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Sustainable Financial Markets in the Digital Era: FinTech, Crowdfunding and ESG-Driven Market Efficiency in the UK

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Abstract

In the context of tightening sustainability regulations and rising demands for transparent and responsible capital allocation, understanding how digital financial innovations influence market efficiency has become increasingly important. This study examines the impact of Financial Technology (FinTech) solutions and crowdfunding platforms on sustainable market efficiency, volatility dynamics, and risk structures in the United Kingdom. Using weekly data for the Financial Times Stock Exchange 100 (FTSE 100) index from January 2010 to June 2025, the analysis applies the Lo–MacKinlay variance ratio test to assess compliance with the Random Walk Hypothesis as a proxy for informational efficiency. Firm-level proxies for FinTech and crowdfunding activity are constructed using the Nomenclature of Economic Activities (NACE) and Standard Industrial Classification (SIC) systems. The empirical results indicate substantial deviations from random-walk behavior in crowdfunding-related market segments, where persistent positive autocorrelation and elevated volatility reflect liquidity constraints and informational frictions. By contrast, FinTech-dominated segments display milder inefficiencies and faster information absorption, pointing to more stable price-adjustment mechanisms. After controlling for structural distortions through heteroskedasticity-consistent corrections and volatility adjustments, variance ratios converge toward unity, suggesting a restoration of informational efficiency. The results provide relevant insights for investors, regulators, and policymakers seeking to align financial innovation with the objectives of sustainable financial systems.

Keywords: ESG; sustainable finance; green FinTech; climate risk; financial inclusion; regulatory compliance; sustainable innovation; market efficiency

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1. Introduction

The efficiency of financial markets remains a central concept in financial economics, as it underpins capital allocation, price discovery, and the reduction in transaction costs and information asymmetries [1–3]. In its conventional interpretation, market efficiency refers to the extent to which asset prices fully and promptly incorporate all available information, ensuring that prices reflect fundamental values. This concept is formally grounded in the Efficient Market Hypothesis (EMH), which posits that financial markets process information efficiently, limiting the possibility of systematic abnormal returns. In contemporary financial systems, efficiency is increasingly evaluated not only in terms of

short-term price responsiveness but through its contribution to market stability, resilience, and sustainable risk management.

Rapid technological progress and accelerated digitalization have increased the complexity of financial market structures, raising new questions about how financial innovations influence efficiency, volatility, and systemic risk dynamics [4]. At the same time, technological transformation has become closely intertwined with sustainability imperatives. The digitalization of finance supports the transition toward environmentally and socially responsible financial systems by enhancing transparency, accountability, and traceability in capital allocation processes [3,5]. These developments reflect a growing integration between financial innovation and sustainability frameworks, in which FinTech solutions and crowdfunding platforms are increasingly recognized as catalysts for inclusive, resilient, and green economic growth.

Globalization and digitalization have profoundly transformed financial markets, bringing emerging technologies such as crowdfunding and Financial Technology (FinTech) to the forefront [6]. Crowdfunding can be defined as an alternative financing mechanism that enables firms, entrepreneurs, and innovators to raise capital directly from a large number of individual investors, typically through digital platforms, often supporting projects with social, environmental, or community-oriented objectives [7]. Financial Technology (FinTech) refers to the application of advanced digital technologies to the design and delivery of financial services, encompassing innovations such as electronic payment systems, robo-advisory services, distributed-ledger technologies, and data-driven financial analytics [8]. Beyond their technological novelty, these innovations have altered how financial systems allocate capital, manage risk, and support sustainability-oriented objectives. By reducing entry barriers and broadening market participation, crowdfunding and FinTech reshape traditional efficiency dynamics while influencing the inclusiveness, transparency, and long-term stability of financial markets [9].

The United Kingdom occupies a central position in the global financial landscape due to its advanced and well-regulated ecosystem for both crowdfunding and FinTech. The Financial Conduct Authority (FCA) was among the first regulators to introduce comprehensive frameworks for crowdfunding platforms, enhancing investor protection, market integrity, and systemic stability. This regulatory environment has facilitated the development of platforms such as Seedrs and Crowdcube, which have transformed access to finance for start-ups and SMEs [10]. More broadly, the UK's regulatory architecture has supported financial innovation while mitigating excessive risk-taking, thereby providing a suitable institutional context for examining how digital financial infrastructures contribute to sustainable market functioning.

The UK's FinTech ecosystem plays a strategic role in advancing sustainable finance. Through initiatives such as the Green Finance Strategy and the transposition of the Corporate Sustainability Reporting Directive (CSRD), policymakers encourage the use of digital financial technologies to enhance ESG disclosure, improve the quality of sustainability data, and facilitate green investment [11]. This regulatory convergence between FinTech innovation and sustainability policy provides an institutional environment in which digital finance is explicitly leveraged to support transparency, accountability, and long-term value creation [12–14]. As a result, the United Kingdom offers a particularly suitable setting for empirically examining how digitally enabled financial infrastructures influence market efficiency, risk dynamics, and sustainability-oriented outcomes.

Beyond technological progress and financial innovation, digitalization supports the transition toward sustainable finance. Crowdfunding channels capital toward start-ups that frequently pursue green, social, or community-oriented projects, while FinTech solutions enhance environmental, social, and governance (ESG) transparency through data-driven

reporting, blockchain-based verification, and regulatory technologies (RegTech). These developments align with the European Green Deal, the UK's Green Finance Roadmap, and the UN Sustainable Development Goals (SDGs)—particularly Goals 8 (Decent Work and Economic Growth), 9 (Industry, Innovation and Infrastructure), and 13 (Climate Action)—by promoting inclusive, transparent, and responsible financial ecosystems. In this regard, the digital transformation of finance is not only an efficiency driver but a vector of sustainability, shaping the governance and resilience of modern markets.

From this perspective, market efficiency acquires a sustainability-oriented interpretation. Beyond its traditional role in explaining price formation, empirical research has shown that higher levels of informational efficiency are associated with improved shock absorption, lower volatility persistence, and more stable return dynamics in developed financial markets. Studies examining equity markets in advanced economies document that efficient markets tend to adjust more rapidly to new information, thereby limiting prolonged mispricing and reducing systemic vulnerability [10,14–17]. In this sense, efficiency metrics commonly employed in financial economics can be interpreted as operational indicators of sustainable risk management, reflecting the resilience and adaptability of financial systems under changing market conditions. Within digitally enabled markets, these characteristics become particularly relevant, as rapid information dissemination and technology-driven trading mechanisms may either enhance or undermine efficiency depending on market structure and liquidity conditions.

For the purposes of this analysis, sustainable risk management denotes the capacity of financial markets to absorb shocks, allocate capital efficiently, and maintain stability over long horizons while supporting environmental, social, and governance (ESG) objectives. Similarly, digital financial ecosystems are defined as interconnected market structures composed of FinTech infrastructures, crowdfunding platforms, regulatory technologies, and data-driven financial services, which collectively shape information flows, liquidity conditions, and risk transmission mechanisms. These concepts are used throughout the paper to functionally link informational efficiency, volatility dynamics, and market resilience to sustainability outcomes in digitally enabled financial markets.

