# The Impact of Financial Market Efficiency on Investment Decision-Making: An Econometric Study of the Bitcoin Market(2025–2016)

أثر كفاءة الأسواق المالية على اتخاذ القرارات الاستثمارية–دراسة قياسية لسوق البتكوين (2016–2025)

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***Abstract***:

This paper examines the impact of financial market efficiency on investment decision-making in the Bitcoin market over the period 2016–2025. It tests the Weak-Form Efficient Market Hypothesis (EMH) and investigates the causal relationship between returns and trading volume using daily data. A quantitative econometric framework is applied, incorporating unit root, autocorrelation, runs, BDS, variance ratio, and Granger causality tests.

The results reject weak-form efficiency, showing that Bitcoin returns display non-linear dependence and are partially predictable from past information. In addition, no significant causal relationship is found between returns and trading volume in either direction, indicating that short-term investment decisions are not driven by historical price movements. Overall, the findings suggest that the Bitcoin market remains in a transitional stage and has yet to attain full informational efficiency.

***Keys words***: **Financial Market Efficiency, Bitcoin, Random Walk Hypothesis, Investment Decision, Nonlinear Dynamics, Granger Causality**.

***JEL classification codes***: G14, G11, G15, C22

**ملخص**:

تتناول هذه الدراسة أثر كفاءة الأسواق المالية على اتخاذ القرارات الاستثمارية في سوق البيتكوين خلال الفترة 2016–2025. وتهدف إلى اختبار فرضية كفاءة السوق في صورتها الضعيفة، ودراسة العلاقة السببية بين العوائد وحجم التداول باستخدام بيانات يومية. ولتحقيق ذلك، تم اعتماد إطار اقتصادي قياسي كمي يشمل اختبارات جذر الوحدة، والارتباط الذاتي، واختبار الرُّتب Runs Test، واختبارBDSلعدم الخطية، واختبار نسبة التباين، واختبار سببية غرانجر.

تشير النتائج إلى رفض فرضية الكفاءة الضعيفة، حيث تُظهر عوائد البيتكوين اعتمادًا غير خطي وقابلية للتنبؤ استنادًا إلى المعلومات التاريخية. كما لم يتم التوصل إلى وجود علاقة سببية ذات دلالة إحصائية بين العوائد وحجم التداول في أي من الاتجاهين، مما يدل على أن القرارات الاستثمارية قصيرة الأجل لا تعتمد على تحركات الأسعار السابقة. وتخلص الدراسة إلى أن سوق البيتكوين لا يزال في مرحلة نضج ولم يحقق بعد الكفاءة المعلوماتية الكاملة.

**الكلمات المفتاحية:كفاءة السوق المالي، البيتكوين، فرضية السير العشوائي، القرار الاستثماري، الديناميكيات اللاخطية، سببية جرانجر.**

**تصنيف JEL:** G14, G11, G15, C22

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**Title:The Impact of Financial Market Efficiency on Investment Decision-Making**

## 1-Introduction

The global financial system is witnessing profound structural shifts with the rising role of cryptocurrencies as an investment asset class, where "Bitcoin" stands at the forefront as a financial asset sparking widespread debate between being a purely speculative tool or a potential safe haven(Kang, 2025). With the accelerated development of this market, the issue of "Market Efficiency" has become the cornerstone in guiding investment decisions, as it determines the extent to which investors can generate abnormal returns based on historical or public information.

The study of Bitcoin market efficiency gains particular importance in the period spanning from 2016 to 2025. This era witnessed pivotal events, ranging from multiple Halving cycles that tested market maturity(Veloso, 2025) , through global crises such as the COVID-19 pandemic, to the institutional recognition represented by the listing of Bitcoin Exchange-Traded Funds (ETFs) in 2024, which radically altered price discovery mechanisms(Mohamad, 2025).

This paper aims to analyze the impact of Bitcoin market efficiency on investment decision-making by examining the applicability of the Efficient Market Hypothesis (EMH) and the Adaptive Market Hypothesis (AMH) to this emerging market. The study discusses whether prices accurately reflect available information—preventing prediction—or if there are price deviations and anomalies that can be exploited for profit, particularly in light of recent technological and regulatory developments.

### ❖ Research Problem

In light of the rapid expansion of cryptocurrency markets—most notably the Bitcoin financial market—a broad scientific debate has emerged regarding the degree of efficiency of these markets and their ability to incorporate historical information into prices, particularly amid sharp volatility and heightened speculative activity. In this context, a fundamental question arises:

**Does the level of efficiency of the Bitcoin financial market genuinely affect investment decision-making, or do investor behavior and trading volume instead drive market dynamics?**

### ➢ Sub-Research Questions

Based on the main research problem, this study seeks to answer the following sub-questions:

- Do Bitcoin returns in the Bitcoin financial market exhibit stationarity and randomness in a manner that supports the weak-form market efficiency hypothesis?
- Are there linear or nonlinear patterns in Bitcoin returns that indicate the possibility of predictability based on historical information?
- Is there a statistically significant causal relationship between the efficiency of the Bitcoin financial market and investment decision-making as proxied by trading volume?

### ❖ Research Hypotheses

Based on the foregoing, the following hypotheses are formulated:

- **(H1):** Bitcoin returns in the Bitcoin financial market are stationary and random and do not exhibit statistically significant linear or nonlinear patterns, thereby supporting weak-form market efficiency.
- **(H2):** There is no statistically significant causal relationship from Bitcoin returns to trading volume, indicating a limited impact of Bitcoin market efficiency on investment decision-making.
- **(H3):** There is a statistically significant causal relationship from trading volume to Bitcoin returns, reflecting the influence of investors' behavioral actions on the dynamics of the Bitcoin financial market.

