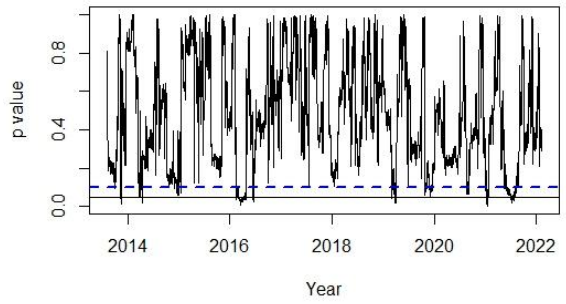


Figure 2d: Time-varying p-values of the Wild Bootstrap Automatic Variance Ratio Test with rolling window of size 100



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Figure 2e: Time-varying p-values of the Wild Bootstrap Automatic Variance Ratio Test with rolling window of size 300

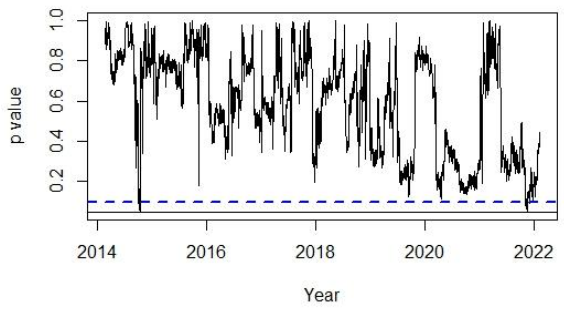


Figure 2f: Time-varying p-values of the Wild Bootstrap Automatic Variance Ratio Test with rolling window of size 500

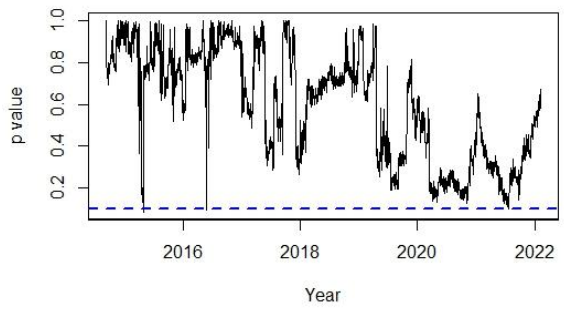


Figure 2g: Time-varying p-values of the General Spectral Test with rolling window of size 100

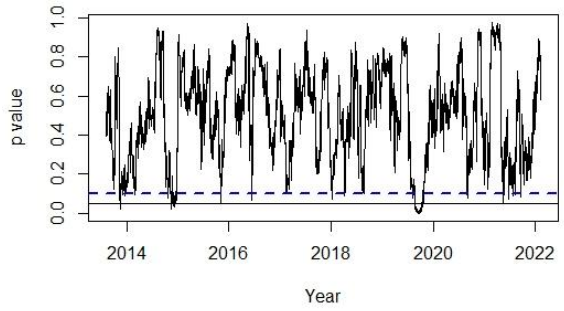
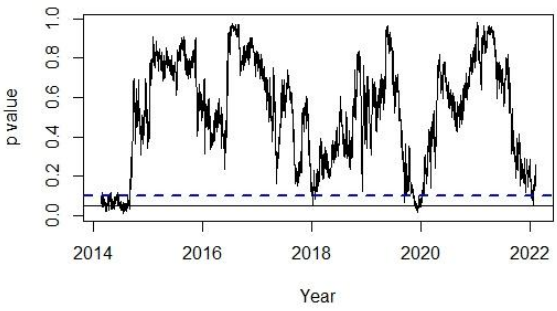


Figure 2h: Time-varying p-values of General Spectral Test with rolling window of size 300



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Figure 2i: Time-varying p-values of the Dominguez and Lobato Test based on Cramer-von Mises statistics with rolling window of size 100