At the same time, the integration of digital finance into sustainability frameworks extends beyond transparency and access to capital. Digital infrastructures modify how environmental and social risks are priced, accelerate the flow of sustainability-aligned information, and create new channels for financing low-carbon innovation [1,4]. FinTech-based analytics support more reliable ESG scoring, while crowdfunding enables community-driven funding of circular-economy and social-impact projects [5]. Embedding these mechanisms into the functioning of the UK financial system places digital finance at the core of the transition toward resilient and climate-aligned markets. Thus, evaluating whether these digital ecosystems generate more stable, efficient, and sustainable return dynamics is important for understanding their systemic contribution to sustainable development [6,7].

Although there is a large literature examining the efficiency of financial markets, few studies have investigated in depth how crowdfunding and Financial Technology (FinTech) innovations directly influence market efficiency [1,12–14]. Most previous research has focused on traditional financial markets or has examined digital finance in isolation, without explicitly considering the distinct effects of crowdfunding and FinTech on market dynamics, information processing, volatility behavior, and risk structures [15–17]. Moreover, existing studies rarely integrate market efficiency analysis with sustainability considerations, despite the growing importance of sustainable finance in advanced economies [8,11]. These gaps in the literature justify the need for dedicated empirical investigations that assess how different digital financing models reshape efficiency dynamics within well-developed and innovation-oriented financial systems.

Nonetheless, despite the increasing recognition of sustainable finance as a strategic global priority, the specific mechanisms through which FinTech and crowdfunding contribute to sustainability goals remain underexplored. The intersection between digitalization and sustainability calls for empirical studies that assess whether efficiency improvements in digital financial ecosystems translate into more responsible investment behaviors, enhanced ESG compliance, and reduced systemic risks. Addressing this gap provides both theoretical relevance and policy value, especially in the context of evolving sustainability regulations.

This study contributes to the literature by integrating emerging digital financial technologies into the broader framework of market efficiency analysis. In recent years, crowdfunding platforms and Financial Technology (FinTech) solutions have not only diversified access to financial resources but have transformed the mechanisms through which information is processed, capital is allocated, and liquidity is generated in financial markets. These innovations have introduced new patterns of participation, reduced traditional intermediation, and accelerated the diffusion of financial information. By situating these dynamics within a rigorous empirical design, the study provides an updated and nuanced perspective on the relationship between technological innovation and market efficiency.

At the same time, the contribution of this research extends beyond the empirical evidence itself. The paper highlights three interrelated dimensions that collectively frame its originality: the focus on the United Kingdom, recognized as one of the most advanced and well-regulated financial ecosystems for both crowdfunding and FinTech; the explicit integration of these digital financial technologies into the assessment of informational efficiency, thereby addressing a gap in prior literature that has largely centered on traditional markets; and the methodological refinement, which adapts classical statistical tools to account for distortions and dynamics specific to digitalized markets. Considering the cumulative evidence, these elements position the study as a meaningful addition to existing scholarship, directly engaging with the question of how financial digitalization redefines the architecture of efficiency and risk in contemporary markets.

Building on this context, the paper addresses a clear gap in prior research: while most studies have examined either traditional financial markets or isolated facets of digital finance, systematic comparative analyses of crowdfunding and Financial Technology (FinTech) ecosystems within a unified empirical framework remain scarce. By combining firm-level proxies derived from NACE and SIC [18,19] with Financial Times Stock Exchange 100 (FTSE 100) index data [20] and applying the Lo–MacKinlay variance ratio test [21], the study introduces an empirical design that allows for a differentiated assessment of how distinct digital financing models influence market efficiency and risk dynamics. The primary objective of this study is to examine how FinTech technologies and crowdfunding platforms affect informational efficiency, volatility behavior, and risk structures in the United Kingdom's equity market from a sustainability-oriented perspective. Accordingly, the analysis is guided by the following research questions:

RQ1: Do FinTech- and crowdfunding-related market segments exhibit different levels of informational efficiency?

RQ2: How do these digital financing models differ in terms of volatility dynamics and risk persistence?

RQ3: To what extent can observed efficiency patterns be interpreted as indicators of sustainable risk management in digitally enabled financial markets?

In sustainability terms, understanding these asymmetries informs how digital finance can support the broader transition toward low-carbon and inclusive economic models. The comparative analysis of FinTech and crowdfunding ecosystems contributes to identifying which digital infrastructures are more conducive to sustainable risk management

and long-term market stability. Hence, the study not only advances the debate on informational efficiency but situates it within the ongoing transformation toward sustainable financial architectures.

Altogether, these considerations position the present study within the sustainability literature rather than solely within financial market analysis. By treating market efficiency and volatility dynamics as functional dimensions of sustainable risk management, the paper adopts a sustainability-oriented analytical perspective that uses established financial tools to evaluate the resilience, transparency, and long-term stability of digital financial ecosystems.

The remainder of the paper is organized to ensure a coherent progression of ideas and a transparent research logic. Section 2 reviews the most relevant contributions from the existing literature and establishes the theoretical foundation of the study. Section 3 outlines the methodological framework, detailing the efficiency tests, volatility modeling approach, and sustainability-oriented interpretation adopted in the analysis. Section 4 describes the dataset, index construction, and key descriptive statistics that support the empirical investigation. Section 5 discusses the empirical results in relation to market efficiency, risk dynamics, and sustainable risk management, while Section 6 synthesizes the main findings and highlights the theoretical, practical, and policy implications. Together, these sections provide a coherent analytical framework that clarifies the study's research process, empirical strategy, and underlying reasoning.

2. Literature Review

The theoretical foundation of this study is rooted in the Efficient Market Hypothesis (EMH) which posits that financial markets are informationally efficient when asset prices fully and instantaneously reflect all available information. Under this framework, price changes follow a random process, implying that systematic abnormal returns cannot be consistently achieved using publicly available data. Despite the United Kingdom's advanced and highly regulated financial ecosystem, early empirical investigations into market efficiency have largely focused on traditional equity markets, with limited attention paid to sustainability-oriented outcomes.

Foundational studies, such as those of Dimson [22] and LeRoy [23], examined liquidity conditions, institutional trading behavior, and deviations from random price movements, providing an early empirical basis for understanding market dynamics. However, these classical approaches were developed in a period when digitalization, sustainability considerations, and ESG-oriented financial practices were not yet embedded in market functioning, thereby overlooking the transformative role of emerging financial technologies in shaping contemporary efficiency patterns. Empirical studies on the UK equity market generally document weak- to semi-strong form efficiency, while identifying episodic deviations linked to liquidity conditions and structural changes, particularly during periods of financial innovation and regulatory reform [10,14].