### ❖ Research Objectives

This study aims to achieve several key scientific objectives, including:

- ✓ Testing the degree of weak-form efficiency in the Bitcoin financial market using an integrated set of linear and nonlinear tests.
- ✓ Analyzing the statistical and dynamic properties of Bitcoin returns over the period 2016–2025.
- ✓ Examining the causal relationship between Bitcoin financial market efficiency and investment decision-making as represented by trading volume.
- ✓ Contributing to the literature on cryptocurrency markets from the perspectives of market efficiency and investor behavior.
- ✓ Providing empirical findings that assist investors and policymakers in understanding risk characteristics and trading dynamics in the Bitcoin financial market.

## ❖ Theoretical Framework

The theoretical framework of this study is based on the interaction between classical financial theory and modern trends in behavioral finance and digital markets.

### ➢ The Efficient Market Hypothesis (EMH)

The Efficient Market Hypothesis, formulated by(Fama, 1970), serves as the primary reference for understanding price behavior. In its "Weak-Form," the theory posits that current prices reflect all historical information; therefore, asset prices follow a "Random Walk," rendering the prediction of future returns based on past prices impossible. Although this hypothesis has proven valid in many traditional and Arab financial markets as indicated by(Al-Hamdooni, 2023), its application to the cryptocurrency market remains a subject of academic debate.

### ➢ The Adaptive Market Hypothesis (AMH)

Given the dynamic nature of the Bitcoin market, recent literature suggests the inadequacy of the traditional EMH in explaining the fluctuations of this market.(Tan, 2025) Tan and proponents of the Adaptive Market Hypothesis suggest that efficiency is not a static state, but rather "Time-Varying Efficiency."

According to this proposition, the market goes through periods of efficiency and inefficiency based on changing market conditions, such as liquidity levels, global financial stress, and crises(Mokni, 2024).

- **Efficiency Determinants and Investor Behavior**

The decision to invest in Bitcoin is influenced by several factors beyond traditional technical and fundamental analysis. These factors include "Financial Literacy," which plays a moderating role in the relationship between investor sentiment and market returns(Jahangir, 2025) . Furthermore, market structure and infrastructure development, such as institutional entry via ETFs, directly affect the quality of information and the speed of its reflection in prices, moving the market from a state of random speculation to a more mature and efficient stage (Mohamad, 2025)(Veloso, 2025).

## ❖ Literature Review

Previous studies addressing Bitcoin and cryptocurrency market efficiency have been categorized into three main axes: efficiency tests and predictive capability, the impact of structural events and market development, and the behavioral and economic determinants of efficiency.

- **First: Weak-Form Efficiency Tests and Price Predictability**

Empirical results vary regarding whether the Bitcoin market follows a random walk or is predictable.

In a recent study,(Wilinski, 2025) used polynomial autoregression tools and tested automated trading strategies. They concluded by rejecting the weak-form efficiency hypothesis, confirming the possibility of exploiting historical price information to generate profits, suggesting the market is not yet fully mature. Supporting this trend,(Özcan, 2024) tested for Calendar Anomalies and found significant effects for specific days of the week (such as Thursday and Saturday) and monthly effects, which contradicts the concept of full efficiency and provides arbitrage opportunities.

Conversely, other studies attempted to use advanced techniques to prove efficiency or the approach towards it. Krachenbuchl and(Krachenbuchl, 2022) used Neural Networks to predict Bitcoin prices using exogenous variables (such as gold and stocks) and concluded that these models could not outperform a "Buy-and-Hold" strategy, supporting the weak-form efficiency hypothesis. In a similar context, (Yi, 2023)applied a model derived from quantum physics (Quantum Harmonic Oscillator) and found that the Bitcoin market is gradually approaching the "Ground State," representing efficiency, especially as liquidity improves over time.

- **Second: The Impact of Structural Development and Major Events (Maturity and Institutionalization)**

A group of studies focused on the evolution of market efficiency over time, especially with the entry of institutional investors.

In a meta-analysis, (Tan, 2025)demonstrated that the Bitcoin market does not permanently adhere to efficiency; rather, its predictability increases in its

early stages and during times of crisis, while efficiency improves with maturity. This was confirmed by (Veloso, 2025)when studying "Halving" events, where they observed a gradual decrease in volatility and abnormal returns in the 2020 and 2024 cycles compared to previous cycles, reflecting increasing market maturity.

The most prominent turning point in market structure appeared in the study by(Mohamad, 2025), which analyzed the impact of the listing of Bitcoin ETFs in January 2024. Results showed that these funds began leading the Price Discovery process by 85%, rendering the spot market a follower, which is strong evidence of the market's transition towards higher efficiency due to institutional liquidity.

- **Third: Economic and Behavioral Determinants of Efficiency**

Studies did not stop at testing for the existence of efficiency but investigated its determinants. (Mokni, 2024)analyzed the drivers of efficiency and found that "Liquidity" enhances efficiency, while "Global Financial Stress" and the COVID-19 pandemic lead to increased inefficiency.

From a behavioral perspective, (Jahangir, 2025)studied the relationship between investor sentiment and Bitcoin returns in the Eurozone, finding that financial literacy increases the market's sensitivity to sentiment. Additionally, (Kang, 2025)provided a comprehensive survey classifying Bitcoin as an asset oscillating between being a high-risk speculative tool and a potential safe haven, emphasizing that its unique financial characteristics require valuation models different from traditional assets.

## ❖ Research Gap

Despite the significant research momentum addressing cryptocurrency market efficiency, existing literature suffers from shortcomings in three fundamental aspects that this study aims to address. First, most prior studies (e.g., (Krachenbuchl, 2022)) focused on testing the random walk hypothesis using traditional linear tools, while ignoring the complex "nonlinear" and "chaotic" nature characterizing modern crypto markets. Second, most research stops at diagnosing the market state (efficient or inefficient) without econometrically linking the degree of efficiency to actual investor behavior, represented by "trading volume," where efficiency is often treated as a variable isolated from decision-making dynamics. Third, both Arab and international literature lack studies covering the modern period extending up to 2025. This is a critical era witnessing radical structural shifts, such as the listing of Bitcoin ETFs and recent Halving cycles, rendering studies that stopped at 2022 or 2023 data incapable of providing an accurate picture of current market reality.