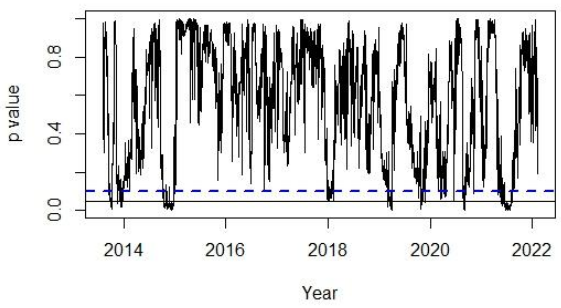


Figure 2j: Time-varying p-values of the Dominguez and Lobato Test based on Kolmogorov-Smirnov statistics with rolling window of size 100

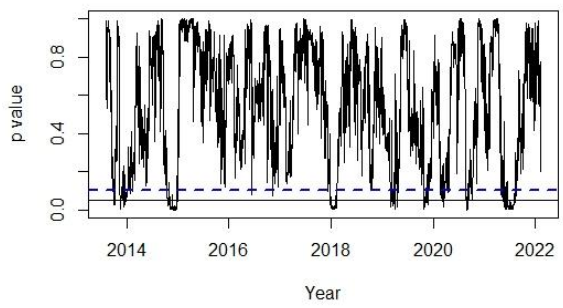


Figure 2k: Time-varying p-values of the Dominguez and Lobato Test based on Cramer-von Mises statistics with rolling window of size 300

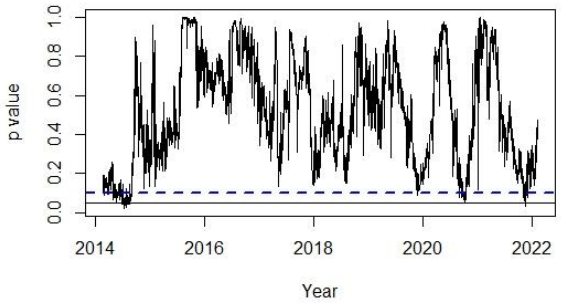
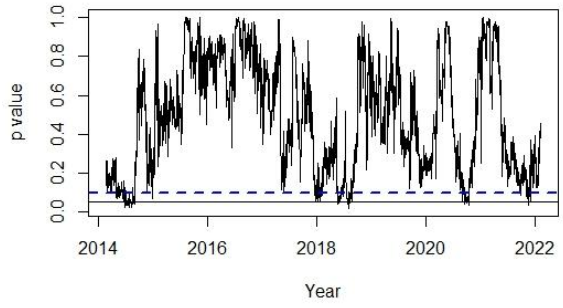


Figure 2l: Time-varying p-values of the Dominguez and Lobato Test based on Kolmogorov-Smirnov statistics with rolling window of size 300



Note: In each figure, the solid horizontal line shows the significance level of 5% and the dashed horizontal line shows the significance level of 10%.

The p-values of the Automatic Portmanteau Test depicted in Figures 2a-2c show that the Bitcoin market turned inefficient for extended periods. In Figure 2a, the longest episodes of inefficiency roughly correspond to the three waves of the COVID-19 pandemic: a period of 14 days from August 20, 2020 to September 2, 2020 during the first wave, a period of 89 days from May 22, 2021 to August 18, 2021 during the second wave, and a period of 18 days from December 11, 2021 to December 28, 2021 during the third wave. In Figure 2b, the longest episode of inefficiency during the COVID-19 phase is found from November 5, 2021 to November 17, 2021 (13 days). Similarly, in Figure 2c, the longest episode of inefficiency during COVID-19 phase runs from May 21, 2021 to July 27, 2021 (68 days). Figures 2d through 2f capture the p-values for the Wild Bootstrap Automatic Variance Ratio Test. In Figure 2d, the longest period of inefficiency during the COVID-19 phase stretches from June 6, 2021 to August 8, 2021(64 days). For Figure 2e, such an extended period of inefficiency is found in November 2021 (11 days). Figures 2g and 2h plot the p-values of the General Spectral Test. What is remarkable about these tests is that the incidence of inefficiency is proportionately higher in the pre-COVID-19 period. There are only a few instances of inefficiency during the COVID-19 phase, e.g. in Figure 2g, the longest stretch of inefficiency runs from May 12, 2021 to May 18, 2021(7 days).