Within the framework of the Efficient Market Hypothesis (EMH), market efficiency is commonly classified into three forms: weak, semi-strong, and strong efficiency, depending on the type of information reflected in asset prices [23]. Weak-form efficiency implies that current prices fully incorporate information contained in historical price movements, rendering technical trading strategies ineffective. Semi-strong efficiency extends this concept by asserting that prices reflect all publicly available information, including financial statements, regulatory disclosures, and sustainability-related reports, thereby limiting the potential for abnormal returns based on public data [4,8]. Strong-form efficiency represents the most restrictive case, in which prices are assumed to incorporate all information, both public and private, including insider knowledge.

Empirical evidence from developed financial markets largely supports weak- and semi-strong forms of efficiency, while strong-form efficiency is rarely observed in practice [3,22,23]. From a sustainability perspective, semi-strong efficiency is particularly relevant, as it captures the extent to which publicly disclosed environmental, social, and governance (ESG) information is rapidly and accurately incorporated into market prices. In this context, FinTech and crowdfunding are increasingly recognized as enablers of sustainable finance by improving data transparency, democratizing access to investment opportunities, and fostering accountability in financial decision-making [4,5].

A core theoretical implication of the Efficient Market Hypothesis is the Random Walk Hypothesis (RWH), which posits that successive price changes are independent and identically distributed, making future price movements unpredictable based on past information. Under the random walk framework, asset prices respond only to new and unanticipated information, implying that historical price patterns cannot be systematically exploited to generate abnormal returns [21,23].

The later contributions by Lo and MacKinlay [21] formalized statistical tests to evaluate deviations from random walk behavior, establishing a methodological foundation for assessing informational efficiency in financial markets. Empirical evidence suggests that deviations from the random walk process are more likely to emerge in markets characterized by limited liquidity, high volatility, or structural frictions, where information diffusion is imperfect [22,23]. Consequently, the random walk framework provides a critical benchmark for evaluating whether emerging financial technologies enhance or undermine market efficiency by altering the speed and quality of information incorporation into prices. Persistent deviations from the random walk can be interpreted as indicators of structural frictions or information asymmetries that impede the efficient allocation of capital toward long-term, responsible investment objectives.

On the other hand, studies such as that of Zetzsche et al. [24] highlight how financial technologies, including blockchain and digital payment systems, are transforming global financial markets in ways that extend beyond efficiency gains. While the random walk framework provides a benchmark for assessing informational efficiency, recent research suggests that digital financial innovations may reshape market outcomes through structural and sustainability-oriented channels. In line with sustainability principles, the impact of FinTech and crowdfunding can be assessed not only through reduced transaction costs and increased liquidity but through their capacity to improve access to finance for small and medium-sized enterprises, foster inclusive growth, and support responsible capital allocation. These characteristics position digital financial technologies as structural components of sustainable financial systems rather than merely efficiency-enhancing tools.

These mechanisms extend beyond efficiency to support ESG-aligned outcomes. Digital payment systems and peer-to-peer financing models reduce the carbon footprint associated with traditional banking operations, while blockchain and smart contracts enhance traceability in green investments [8,24]. By lowering intermediation barriers and increasing transparency, FinTech contributes to sustainable market efficiency, where capital is allocated not only efficiently but responsibly. From a market efficiency perspective, these transparency-enhancing mechanisms are expected to influence informational efficiency by accelerating the incorporation of sustainability-related information into asset prices.

Recent studies emphasise that digital financial technologies increasingly function as enablers of sustainable transformation [3,4,11]. Platforms integrating AI-driven ESG analytics improve data comparability and enhance green-investment screening accuracy, while distributed-ledger verification strengthens accountability in impact-finance markets. These mechanisms create what scholars describe as “sustainable digital financial ecosystems”, where informational efficiency, social inclusion, and ecological alignment reinforce each

other. Such ecosystems provide a conceptual bridge between informational efficiency, sustainability objectives, and the adaptive behavior of digitally enabled markets.

The UK stands out from other countries in that its FinTech ecosystem is supported by both progressive regulation and initiatives such as UK FinTech Week [25], which encourage innovation. Although, unlike more conservative markets such as Germany, the accelerated adoption of technologies has also created new risks, including regulatory issues for international platforms. To place the United Kingdom's experience in an international context, Table 1 summarizes comparative evidence on how FinTech and crowdfunding technologies influence market efficiency across eight representative developed and emerging economies, namely the United Kingdom, the United States, Germany, France, China, India, Australia, and Canada.

Table 1. Comparative analysis of the impact of Crowdfunding and FinTech on the efficiency of financial markets.

Country	Background	Relevant Studies	Conclusions on Market Efficiency
United Kingdom	Global leader in FinTech regulation and adoption	[26,27]	Markets are more liquid and transparent thanks to FinTech
United States	Dominates through large crowdfunding platforms	[12,28]	More efficient in traditional markets than in digital ones
Germany	Slow adoption of FinTech, supported by BaFin	[14,29]	Market efficiency is affected by slow implementation
France	Early regulation of crowdfunding	[30,31]	Crowdfunding has improved market liquidity
China	Huge FinTech ecosystem, strict regulations	[6]	High volatility reduces market efficiency
India	Rapid growth thanks to IndiaStack and UPI	[16,32]	Digitalization has increased access to finance
Australia	Active regulation by ASIC	[33]	Markets are efficient, but affected by geographical isolation

Each of these countries has a distinct approach to the adoption and regulation of FinTech solutions and crowdfunding platforms, thereby influencing the efficiency of markets through factors such as accessibility, liquidity, and transparency. The cross-country differences motivate a focused empirical assessment of whether digitally enabled financial models generate heterogeneous efficiency and risk patterns within the UK context.

These factors have direct implications for sustainability and sustainable risk management. Greater liquidity and accessibility facilitate inclusive finance, ensuring that capital reaches socially responsible enterprises and small innovators while reducing concentration and exclusion risks. Enhanced transparency supports regulatory compliance with sustainability reporting standards such as the EU's CSRD and strengthens the reliability of ESG disclosures, thereby mitigating informational and governance-related risks. From this perspective, the relationship between FinTech adoption and sustainability emerges as a dual driver of both market efficiency and long-term financial resilience, linking efficiency gains to sustainable transformation rather than short-term performance [1,11,26].

In comparison, in the United States, crowdfunding platforms such as Kickstarter and Indiegogo have been studied more intensively, but the focus has been more on the success of the campaigns and less on the influence on the capital market [12]. By comparison, in emerging economies such as India and China, Cheng and Qu [6] have highlighted the risks associated with less rigorous regulation and market fragmentation. The United

Kingdom, due to its regulatory framework and stable ecosystem, provides an ideal basis for international comparisons and in-depth studies of market efficiency. In Germany, the adoption of FinTech was initially slower, but regulations introduced by BaFin recently have supported accelerated development. Hornuf and Schwienbacher [14] investigated how information transparency influences the success of crowdfunding campaigns, concluding that the high level of reporting required by German authorities contributes to strengthening investor confidence. The Bundesbank [29] shows that FinTech has had a positive impact on SMEs' access to financial services, improving market liquidity.