- **Study Contribution**

This study derives its importance and distinctiveness from several points:

- ✓ Recency of the Time Frame: The time series covers the period from 2016 to the end of 2025, providing a comprehensive analysis that captures the

latest structural shocks and regulatory developments, which previous studies have not addressed with the same level of comprehensiveness.

- ✓ Dual Methodology (Linear and Nonlinear): The study distinguishes itself by integrating linear stationarity and correlation tests with advanced tests to detect nonlinear structures (such as the BDS test), providing a more accurate diagnosis of the nature of Bitcoin return generation.
- ✓ Linking Efficiency to Decision-Making: The study goes beyond merely testing efficiency to investigate the causal relationship (Granger Causality) between market returns (as a proxy for price efficiency) and trading volume (as a proxy for investment decisions), offering a deeper understanding of how investors interact with historical information in this emerging market.

## 2. Methodology

### 2.1. Research Approach

This study adopts a quantitative econometric approach to analyze the impact of Bitcoin financial market efficiency on investment decision-making. This is achieved by examining the statistical and econometric properties of financial time series and testing dynamic and causal relationships among them. This approach is particularly suitable for such studies, given its ability to test market efficiency hypotheses and analyze investor behavior using actual quantitative data.

### 2.2. Data and Sources

The study relies on daily Bitcoin market data covering the period from January 1, 2016, to December 31, 2025, comprising a total of 3,652 observations. This sample size is sufficient to conduct market efficiency tests and causal analysis with a high degree of statistical accuracy.

The data include:

•Daily closing prices, used to compute returns.

•Daily trading volume, serving as a proxy for investment decision-making.

The data were obtained from specialized and reliable financial sources in cryptocurrency markets. The selected period is particularly appropriate, as it encompasses sharp volatility, financial crises, and phases of expansion and maturation, allowing for an in-depth dynamic analysis of Bitcoin market behavior under varying market conditions.

### 2.3. Definition of Study Variables

- ✓ **Independent Variable: Bitcoin Market Efficiency**

Bitcoin market efficiency is examined at the weak-form level through an analysis of Bitcoin returns, which reflect the extent to which prices respond to historical information.

Daily returns are calculated using the following logarithmic formula:

$$(r_t = \ln P_t - \ln P_{t-1})$$

- ✓ **Dependent Variable: Investment Decisions**

Investment decisions are proxied by daily trading volume, as it reflects the level of investor activity and the intensity of their interaction with market information. The trading volume series is transformed into its natural logarithmic form to reduce variance and improve the statistical properties of the time series.

### 2.4. Preliminary Data Treatment

Prior to econometric analysis, a natural logarithmic transformation is applied to both:Bitcoin returns,Trading volume

This transformation aims to:Reduce heteroskedasticity,Improve distributional properties, and Enhance linearity and econometric interpretability of economic relationships.

### 2.5. Financial Market Efficiency Tests

To test weak-form efficiency in the Bitcoin market, an integrated set of linear and nonlinear tests is employed as follows:

#### 2.5.1. Unit Root Tests (ADF and PP)

The Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests are used to examine the stationarity of the return series, as stationarity at level is a necessary condition for supporting the weak-form efficiency hypothesis.

#### 2.5.2. Autocorrelation Test

This test examines the presence of linear dependence among successive returns. The absence of autocorrelation indicates the inability to predict future returns based on past values.

#### 2.5.3. Runs Test

The Runs Test is applied to assess the randomness of returns without assuming normality, making it particularly suitable for cryptocurrency markets characterized by high volatility and instability.

#### 2.5.4. BDS Test

The Brock–Dechert–Scheinkman (BDS) test is used to detect nonlinear dependence and complex dynamic patterns in the time series and is considered an advanced tool for evaluating efficiency in modern financial markets.

#### 2.5.5. Variance Ratio Test

The Variance Ratio Test is employed to verify whether Bitcoin returns follow a random walk, which is a fundamental pillar of the weak-form market efficiency hypothesis.

### 2.6. Stationarity of Trading Volume

Before conducting causality analysis, the logarithmically transformed trading volume series is subjected to ADF and PP unit root tests to determine its order of integration and ensure the econometric validity of the causality testing framework.

### 2.7. Causality Analysis (Granger Causality Test)

To examine the impact of Bitcoin market efficiency on investment decision-making, the Granger Causality Test is used to identify the direction of causality between:

•Bitcoin returns ⟶ trading volume

•Trading volume ⟶ Bitcoin returns

This test seeks to determine whether market movements—reflecting price efficiency—precede investor decisions, or whether investor behavior drives the dynamics of the Bitcoin financial market.

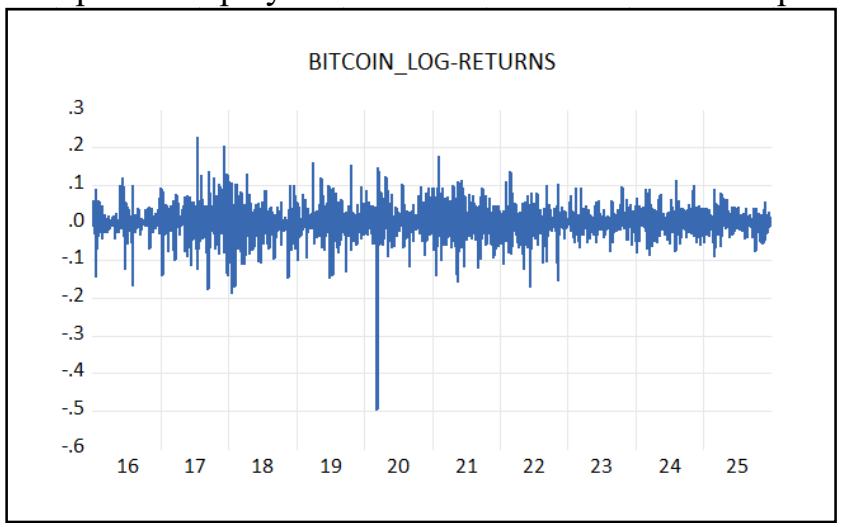
### 2.8. Analytical Tools

All statistical and econometric analyses are conducted using EViews 13, due to its advanced capabilities in financial time series analysis and its high level of accuracy and reliability.