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Figures 2i through 2l depict the results of the Dominguez and Lobato Test. In Figure 2i, the longest period of inefficiency extends from June 13, 2021 to August 2, 2021(51 days). Figure 2j shows a stretch of 55 days from June 13, 2021 to August 6, 2021during the COVID-19 phase when the market is inefficient. Such patches of inefficiency are from September 29, 2020 to October 5, 2020 (7 days) in Fig 2k, and from September 24, 2020 to October 11, 2020 (18 days) in Fig 2l.
An interesting pattern emerges in the test results described above. To give a quantitative estimate of the difference, an inefficiency index has been constructed based on the number of days on which the p-value of an efficiency test was less than or equal to 10% as a proportion of the total number of days on which the test could have been conducted. Table 2 shows the Inefficiency Index for the three periods of concern. Tests based on linear measures clearly demonstrate an increase in inefficiency after the start of the COVID-19 pandemic. However, the evidence from the remaining tests is mixed. Two variants of the Dominguez and Lobato test indicate an increase in inefficiency after the pandemic while two other variants of the Dominguez and Lobato test and the General Spectral test show the opposite change in inefficiency after the onset of the pandemic.

Table 2: The Inefficiency Index of the Bitcoin market based on various tests

	Inefficiency Index		
Test	Full sample	Pre-COVID-19 period	COVID-19 period
Automatic Portmanteau Test with rolling window of size 100	9.32	6.86	19.43
Automatic Portmanteau Test with rolling window of size 300	1.82	1.58	4.09
Automatic Portmanteau Test with rolling window of size 500	4.94	3.29	25.38
Wild Bootstrap Automatic Variance Ratio Test with rolling window of size 100	7.68	6.05	14.61
Wild Bootstrap Automatic Variance Ratio Test with rolling window of size 300	0.52	0.14	2.59
Wild Bootstrap Automatic Variance Ratio Test with rolling window of size 500	0.11	0.1	0.38
General Spectral Test with rolling window of size 100	4.53	5.41	2.11
General Spectral Test with rolling window of size 300	8.73	11.5	1.29
Dominguez and Lobato Test based on Cramer-von Mises statistics with rolling window of size 100	9.58	8.05	15.36
Dominguez and Lobato Test based on Cramer-von Mises statistics with rolling window of size 300	4.43	4.33	3.02
Dominguez and Lobato Test based on Kolmogorov-Smirnov statistics with rolling window of size 100	11.83	10.14	16.72
Dominguez and Lobato Test based on Kolmogorov-Smirnov statistics with rolling window of size 300	7.73	8.24	3.45

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4. Conclusions

While there are some differences in the results of the four tests applied in this paper, the findings are consistent with the adaptive market hypothesis. Despite being a relatively new market, the Bitcoin market exhibits weak-form efficiency over extended periods with episodes of inefficiency which may be linked to global shocks, including the COVID-19 pandemic. This study does not attempt to explore any causative links but the inefficiency index shows that the market went through proportionately more frequent episodes of inefficiency as the pandemic ravaged the world. The empirical evidence is consistent with the concept of market efficiency as a time-varying characteristic and not as a static characteristic that remains fixed over time. Instead of describing the Bitcoin market as an inefficient market moving towards efficiency (Urquhart 2018), our empirical evidence supports the view that it is a market that exhibits time-varying efficiency and goes through extended episodes of inefficiency. The inefficiency index associated with all the tests except for the Generalized Spectral Test and one version of the Dominguez-Lobato Test went up after the onset of the COVID-19 pandemic. This suggests that the market went through proportionately longer and more frequent episodes of inefficiency as the pandemic ravaged the world. These findings are important from the perspective of traders, regulators, and researchers. For traders, evidence of market efficiency can be crucial in devising suitable trading strategies. The use of technical trading rules, for example, may be justified if the market goes through extended episodes of inefficiency. Regulators need to consider the efficiency characteristics of the cryptocurrency market to design an appropriate regulatory framework. For researchers, it contributes to the growing literature on the efficiency of cryptocurrency markets and the literature on the impact of the COVID-19 pandemic.

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