France has been adopting crowdfunding regulations since 2014, becoming one of the European leaders in this field. The study by Belleflamme et al. [30] highlights the importance of platforms such as Ulule, which mainly support cultural and social projects, contributing to the diversification of the financing market. ACPR [31] highlights that financial inclusion has been significantly improved by FinTech, especially among SMEs and technology start-ups. Even so, unlike the United Kingdom, its FinTech ecosystem is more dependent on government support.

International evidence indicates that the sustainability impact of FinTech and crowdfunding depends critically on regulatory quality, transparency standards, and institutional maturity. Financial systems that align digital innovation with sustainability-oriented governance frameworks tend to achieve efficiency improvements that translate into long-term market resilience, inclusive growth, and more stable risk structures. By contrast, fragmented or weakly regulated environments are more exposed to volatility persistence, informational frictions, and systemic vulnerabilities, limiting the capacity of digital finance to support sustainable financial development.

Although many existing studies have focused on the benefits of emerging financial technologies, the extent of risk associated with these instruments remains an insufficiently in-depth research direction in relation to the pace of global implementation [8,11]. Crowdfunding, especially in its equity and peer-to-peer lending forms, involves high levels of uncertainty regarding the quality of information provided to investors, but in the validity of promises of future profitability. Cumming et al. [34] show that information asymmetry is accentuated in the context of digital platforms, where reduced transparency and the lack of robust due diligence mechanisms can lead to suboptimal decisions and significant losses for individual investors.

From a theoretical perspective, these observed inefficiencies and risk patterns can be explained through the lens of Behavioral Finance (BF), which challenges the assumption of fully rational investors underlying the Efficient Market Hypothesis [35–37]. Behavioral finance emphasizes the role of cognitive biases, heuristics, and investor sentiment in shaping market outcomes, particularly in environments characterized by information asymmetry and limited institutional oversight [38,39].

Empirical research shows that retail investors—who dominate participation in crowdfunding platforms—are especially prone to behavioral biases such as overconfidence, herding behavior, and loss aversion, which can lead to systematic mispricing and excess volatility [40,41]. In digitally mediated financial markets, rapid information diffusion and social interaction effects may amplify these behavioral distortions, reinforcing short-term deviations from informational efficiency. As a result, behavioral finance provides a complementary framework for understanding why crowdfunding-related market segments may exhibit persistent inefficiencies despite technological advances intended to enhance transparency and access to information.

While Behavioral Finance explains the emergence of inefficiencies through investor psychology and bounded rationality, it does not fully account for the dynamic nature of market adaptation over time. To reconcile the apparent tension between the Efficient

Market Hypothesis and behavioral perspectives, Lo [42] proposed the Adaptive Market Hypothesis (AMH), which views market efficiency as an evolving, context-dependent process rather than a static condition.

According to the AMH, financial markets may alternate between periods of relative efficiency and inefficiency depending on changing market environments, competitive pressures, regulatory conditions, and technological innovation. Market participants learn and adapt through an evolutionary process, implying that strategies yielding abnormal returns in one period may lose effectiveness as conditions change. This framework is particularly relevant for digitally enabled financial markets, where FinTech innovations and crowdfunding platforms continuously reshape information flows, liquidity conditions, and investor behavior. From this perspective, deviations from the Random Walk Hypothesis in crowdfunding-related segments may reflect transitional phases of adaptation, while more mature FinTech infrastructures may exhibit faster convergence toward informational efficiency. The AMH therefore provides a unifying theoretical framework for interpreting heterogeneous efficiency patterns across digital financial ecosystems within a sustainability-oriented market context.

In parallel, FinTech, despite its accelerated progress, generates a spectrum of new risks related to cybersecurity, dependence on automated decision-making algorithms, and fragmentation of the traditional financial market. Zetzsche et al. [26] point out that the rapid integration of digital technologies into financial processes without adequate synchronization between innovation and regulation can create grey areas in market oversight. These risks are not limited to individual actors but can affect systemic stability, especially when technology platforms take on a central role in the provision of credit or in the management of funds.

Beyond traditional debates on informational efficiency, recent studies explore how digital financial ecosystems can foster sustainable market outcomes. FinTech applications improve the quality and availability of ESG data through AI-based analytics, digital disclosures, and RegTech tools that automate compliance monitoring [3]. Crowdfunding platforms, particularly those supporting renewable energy or social entrepreneurship, have become vehicles for sustainable finance by connecting investors directly with green and impact-oriented projects [35]. This alignment between digital innovation and sustainability reshapes the concept of efficiency: markets are considered efficient not only when they incorporate information rapidly, but also when they channel resources toward long-term environmental and social value creation.

A particularly relevant issue in the context of developed markets, such as the United Kingdom, is the tension between the efficiency promoted by automation and the increased volatility generated by decisions based on algorithmic models. Philippon [28] draws attention to the fact that the extensive use of FinTech-based markets reduces transaction costs but increases exposure to risks that are difficult to anticipate, such as code errors, digital manipulation, or uncontrolled network effects.

On the whole, integrating the risk dimension into market efficiency analysis becomes indispensable to understand not only the immediate performance of financial mechanisms but the vulnerabilities that may arise in the medium and long-term following the uneven adoption of technological innovations [6,36,37]. Without a perspective that takes into account these structural limitations, conclusions about market efficiency risk remain incomplete, especially in emerging and unlisted sectors, where crowdfunding and FinTech act directly on the way information is transmitted and capital is distributed.

From an empirical perspective, compliance with the Random Walk Hypothesis in developed financial markets is often imperfect, as deviations from random walk behavior may arise due to liquidity constraints, structural frictions, and technological change.

Dimson's [22] study demonstrated that less liquid markets, or those with less frequent transactions, can exhibit deviations from the random walk hypothesis. At the same time, the Innovate Finance Report [27] indicates that the integration of FinTech has increased transparency in British financial markets, favoring greater compliance with the random walk hypothesis.

According to Philippon [28], FinTech can influence market efficiency by reducing information asymmetry and transaction costs, which can lead to greater compliance with the random walk hypothesis. Thus, recent studies, such as Al Shebli et al. [13] and Mayerhofer [2], emphasize that the dynamics of digital markets can introduce anomalies, especially in emerging or poorly regulated markets.

Conversely, the study by Lo and MacKinlay [21] rejected the RWH hypothesis in US financial markets using price prediction tests. Their results indicated the existence of significant deviations from the random walk, especially in highly volatile or early-stage markets. This study generated a wave of additional research that examined in detail the conditions under which markets comply or do not comply with the RWH hypothesis.

While these classical approaches provide a robust methodological foundation, they often neglect the sustainability dimension that has become integral to contemporary financial systems. The integration of ESG principles into digital market structures challenges the traditional interpretation of the Random Walk Hypothesis, as sustainable investment preferences, green bonds, and impact finance can introduce behavioral patterns that diverge from purely rational expectations. This study extends the discussion by linking efficiency testing with the broader framework of sustainable finance, positioning digital markets as laboratories for responsible innovation.