## 3. Results

Before proceeding with econometric tests and specifying the statistical framework for measuring market efficiency, a preliminary visual inspection of daily closing price returns was conducted. This time series represents the main indicator of Bitcoin in the financial market. Data extracted from *investing.com* for the period 2016–2025 were transformed into daily returns using the logarithmic equation: ( $\boldsymbol{r_t = \ln P_t - \ln P_{t-1}}$)By computing the natural logarithm of the current closing price relative to the previous one, first-degree differencing was effectively applied to eliminate stochastic trend components, as illustrated in Figure (1).

**Figure 1:** Graphical display of bitcoin finance Market Index price returns**.**




**Source:** EViews line plot based on transformed bitcoin closing prices

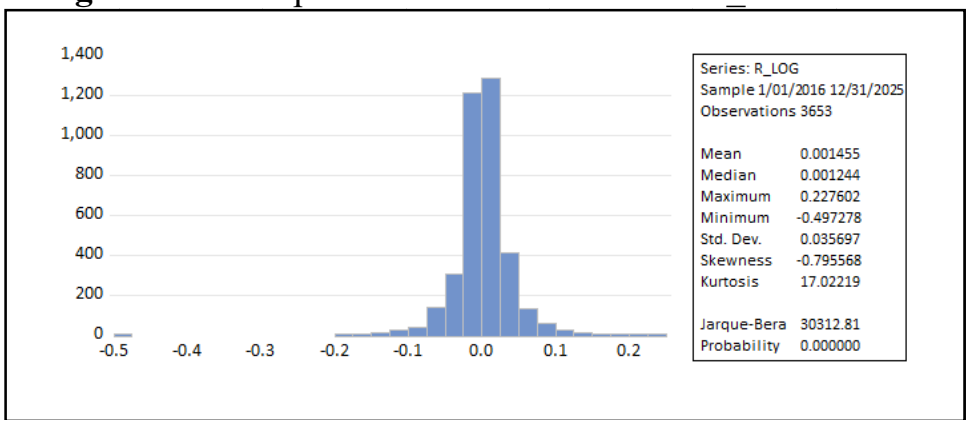
The graph in Figure (1) shows that Bitcoin logarithmic returns fluctuate around a zero mean, providing preliminary evidence of mean stability (mean reversion). However, the presence of volatility clustering is clearly observed, whereby

periods of large price changes tend to be followed by similar periods, and vice versa. Moreover, the existence of sharp spikes, particularly a large negative spike approaching –0.5, indicates the occurrence of strong shocks and outliers affecting market stability. This behavior is characteristic of high-risk financial markets.

### 3.1. Descriptive Statistics and Jarque–Bera Normality

The probabilistic distribution of stock returns constitutes a fundamental pillar of the Efficient Market Hypothesis, as the normal distribution is a key assumption of the Random Walk Model. For a distribution to be considered normal, skewness should equal zero and kurtosis should be equal or close to three. Figure (2) reports the normality test based on the null hypothesis , which assumes that the series follows a normal distribution, against the alternative hypothesis , which rejects this assumption.

**Figure 2:** Descriptive Statistics for BITCOIN_RETURNS.




**Source:** EViews histogram and summary statistics output for BITCOIN_RETURNS

The descriptive statistics in Figure (2) indicate that the time series does not follow a normal distribution:

- **Skewness:** The value of –0.795568 indicates negative skewness (a longer left tail), implying that large negative returns occur more frequently than predicted by a normal distribution.
- **Kurtosis:** The extremely high value of 17.02219 (far above 3) indicates a leptokurtic distribution, reflecting the presence of fat tails and a high probability of extreme values.
- **Jarque–Bera Test:** The test statistic is very large (30,312.81), with a probability value of 0.000000.

**Decision:** Since the p-value is less than 0.05, the null hypothesis is rejected. Consequently, Bitcoin returns are not normally distributed, violating one of the strict assumptions of the random walk model.

### 3.2. Unit Root Tests : ADF and Phillips–Perron Tests

Stationarity of returns ensures the stability of their statistical properties—such as the mean and unconditional variance—over time, providing a sound basis for autocorrelation, randomness, and martingale behavior tests that underpin weak-form market efficiency diagnostics, as emphasized by Fama (1991).

**Table 1 :** ADF and PP Unit-Root Tests for BITCOIN_RETURNS

| Variable | | 1st difference | | | Level | | |
|---|---|---|---|---|---|---|---|
| | | Intercept | Trend & Intercept | None | Intercept | Trend & Intercept | None |
| BITCOIN_RETURNS | ADF | -24.55321 (0.0000) | -24.54981 (0.0000) | -24.55661 (0.0000) | -63.22034 (0.0001) | -63.23932 (0.0000) | -63.11947 (0.0001) |
| | PP | -970.5597 (0.0001) | -970.4091 (0.0001) | -970.7172 (0.0001) | -63.15653 (0.0001) | -63.17496 (0.0000) | -63.06196 (0.0001) |

**Source:** EViews unit-root (ADF and PP) output for BITCOIN_RETURNS

- **ADF Test:**
  The t-statistics at level are extremely large in absolute value and negative (e.g., –63.22 for the model with a constant only), with a probability value of 0.0001.
- **PP Test:**
  Confirms the same conclusion with similarly large negative statistics and a probability value of 0.0001.