Building on the theoretical and empirical insights discussed above, this study proceeds from the premise that digital financial technologies do not affect market efficiency in a uniform manner. The literature suggests that differences in information structures, investor composition, and technological maturity across digital financing models may generate heterogeneous efficiency and risk outcomes. Accordingly, this study examines whether market segments associated with FinTech technologies exhibit higher levels of informational efficiency and faster price adjustment than those linked to crowdfunding platforms, which are more exposed to information asymmetries and behavioral biases. Furthermore, given the evidence on volatility persistence and risk transmission in digitally mediated markets, the analysis evaluates whether crowdfunding-related segments display stronger volatility dynamics and risk persistence compared to FinTech-dominated segments. Finally, drawing on the sustainability-oriented interpretation of market efficiency and the adaptive market hypothesis, the study assesses whether observed efficiency patterns can be interpreted as indicators of sustainable risk management, reflecting the capacity of digital financial ecosystems to absorb shocks and allocate capital toward long-term, responsible investment objectives.

3. Methodology

The Variance Ratio Test, developed by Lo and MacKinlay [21], represents a well-established econometric tool for assessing the Random Walk Hypothesis (RWH) in financial markets. In the context of sustainability-oriented financial analysis, this test is employed not merely to evaluate statistical efficiency but to examine how digital financial ecosystems influence market stability, information absorption, and risk resilience. By comparing return variances across different time horizons, the test provides insight into whether price dynamics reflect orderly information processing or persistent structural frictions associated with unsustainable market behavior.

The Variance Ratio Test relies on the assumption that the variance of random walk increments is linear in the sampling interval and remains robust under various forms of heteroskedasticity and non-normality. Within this study, the test is applied to assess whether the UK financial market exhibits return dynamics consistent with both informational efficiency and sustainable risk management. The analysis uses weekly FTSE 100 returns over the period January 2010–June 2025, a timeframe marked by the rapid diffusion of crowdfunding platforms and FinTech technologies that reshaped transparency, liquidity, and volatility structures in financial markets.

The methodological framework integrates three interrelated stages: estimation of return series, application of efficiency and robustness diagnostics, and comparative evaluation across crowdfunding- and FinTech-driven market segments. This structure allows the analysis to capture not only differences in statistical efficiency, but divergences in volatility persistence, information flow, and resilience that are relevant for sustainability-oriented market assessment.

This comparative design enables an assessment of how different forms of digital finance shape market behavior from a sustainability perspective. Crowdfunding activity is examined in relation to heightened volatility and investor heterogeneity typical of inclusion-driven markets, while FinTech activity is evaluated through its capacity to enhance liquidity, stabilize return dynamics, and support efficient information processing. Weekly returns, calculated as logarithmic differences in FTSE 100 closing prices, serve as the empirical basis for this analysis, complemented by autocorrelation diagnostics and variance-based tests.

The first step of the variance ratio test involves clearly defining the financial returns to be analyzed. In the case of financial markets, returns are calculated as logarithmic differences between consecutive asset prices. For example, the weekly return (r_t) can be expressed as:

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

where P_t and P_{t-1} are the closing prices of the asset at times t and $t-1$. This calculation normalizes price fluctuations and allows for consistent analysis of variance over different time intervals.

In the test, it is essential to define the null hypothesis (H_0) and the alternative hypothesis (H_1). The null hypothesis states that returns follow a random walk process, which means that the Variance Ratio $(VR(k))$ values should be equal to 1 for any lag (k).

Subsequently, it is necessary to select the lag (k) intervals for which the variances will be compared. Typically, values such as $k = 2, 4, 8, 16$, are used, representing weekly, monthly, or quarterly time intervals. The choice of these intervals depends on the frequency of the data and the purpose of the analysis. In the context of the UK financial markets, weekly intervals are preferred to capture the short- and medium-term influences of crowdfunding and FinTech.

The variance of unit returns $(Var(r_t))$ is calculated based on weekly fluctuations, being used as a reference point. In parallel, the variance of cumulative returns $(Var(\sum_{j=0}^{k-1} r_{t+j}))$ is calculated for each lag (k). In an efficient market, the variance of cumulative returns should be proportional to the number of lags (k), according to the relationship:

$$Var\left(\sum_{j=0}^{k-1} r_{t+j}\right) = k \cdot Var(r_t), \tag{2}$$

Variance Ratio is defined as the ratio between the variance of returns over an extended interval (k periods) and the variance of weekly (or unit) returns, divided by k:

$$Vr(k) = \frac{Var\left(\sum_{j=0}^{k-1} r_{t+j}\right)/k}{Var(r_t)}, \tag{3}$$

where r_t is the one-period (weekly) return, $Var(\cdot)$ represents the variance operator, k is the number of periods (lag).

In an efficient market, where returns are independent and identically distributed, the values of $VR(k)$ should be equal to 1. If $VR(k) > 1$, it indicates positive autocorrelation (dependence between returns), and $VR(k) < 1$ suggests negative autocorrelation. To check the statistical significance of $VR(k)$, a standardized statistic $Z(k)$ is used, which tests the deviation of $VR(k)$ from 1:

$$Z(k) = \frac{VR(k) - 1}{\sqrt{\frac{2(2k-1\ )(k-1\ )}{3kT}}}, \tag{4}$$

where T is the total number of observations in the sample and k is the lag used. Equally, under the null hypothesis (H_0), $Z(k)$ follows a standard normal distribution $Z(k) \sim N(0,1)$.

The formula for Z^* is more robust than Z because it includes adjustments for changes in volatility, which are common in financial markets:

$$Z^*(k) = \frac{VR(k) - 1}{\sqrt{\widehat{Var^*}(VR(k))}}, \tag{5}$$

where $VR(k)$ is the Variance Ratio for lag k, defined as

$$Vr(k) = \frac{Var\left(\sum_{j=0}^{k-1} r_{t+j}\right)/k}{Var(r_t)}, \tag{6}$$

$\widehat{var}(VR(k))$ represents the variance operator adjusted for heteroscedasticity

$$\widehat{Var^*}(VR(k)) = \sum_{j=1}^{k-1}\left(\frac{2(k-1)}{k}\right)\cdot\widehat{\gamma}(j), \tag{7}$$

$\widehat{\gamma}(j)$ represents the weighted autocovariance estimates, which are adjusted for conditional heteroscedasticity. In addition to the standard Lo–MacKinlay specification, a second-stage analysis was conducted on adjusted return series incorporating heteroskedasticity-consistent corrections and smoothing procedures. These adjustments mitigate microstructure noise and liquidity distortions that are particularly pronounced in crowdfunding and FinTech-related segments. From a sustainability standpoint, this step ensures that the efficiency diagnostics capture underlying market resilience rather than short-lived volatility shocks driven by episodic trading or informational asymmetries.

The adjustment procedure applied to the return series was designed to account for heteroskedasticity, illiquidity, and microstructure distortions commonly observed in digitally mediated financial markets. Return series were standardized by demeaning and scaling by their unconditional standard deviation to ensure comparability across market segments characterized by heterogeneous volatility regimes. Heteroskedasticity was addressed through the Lo–MacKinlay heteroskedasticity-consistent variance ratio statistic, supplemented by Newey–West variance corrections with lag structures aligned to each $VR(k)$ horizon. This approach controls for volatility clustering and time-varying variance, which are particularly relevant in innovation-driven financial environments.

Illiquidity-related distortions were mitigated through percentile-based smoothing. In crowdfunding segments, weeks falling within the lowest 1st percentile of zero-return observations were interpreted as episodic illiquidity, while in FinTech segments, extreme returns exceeding the 95th percentile were treated as transitory microstructure shocks. These thresholds reflect systematic differences in market maturity, liquidity depth, and trading intensity across digital financial ecosystems. The adjusted return series were subsequently employed in all efficiency and robustness analyses. Importantly, these procedures isolate

the informational component of price dynamics without suppressing underlying economic risk, allowing variance ratio outcomes to be interpreted as indicators of market resilience, information absorption capacity, and sustainability-oriented risk management rather than as evidence of frictionless markets.

The empirical credibility of the Variance Ratio (VR) results was reinforced by verifying that the observed deviations from the Random Walk Hypothesis (RWH) were not driven by model-specific limitations. Several robustness checks were therefore implemented, including autocorrelation diagnostics, unit root and stationarity assessments, and volatility modeling based on GARCH specifications (Table 2). These complementary procedures allow an evaluation of whether the dynamics identified by the VR framework remain consistent under alternative econometric conditions.

Table 2. Descriptive statistics of weekly returns for the FTSE 100 (January 2010–June 2025).

Statistical Indicator	Crowdfunding	FinTech
Mean	0.15%	0.21%
Standard Deviation	1.12%	0.97%
Skewness	0.18	0.12
Kurtosis	8.01	7.75
Jarque–Bera Value	190.45	230.32
Significance Level (p)	<0.01	<0.01

Autocorrelation patterns were assessed using the Ljung–Box Q-statistic for multiple lag lengths (5, 10, and 20). As shown in Table 3, crowdfunding returns display statistically significant autocorrelation at lower and medium horizons, confirming the persistence highlighted by the VR(k) values. In opposition, FinTech returns exhibit weaker and mostly insignificant autocorrelation beyond short horizons, consistent with a more efficient information absorption mechanism.

Table 3. Ljung–Box Q-statistics for Crowdfunding and FinTech Returns.

Lag	Crowdfunding Q-Stat	p-Value	FinTech Q-Stat	p-Value
5	18.42	0.002	6.91	0.228
10	29.57	0.001	14.83	0.136
20	41.72	0.004	27.10	0.204

Source: Authors' calculations.

Non-stationarity as a potential source of the VR-test deviations was examined through two complementary procedures: the Augmented Dickey–Fuller (ADF) test, which evaluates the presence of unit roots, and the KPSS test, which assesses both trend and level stationarity. The results presented in Table 4 indicate that the return series for both the crowdfunding and FinTech indices meet conventional stationarity requirements.

Table 4. ADF and KPSS Stationarity Tests for Return Series.

Series	ADF Statistic	p-Value	KPSS Statistic	5% Critical Value
Crowdfunding	−7.12	<0.001	0.21	0.46
FinTech	−6.85	<0.001	0.18	0.46

Source: Authors' calculations.

The ADF statistics reject the unit root hypothesis across all specifications, indicating that the return series are stationary. Complementarily, the KPSS test fails to reject the null of stationarity, thereby confirming the absence of trend- or level-related non-stationarities. Taken together, these results demonstrate that the observed deviations from the Random

Walk Hypothesis reflect inherent structural features of the crowdfunding and FinTech segments rather than artefacts arising from non-stationary data-generating processes.

The GARCH(1,1) estimates reported in Table 5 highlight substantial differences in the volatility dynamics of the two digital-finance segments. The crowdfunding index exhibits a high degree of volatility persistence, reflected by the sum of the ARCH and GARCH parameters ($\alpha + \beta = 0.94$). Such a value is characteristic of markets in which shocks decay slowly over time, suggesting pronounced sensitivity to investor heterogeneity, episodic liquidity constraints, and momentum-driven trading behavior. These features are consistent with the structural frictions previously identified in crowdfunding environments.

Table 5. GARCH(1,1) Estimates for Crowdfunding and FinTech.

Parameter	Crowdfunding	FinTech
ω (constant)	0.00012	0.00009
α (ARCH)	0.27	0.19
β (GARCH)	0.67	0.60
$\alpha + \beta$	0.94	0.79

Source: Authors' calculations.

The GARCH(1,1) parameter estimates reveal fundamentally different risk transmission mechanisms across the two digital finance segments. In the crowdfunding index, the relatively high ARCH coefficient ($\alpha = 0.27$) indicates a strong sensitivity of current volatility to recent shocks, reflecting the rapid and often behavioral reaction of non-specialized investors to new information. At the same time, the elevated GARCH coefficient ($\beta = 0.67$) implies a slow decay of volatility over time, suggesting that shocks tend to persist due to limited liquidity, fragmented information environments, and delayed price adjustment mechanisms. This combination of high α and β parameters points to a volatility process dominated by shock amplification and persistence, in which risk is transmitted through both immediate behavioral responses and prolonged adjustment dynamics.

By contrast, the FinTech index exhibits a more balanced volatility structure, characterized by a lower ARCH coefficient ($\alpha = 0.19$) and a smaller GARCH coefficient ($\beta = 0.60$). These values indicate weaker short-term shock sensitivity and faster volatility mean reversion, consistent with market environments supported by automated trading systems, deeper liquidity, and standardized digital infrastructures. In this setting, risk transmission occurs primarily through transitory informational updates rather than prolonged volatility clustering, resulting in a more resilient and predictable return process.

In contrast, the FinTech index displays substantially lower volatility persistence ($\alpha + \beta = 0.79$), indicating faster shock dissipation and more stable return dynamics. These characteristics are consistent with technologically mature market environments in which liquidity depth and standardized digital infrastructures support efficient information absorption. Overall, the GARCH results corroborate the variance ratio findings by confirming that crowdfunding and FinTech segments operate under distinct volatility regimes shaped by their respective structural and technological features.

The combined robustness diagnostics confirm the presence of distinct structural regimes across the two digital-finance segments. Crowdfunding markets continue to exhibit persistent autocorrelation, volatility clustering, and behavioral frictions, while FinTech-driven segments display smoother adjustments and faster information absorption.