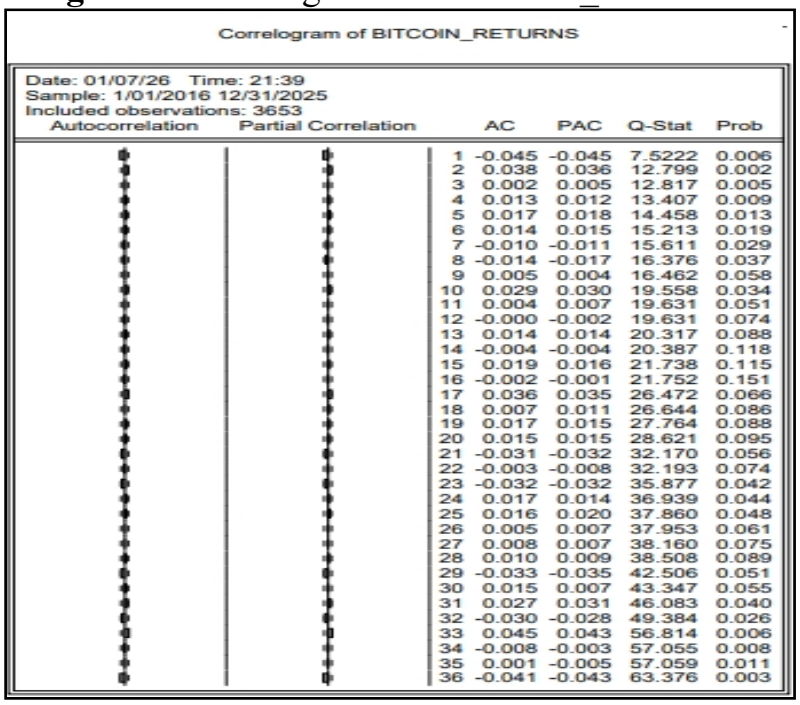
**Decision:**

Since the p-values are below 5%, the null hypothesis of a unit root is rejected. This indicates that the Bitcoin return series (BITCOIN_RETURNS) is stationary at level, i.e., integrated of order zero . While this is expected for return series, it is a necessary condition for subsequent tests but does not, by itself, confirm market efficiency.

### 3.3. Serial Correlation (ACF/PACF and Ljung-Box)

In this section, autocorrelation tests are employed to assess informational efficiency. These tests aim to determine whether the time series exhibits serial dependence, i.e., whether past values influence current returns. Under the random walk hypothesis, returns should be serially uncorrelated

**Figure 3:** Correlogram of BITCOIN_RETURNS




| | AC | PAC | Q-Stat | Prob |
|---|---|---|---|---|
| 1 | -0.045 | -0.045 | 7.5222 | 0.006 |
| 2 | 0.038 | 0.036 | 12.799 | 0.002 |
| 3 | 0.002 | 0.005 | 12.817 | 0.005 |
| 4 | 0.013 | 0.012 | 13.407 | 0.009 |
| 5 | 0.017 | 0.018 | 14.458 | 0.013 |
| 6 | 0.014 | 0.015 | 15.213 | 0.019 |
| 7 | -0.010 | -0.011 | 15.611 | 0.029 |
| 8 | -0.014 | -0.017 | 16.376 | 0.037 |
| 9 | 0.005 | 0.004 | 16.462 | 0.058 |
| 10 | 0.029 | 0.030 | 19.558 | 0.034 |
| 11 | 0.004 | 0.007 | 19.631 | 0.051 |
| 12 | -0.000 | -0.002 | 19.631 | 0.074 |
| 13 | 0.014 | 0.014 | 20.317 | 0.088 |
| 14 | -0.004 | -0.004 | 20.387 | 0.118 |
| 15 | 0.019 | 0.016 | 21.738 | 0.115 |
| 16 | -0.002 | -0.001 | 21.752 | 0.151 |
| 17 | 0.036 | 0.035 | 26.472 | 0.066 |
| 18 | 0.007 | 0.011 | 26.644 | 0.086 |
| 19 | 0.017 | 0.015 | 27.764 | 0.088 |
| 20 | 0.015 | 0.015 | 28.621 | 0.095 |
| 21 | -0.031 | -0.032 | 32.170 | 0.056 |
| 22 | -0.003 | -0.008 | 32.193 | 0.074 |
| 23 | -0.032 | -0.032 | 35.877 | 0.042 |
| 24 | 0.017 | 0.014 | 36.939 | 0.044 |
| 25 | 0.016 | 0.020 | 37.860 | 0.048 |
| 26 | 0.005 | 0.007 | 37.953 | 0.061 |
| 27 | 0.008 | 0.007 | 38.160 | 0.075 |
| 28 | 0.010 | 0.009 | 38.508 | 0.089 |
| 29 | -0.033 | -0.035 | 42.506 | 0.051 |
| 30 | 0.015 | 0.007 | 43.347 | 0.055 |
| 31 | 0.027 | 0.031 | 46.083 | 0.040 |
| 32 | -0.030 | -0.028 | 49.384 | 0.026 |
| 33 | 0.045 | 0.043 | 56.814 | 0.006 |
| 34 | -0.008 | -0.003 | 57.055 | 0.008 |
| 35 | 0.001 | -0.005 | 57.059 | 0.011 |
| 36 | -0.041 | -0.043 | 63.376 | 0.003 |

**Source:** EViews correlogram for BITCOIN_RETURNS.

The correlogram reveals the following:

- Several autocorrelation (AC) and partial autocorrelation (PAC) coefficients differ significantly from zero across multiple lags.
- The Ljung–Box Q-statistic probability values for all reported lags (from 1 to 36) are below the 5% significance level (e.g., 0.006 at lag 1 and 0.002 at lag 2).

**Decision:** The null hypothesis of no serial correlation is rejected. The presence of statistically significant autocorrelation implies that past returns partially predict future returns, indicating that the Bitcoin market is weak-form inefficient.

### 3.4. Runs Test of Randomness

Nonparametric tests do not rely on strict distributional assumptions, making them less sensitive to outliers and particularly effective in testing the random walk hypothesis. Among the most prominent are the Runs Test and the BDS test. The Runs Test examines the null hypothesis that the series follows a random process.

**Figure 4:** Runs Test for BITCOIN_RETURNS




**Source:** EViews runs-test output based on signs of BITCOIN_RETURNS.

- The reported probability value (associated with the test statistic) is 8.60E–05 (0.000086).