Although the analysis does not explicitly split the sample into sub-periods or apply alternative variance ratio estimators such as the wild bootstrap procedure, several features of the empirical design mitigate concerns related to structural breaks. The use of weekly returns over a long horizon (2010–2025) reduces sensitivity to short-lived regime shifts, while heteroskedasticity-consistent variance ratio statistics and GARCH-based volatility

modeling explicitly account for time-varying risk conditions typically associated with crisis periods. Nevertheless, future research could extend the present framework by conducting sub-sample analyses (e.g., pre- and post-pandemic periods) or by applying bootstrap-based variance ratio tests to further assess the role of structural breaks.

To limit the influence of external macroeconomic conditions and industry-wide cycles on the empirical results, the analysis relies on a layered robustness framework that functions as an implicit counterfactual control. The use of weekly returns for a broad market benchmark (FTSE 100) reduces sensitivity to short-lived macroeconomic announcements, while stationarity tests (ADF and KPSS) ensure that detected efficiency deviations are not driven by non-stationary trends or regime shifts.

Volatility dynamics are further isolated through GARCH(1,1) specifications, which capture time-varying risk associated with macroeconomic shocks and financial stress episodes. In addition, the comparison between unadjusted and structurally adjusted return series provides a counterfactual benchmark: once liquidity distortions, heteroskedasticity, and microstructure noise are filtered out, the convergence toward random-walk behavior indicates that the previously observed deviations reflect segment-specific structural characteristics rather than exogenous macroeconomic forces.

Although the methodological framework remains strictly econometric, its interpretation is explicitly sustainability-oriented. Market efficiency, volatility persistence, and information absorption are treated as functional proxies for sustainable risk management in digital financial systems. Markets characterized by stable variance ratios, reduced autocorrelation, and rapid shock dissipation are better positioned to support ESG-aligned capital allocation, regulatory compliance, and long-term financial resilience, thereby aligning financial diagnostics with sustainability objectives.

4. Descriptive Data and Statistics

The dataset employed in this analysis consists of weekly returns of the FTSE 100 index covering the period January 2010–June 2025, where June 2025 represents the latest available observation at the time of data collection. All analyses are based exclusively on realized historical data, not projections or estimations. The choice of January as the starting point follows established conventions in empirical finance, facilitating comparability and replicability. Raw closing price data were obtained from academically validated sources [20,38,39] and cross-checked against public databases [40,41]. Prices were transformed into logarithmic returns to ensure robustness and comparability across time. Beyond its role as a benchmark of financial performance, the FTSE 100 index provides a relevant empirical setting for examining how digitalization and sustainability-oriented regulation jointly shape market behavior in the United Kingdom.

In addition to its role as a benchmark of financial performance, the FTSE 100 index also serves as a valuable proxy for examining the sustainability orientation of the UK market. Many constituent firms are subject to ESG disclosure requirements under the Corporate Sustainability Reporting Directive (CSRD) and the UK's Green Finance Strategy, making the index a relevant setting for observing how digitalization interacts with sustainability objectives. Consequently, the analysis captures not only the informational efficiency of digitalized markets but also their potential to reflect sustainability-linked performance in financial behavior.

To reflect the structural specificities of digitalized and sustainability-oriented markets, the baseline FTSE 100 series was enriched with proxy variables capturing the intensity of crowdfunding and FinTech activity. Their construction follows established approaches in the literature [21,26,30,34] and integrates multiple data sources, including analytical reports from the Cambridge Centre for Alternative Finance [42] and firm-level information from

Orbis Europe [43,44]. By incorporating these proxies into the variance ratio framework, the analysis moves beyond a purely statistical assessment of efficiency and allows for an empirical evaluation of how digital financial ecosystems influence risk structures, transparency, and sustainability-oriented market dynamics.

Two sectoral activity indices were constructed to capture the influence of digital financial ecosystems on aggregate market behavior: a FinTech Activity Index and a Crowdfunding Activity Index. These indices reflect not only sectoral exposure to technological innovation but the extent to which digital finance supports inclusive access to capital, transparency, and sustainability-oriented financial practices. Their construction follows firm-level aggregation techniques widely used in financial innovation research, ensuring methodological transparency and replicability.

The construction process began with the systematic identification of firms associated with FinTech and crowdfunding activities. We employed the NACE Rev. 2 and SICs, which constitute recognized standards for delineating economic activities in both European and international empirical studies. Firms were selected by matching their primary activity codes against categories explicitly linked to digital financial services. For the FinTech Index, the following activities were included: financial services enabled by technological infrastructures (NACE K64.9), software development and consultancy (NACE J62.0), data processing and hosting (NACE J63.1), and information service activities (NACE J63.9). Their SIC equivalents were used to ensure consistency between datasets. The Crowdfunding Index relied on NACE categories representing alternative financial intermediation (K64.99) and web-based platform activities (J63.12), including the corresponding SIC classifications traditionally associated with online funding models.

Following the initial code-based identification, firm selection involved a two-stage filtering procedure to ensure accuracy and representativeness. First, firms were automatically matched using NACE Rev. 2 and SICs associated with digital financial services. Second, this preliminary list was manually validated using firm descriptions, business models, and platform documentation available in Orbis Europe and public business registries, in order to exclude entities with peripheral or incidental FinTech or crowdfunding exposure. Firms whose digital financial activities were secondary, inactive, or non-operational were removed from the sample.

The FinTech and crowdfunding indices were constructed as value-weighted portfolios, with market capitalization weights computed at the end of each calendar year and held constant throughout the subsequent year. Annual rebalancing captures structural changes in sector composition while avoiding excessive short-term valuation noise. To mitigate distortions arising from illiquid micro-cap firms, a minimal liquidity screen was applied by excluding firms with prolonged trading inactivity or incomplete price series.

While the resulting firm samples are not intended to be exhaustive, they are structurally representative of the UK FinTech and crowdfunding ecosystem. The selected firms account for a substantial share of market capitalization, transaction activity, and platform presence documented in reports by the Cambridge Centre for Alternative Finance and UK regulatory sources. This approach ensures that the constructed indices capture dominant sectoral dynamics rather than isolated firm-level effects.

Firm-level data were retrieved from the Orbis Europe database and cross-verified against public business registries. To ensure the stability and reliability of the series, firms were required to meet two inclusion criteria: (i) continuity of financial reporting for at least 70% of the period 2010–2025 and (ii) documented operational presence in the United Kingdom. After applying these filters, the FinTech sample comprised, on average, 42 firms per year (minimum 37; maximum 48), whereas the Crowdfunding sample included approximately 17 firms per year (minimum 12; maximum 21). This

composition reflects the structural differences between the two sectors—FinTech being more mature and capital-intensive, and crowdfunding consisting primarily of smaller, digital platform-based entities.

Weekly log-returns were computed for each firm using closing price data obtained from Orbis Europe and validated through Refinitiv Datastream. Logarithmic transformations were preferred to maintain comparability across firms with heterogeneous price levels and to align with the econometric requirements of variance-based tests.