**Decision:** Since this value is far below 0.05, the null hypothesis is rejected. This implies that Bitcoin returns are not purely random, reinforcing the autocorrelation test results that indicate the presence of non-random patterns in price movements.

### 3.5. BDS Test for Nonlinear Dependence

The BDS test is a powerful tool for detecting nonlinear dependence in time series data. It is based on the null hypothesis that the series is independently and identically distributed (i.i.d.), against the alternative hypothesis of dependence.

**Figure 5:** BDS Test for BITCOIN_RETURNS

BDS Test for BITCOIN_RETURNS
Date: 01/07/26 Time: 21:49
Sample: 1/01/2016 12/31/2025
Included observations: 3653

| Dimension | BDS Statistic | Std. Error | z-Statistic | Prob. |
|---|---|---|---|---|
| 2 | 0.017409 | 0.001753 | 9.932484 | 0.0000 |
| 3 | 0.035093 | 0.002783 | 12.60867 | 0.0000 |
| 4 | 0.047045 | 0.003313 | 14.20149 | 0.0000 |
| 5 | 0.056279 | 0.003452 | 16.30499 | 0.0000 |
| 6 | 0.061131 | 0.003328 | 18.36902 | 0.0000 |

| | | | |
|---|---|---|---|
| Raw epsilon | 0.043365 | | |
| Pairs within epsilon | 9374903. | V-Statistic | 0.702534 |
| Triples within epsilon | 2.66E+10 | V-Statistic | 0.546516 |

| Dimension | C(m,n) | c(m,n) | C(1,n-(m-1)) | c(1,n-(m-1)) | c(1,n-(m-1))^k |
|---|---|---|---|---|---|
| 2 | 3405085. | 0.510758 | 4682628. | 0.702388 | 0.493349 |
| 3 | 2542039. | 0.381511 | 4679597. | 0.702318 | 0.346419 |
| 4 | 1932884. | 0.290248 | 4676587. | 0.702251 | 0.243203 |
| 5 | 1510693. | 0.226975 | 4673513. | 0.702174 | 0.170696 |
| 6 | 1203425. | 0.180908 | 4670422. | 0.702094 | 0.119777 |

**Source:** EViews BDS-test output for BITCOIN_RETURNS

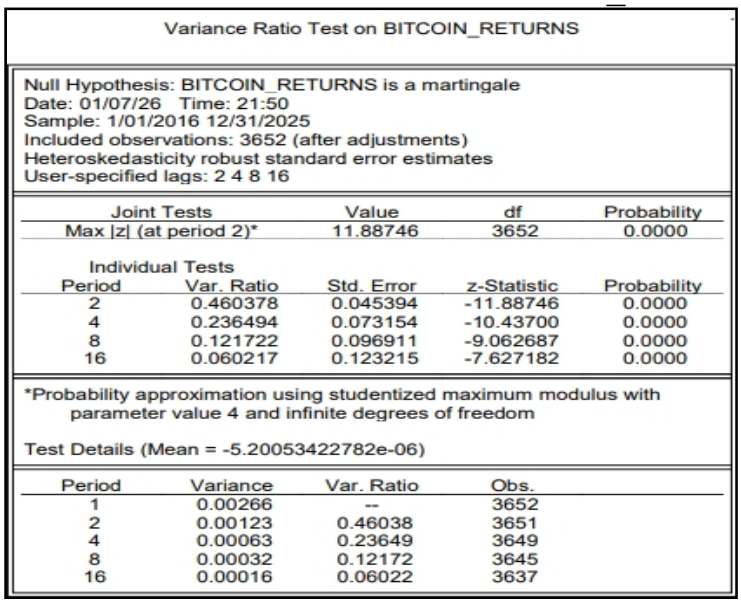
- The **z-statistics** are extremely high for all embedding dimensions (2–6), ranging from 9.93 to 18.36.
- All probability values equal 0.0000.

**Decision:** The null hypothesis is strongly rejected, indicating the presence of strong nonlinear dependence in Bitcoin returns. This suggests a chaotic or nonlinear structure not captured by simple linear models, further rejecting the assumption of pure randomness.

### 3.6. Variance-Ratio Test and the Martingale Property

- Variance Ratio (VR) tests are generally more robust than autocorrelation tests in assessing whether a time series follows a random walk. While autocorrelation measures linear dependence, the VR test compares the variance of multi-period returns to that implied by a linear benchmark.

**Figure 6:** Variance-Ratio Test on BITCOIN_RETURNS



Variance Ratio Test on BITCOIN_RETURNS

Null Hypothesis: BITCOIN_RETURNS is a martingale
Date: 01/07/26 Time: 21:50
Sample: 1/01/2016 12/31/2025
Included observations: 3652 (after adjustments)
Heteroskedasticity robust standard error estimates
User-specified lags: 2 4 8 16

| Joint Tests | Value | df | Probability |
|---|---|---|---|
| Max \|z\| (at period 2)* | 11.88746 | 3652 | 0.0000 |

Individual Tests

| Period | Var. Ratio | Std. Error | z-Statistic | Probability |
|---|---|---|---|---|
| 2 | 0.460378 | 0.045394 | -11.88746 | 0.0000 |
| 4 | 0.236494 | 0.073154 | -10.43700 | 0.0000 |
| 8 | 0.121722 | 0.096911 | -9.062687 | 0.0000 |
| 16 | 0.060217 | 0.123215 | -7.627182 | 0.0000 |

*Probability approximation using studentized maximum modulus with parameter value 4 and infinite degrees of freedom

Test Details (Mean = -5.20053422782e-06)

| Period | Variance | Var. Ratio | Obs. |
|---|---|---|---|
| 1 | 0.00266 | -- | 3652 |
| 2 | 0.00123 | 0.46038 | 3651 |
| 4 | 0.00063 | 0.23649 | 3649 |
| 8 | 0.00032 | 0.12172 | 3645 |
| 16 | 0.00016 | 0.06022 | 3637 |

**Source:** EViews variance-ratio output.

•The joint test reports a probability value of 0.0000.
•Individual tests for holding periods (2, 4, 8, and 16) also yield probability values of 0.0000.
•Variance ratio values are substantially below 1, declining from 0.46 to 0.06 as the holding period increases.

**Decision**: Since all probabilities are below 0.05, the null hypothesis that returns follow a martingale process is rejected. Variance ratios below unity typically indicate negative serial correlation (mean aversion) over short and medium horizons, confirming Bitcoin market inefficiency during the study period.

### 3.7. Stationarity of Trading Volume

Before conducting causality analysis, the logarithmically transformed trading volume series is subjected to ADF and PP unit root tests to determine its order of integration and ensure the econometric validity of the Granger causality framework.

**Table 2 :** ADF and PP Unit-Root Tests for trading volume

| Variable | | Level | | |
|---|---|---|---|---|
| | | **Intercept** | **Trend & Intercept** | **None** |
| **BITCOIN_RETURNS** | **ADF** | -14.49835 (0.0000) | -14.49734 (0.0000) | -14.50028 (0.0000) |
| | **PP** | -89.17960 (0.0001) | -89.16950 (0.0001) | -89.19520 (0.0001) |

**Source:** EViews unit-root (ADF and PP) output for trading volume

•ADF Test: The t-statistic at level is significantly negative (e.g., –14.49), with a probability value of 0.0000.

•PP Test: Confirms the same conclusion with a probability value of 0.0001.

**Decision**: Since the p-values are below 5%, the null hypothesis of a unit root is rejected. Therefore, the daily Bitcoin trading volume series is stationary at level , allowing the analysis to proceed with the Granger causality test.

### 3.8. Granger Causality Test

The Granger causality test is a central tool for understanding the dynamic interaction between market efficiency and investor behavior. It examines whether past values of Bitcoin returns (as a proxy for efficiency) help predict current trading volume (as a proxy for investment decisions), or vice versa.

**Figure 6:** Granger Causality Test for BITCOIN_RETURNS

Pairwise Granger Causality Tests
Date: 01/07/26 Time: 23:18
Sample: 1/01/2016 12/31/2025
Lags: 2

| Null Hypothesis: | Obs | F-Statistic | Prob. |
|---|---|---|---|
| BITCOIN_RETURNS does not Granger Cause VOL_LOG | 3651 | 0.99617 | 0.3694 |
| VOL_LOG does not Granger Cause BITCOIN_RETURNS | | 0.30224 | 0.7392 |

**Source:** EViews Granger Causality Test output for BITCOIN_RETURNS

- **Effect of returns on trading volume:**
  - BITCOIN_RETURNS do not Granger-cause VOL_LOG.
  - Probability value: 0.3694.
  - Interpretation: Since the p-value exceeds 0.05, the null hypothesis cannot be rejected. Statistically, changes in Bitcoin returns do not precede or explain changes in trading volume.
- **Effect of trading volume on returns:**
  - VOL_LOG does not Granger-cause BITCOIN_RETURNS.
  - Probability value: 0.7392.
  - Interpretation: Similarly, the null hypothesis cannot be rejected, indicating no causal effect from trading volume to returns.
- **Independence of investment decisions:**
  The results suggest a short-run statistical separation between price movements and trading activity. Investors' entry and exit decisions, as reflected in trading volume, do not directly depend on past daily returns.
- **Absence of feedback trading strategies:**
  The lack of causality from returns to volume rejects the presence of systematic "return-chasing" behavior, implying that investment decisions may be driven by other factors such as global news, regulatory developments, or macroeconomic shocks.

- **Confirmation of inefficiency from a different perspective:** Although earlier tests (e.g., autocorrelation and BDS) confirm market inefficiency through detectable patterns in returns, the causality results indicate that these patterns are not clearly exploited by investors to influence trading volume, or that the market absorbs such decisions without generating statistically detectable linear causality.

## 4. Discussion

Based on the empirical findings presented in the previous section, this part discusses the economic implications of the results and compares them with the theoretical framework and previous literature.

### 4.1. Interpreting Weak-Form Inefficiency

The results of the autocorrelation, Runs, and Variance Ratio tests collectively lead to the rejection of the Random Walk Hypothesis (RWH) for the Bitcoin market during the 2016–2025 period. The significant autocorrelation and the deviations of the variance ratio from unity indicate that Bitcoin prices do not adjust instantaneously to new information. Instead, the market exhibits "memory," where past price behaviors influence future trends.

These findings align with the conclusions of Wilinski et al. (2025) and Özcan et al. (2024), who confirmed the possibility of predicting returns based on historical patterns due to market anomalies. However, our results contradict the findings of Krachenbuchl and Osterrieder (2022) and Yi et al. (2023), who suggested that the market is approaching efficiency. This discrepancy can be attributed to the extended time frame of our study (up to 2025), which captures recent periods of high volatility and speculative institutional entry that may have reintroduced inefficiencies or "noise" into the pricing mechanism, supporting the view that market maturity does not follow a linear path.

### 4.2. Nonlinear Dynamics and Market Complexity

A key finding of this study is the strong rejection of the i.i.d. assumption by the BDS test, confirming the presence of nonlinear dependence in Bitcoin returns. This implies that the Bitcoin market is governed by complex, chaotic dynamics rather than simple linear relationships. This nonlinearity suggests that the market is highly sensitive to exogenous shocks—such as regulatory news or macroeconomic shifts—and that information is processed in a heterogeneous manner by investors. This supports the Adaptive Market Hypothesis (AMH) perspective discussed by Tan (2025), where market efficiency is not a static state but fluctuates based on market conditions and the intensity of speculative activity.

### 4.3. The Disconnect Between Efficiency and Investment Decisions

The Granger causality analysis revealed a notable absence of a causal relationship between Bitcoin returns and trading volume in either direction.

- **Returns not causing Volume:** This suggests that investors in the Bitcoin market, over the study period, did not systematically alter their trading volume based on past daily price movements. This could be interpreted as a sign that investment decisions are driven more by external factors—such as "Fear of Missing Out" (FOMO), global liquidity trends, or social media sentiment—rather than rational analysis of past price efficiency or technical patterns.
- **Volume not causing Returns:** The lack of feedback from volume to returns indicates that trading activity, despite its magnitude, does not immediately dictate price direction in a linear fashion. This challenges the assumption that higher liquidity (volume) automatically corrects price inefficiencies in the short run.

### 4.4. Synthesis

The combination of statistical inefficiency (predictability) and the lack of causality with trading volume paints a picture of a market that is structurally developing but behaviorally immature. While the price formation process contains exploitable patterns (inefficiency), the "average" investor decision-making process (proxied by volume) appears disconnected from these technical signals. This supports the notion that the Bitcoin market remains dominated by speculative behavior rather than information-based trading, even after the introduction of institutional vehicles like ETFs in 2024.

## 5. Conclusion

This study aimed to analyze the impact of financial market efficiency on investment decision-making in the Bitcoin market during the period spanning from 2016 to 2025, an era characterized by profound structural shifts and sharp volatility. By employing an econometric methodology combining linear and nonlinear tests with causality tests, the study reached a set of results and conclusions that answer the research problem and test the foundational hypotheses.

The empirical analysis results demonstrated a categorical rejection of the Weak-Form Efficient Market Hypothesis for the Bitcoin market. Autocorrelation and Runs Tests proved that Bitcoin returns do not follow a Random Walk; instead, they exhibit repetitive patterns and dependence between current and past prices. Furthermore, the BDS test reinforced this result by revealing strong Nonlinear Dependence, indicating that the market structure is characterized by complexity and Chaos that cannot be explained by traditional linear models. Accordingly, the first hypothesis (H1) was rejected, confirming that the Bitcoin market remains inefficient, offering the potential to generate abnormal returns by exploiting historical information.

Regarding the relationship between market efficiency and investment decisions, the Granger Causality test results revealed a fundamental finding: the absence of

a statistically significant causal relationship in either direction between Bitcoin returns and trading volume. This means price movements (reflecting efficiency) do not necessarily drive investor decisions (represented by volume) in the short run, nor does investor behavior directly explain changes in returns. This result supports the second hypothesis (H2), stating no causal effect from returns to trading volume, while leading to the rejection of the third hypothesis (H3).

This disconnect is attributed to the fact that Bitcoin investment decisions may be driven by factors outside the scope of historical price information, such as global news, regulatory developments, or pure Speculation not based on traditional technical analysis.

❖ **Recommendations:**

Based on the findings, the study recommends the following:

- **For Investors:** The necessity of exercising caution when relying on automated trading strategies or simple technical analysis, given the nonlinear and complex nature of Bitcoin returns, with a focus on risk management rather than merely chasing price patterns.
- **For Policymakers:** The need to develop regulatory frameworks that increase market transparency and curb manipulation, which may contribute to driving the market towards maturity and efficiency in the future.
- **For Researchers:** Expanding the research scope to include the "Adaptive Market Hypothesis" (AMH) as a more realistic alternative for explaining cryptocurrency dynamics, while studying the impact of behavioral factors (such as investor sentiment) as explanatory variables for trading decisions.

## 6. References

Al-Hamdooni, E. K. (2023). The relationship between the random walk of the returns of financial market indices and market efficiency: An analytical study of the indicators of a sample of Arab financial markets. *International Journal of Professional Business Review, 8(31)*, 1-28. doi: https://doi.org/10.26668/businessreview/2023.v8i3.663

Fama, E. F. (1970). Efficient capital markets: A review of theory and empirical work. *The Journal of Finance, 25(2)*, 383–417. doi: https://doi.org/10.2307/2325486

Jahangir, R. T. (2025). Financial literacy, investor sentiment, and Bitcoin returns: Panel evidence from the Eurozone . *Borsa Istanbul Review, 25(1)*, 73–86. doi:https://doi.org/10.1016/j.bir.2025.09.006

Kang, D. R. (2025). Bitcoin as a financial asset: A survey. *Financial Innovation, 11*, 101. doi: https://doi.org/10.1186/s40854-025-00773-0

Krachenbuchl, M. &. (2022). The efficient market hypothesis for Bitcoin in the context of neural networks. *arXiv preprint arXiv:2208.07254*. Retrieved from https://arxiv.org/abs/2208.07254

Mohamad, A. (2025). Do Bitcoin ETFs lead price discovery following their introduction in the Bitcoin market? *Computational Economics, 66*, 947–969. doi: https://doi.org/10.1007/s10614-025-10998-x

Mokni, K. E. (2024). On the efficiency and its drivers in the cryptocurrency market: The case of Bitcoin and Ethereum. *Financial Innovation, 10*, 39. doi:https://doi.org/10.1186/s40854-023-00566-3

Özcan, R. K. (2024). Whether the crypto market is efficient? Evidence from testing the validity of the efficient market hypothesis. *Bulletin of Monetary Economics and Banking, 27(1)*, 113–132. doi:https://doi.org/10.59091/2460-9196.2227

Tan, K. H. (2025). Is Bitcoin an efficient market? A meta-analytic review of price dynamics and efficient market hypothesis tests. *Singapore University of Social Sciencesre University of Social Sciences. ResearchGate.*

Veloso, V. G. (2025). Is Bitcoin's market maturing? Cumulative abnormal returns and volatility in the 2024 halving and past cycles. *Journal of Risk and Financial Management, 18-5*, 242. doi: https://doi.org/10.3390/jrfm18050242

Wilinski, A. K. (2025). Assessing weak form information efficiency in cryptocurrency market using polynomial autoregression tools. Quality & Quantity. *Advance online publication*. doi: https://doi.org/10.1007/s11135-025-02390-6

Yi, E. Y. (2023). - Yi, E., Yang, B., Jeong, M., Sohn, S., & Ahn, K. (2023). Market efficiency of cryptocurrency: Evidence from the Bitcoin market. *Scientific Reports, 13, 4789.* doi:https://doi.org/10.1038/s41598-023-31618-4