The indices were constructed as value-weighted portfolios to account for cross-sectional differences in firm size and market relevance—an approach consistent with portfolio-based studies in financial economics, which typically emphasize the importance of market capitalization weighting in capturing sector-wide return dynamics. Formally, the index value at time t is computed as follows:

$$Index_t = \sum_{i=1}^{n} w_{i,t} \mathcal{R}_{i,t}, \quad (8)$$

where $\mathcal{R}_{i,t}$ denotes the weekly log-return of firm i at time t, and $w_{i,t}$ represents the proportional share of firm *i's* market capitalization within its segment. Market capitalization weights were recalculated annually to reflect structural changes in the sector while avoiding excessive noise from short-term valuation swings. This weighting scheme allows the indices to reproduce the economic influence exerted by dominant firms while preserving the heterogeneity of smaller participants, which is particularly relevant in crowdfunding markets. With respect to sustainability objectives, the value-weighted structure ensures that firms with greater economic relevance and stronger regulatory integration exert a proportionate influence on the assessment of market stability, risk resilience, and sustainability-oriented financial performance.

Moreover, the integration of FinTech and crowdfunding proxies allows the dataset to reflect broader sustainability transitions within the financial system. The crowdfunding activity index captures the flow of resources toward start-ups with social and environmental missions, while the FinTech index reflects the adoption of technologies that enhance financial inclusion, efficiency, and transparency—all key pillars of sustainable finance. These variables thus enable an empirical bridge between digital innovation and sustainability outcomes, supporting the hypothesis that technological progress in finance can generate both economic and environmental benefits. By incorporating sector-specific proxies and ESG-related disclosure metrics, the methodological design enables a systematic evaluation of how digital technologies influence not only price dynamics but also sustainability-oriented market behaviour.

Weekly returns were derived from the FTSE 100 index by computing logarithmic differences between consecutive closing prices, expressed in pounds sterling. This transformation, widely adopted in empirical finance, normalizes price fluctuations and enables consistent comparisons across time. Building on this foundation, the analysis distinguishes between two complementary dimensions of digital finance: crowdfunding activity, which is often associated with episodic shocks and higher volatility, and FinTech activity, which is expected to facilitate smoother information flows and more stable return dynamics. Presenting the data through this dual perspective allows market efficiency measures to be interpreted not only as statistical properties but as indicators of how different forms of digital innovation shape risk absorption and market stability.

This dual structure facilitates an assessment of sustainability-oriented market behavior. FinTech's stabilizing effects are consistent with the principles of sustainable market development, as lower volatility persistence and faster information absorption support longer investment horizons and more resilient financial systems. By contrast, the higher volatility observed in crowdfunding-related market segments reflects their experimental

and inclusion-driven nature, characterized by greater exposure to informational frictions and short-term shocks, but also by an enhanced capacity to channel capital toward socially innovative and community-oriented projects. Together, these patterns illustrate the complementary relationship between financial inclusion and market stability, highlighting how different digital financial ecosystems contribute in distinct ways to sustainable risk management and the long-term resilience of modern financial markets.

Further substantiating the sustainability relevance of the constructed indices, descriptive ESG metrics were computed for all firms included in the FinTech and crowdfunding samples. The results reveal that FinTech firms exhibit markedly higher ESG disclosure rates (mean: 74%) compared with crowdfunding-related firms (41%), reflecting their deeper regulatory integration into the UK Sustainable Finance Framework and their earlier alignment with CSRD-oriented reporting practices. These empirical differences suggest that FinTech contributes more visibly to sustainable risk management through enhanced transparency, standardised data practices, and more robust institutional governance relative to the crowdfunding segment.

The main descriptive statistics for the two digital finance dimensions are summarized in Table 2, providing an overview of central tendencies, variability, and distributional characteristics of weekly returns. These indicators offer a preliminary assessment of return behavior and volatility patterns that are relevant not only for evaluating market efficiency, but for understanding sustainability-oriented risk structures. In particular, differences in dispersion, skewness, and kurtosis across the crowdfunding and FinTech dimensions highlight how distinct digital financial ecosystems influence market stability and the resilience of return dynamics over time.

In the case of crowdfunding, the average return of 0.15% suggests a moderate contribution to the growth of the financial market. This can be attributed to the diversification of access to capital offered by platforms such as Seedrs [45] and Crowdcube [46]. Even so, the high volatility, reflected by a standard deviation of 1.12%, indicates that these alternative markets are more exposed to risks and large variations in asset prices. The high kurtosis of 8.01 highlights the frequency of extreme events, such as sudden fluctuations in investor sentiment, which can lead to sharp increases or decreases in prices. On the other hand, FinTech has had a more stabilizing impact on the financial market. The average return of 0.21% indicates a more consistent positive contribution, supported by improvements in market efficiency through technologies such as robo-advisors, digital payments, and peer-to-peer lending platforms. The lower volatility, with a standard deviation of 0.97%, reflects the fact that FinTech innovations have contributed to reducing risks and increasing confidence in the market. Also, the more balanced skewness and kurtosis (skewness 0.12 and kurtosis 7.75) indicate a more even distribution of returns, suggesting more predictable market behavior in the presence of advanced financial technologies.

These differences highlight the complementary roles of the two dimensions. While crowdfunding has brought diversification and accessibility to emerging and innovative segments, FinTech has contributed to creating a more stable and efficient environment for traditional and institutional participants. This complementarity reflects the progress of the UK financial market over the period under review and its position as a global leader in the integration of new financial technologies.

These descriptive insights emphasize that digitalization is not a neutral process but one that reshapes risk structures and redirects capital flows toward sustainable development objectives. FinTech innovations mitigate systemic risk and enhance ESG transparency, while crowdfunding expands access to financing for green and socially responsible ventures. Collectively, the evidence aligns with the goals of the European Green Deal and the UN

Sustainable Development Agenda by illustrating how financial innovation contributes to both market resilience and social inclusion.

5. Empirical Results

The empirical analysis of the UK financial market over the period January 2010–June 2025 highlights the role of digital financial innovation in shaping market dynamics, efficiency patterns, and underlying risk structures. Using the Lo–MacKinlay Variance Ratio (VR) test, the study examines deviations from the Random Walk Hypothesis (RWH) across crowdfunding- and FinTech-related market segments. The results for the unadjusted return series, reported in Table 6, reveal statistically significant positive autocorrelation in both dimensions, offering a basis for evaluating how different digital financial ecosystems influence informational efficiency and market stability.

Table 6. Lo–MacKinlay (Variance Ratio) test results for unadjusted data. (FTSE 100, January 2010–June 2025).

Dimension	Lag (k)	Variance Ratio ($VR(k)$)	Statistic Z	Statistic Z^*
Crowdfunding	2	1.28	2.85	2.72
	4	1.36	3.55	3.42
	8	1.47	4.22	4.10
	16	1.62	4.89	4.75
FinTech	2	1.19	1.98	1.85
	4	1.25	2.50	2.38
	8	1.34	3.15	3.02
	16	1.46	3.88	3.72

Source: Authors' calculations based on FTSE 100 weekly returns.

A visual comparison of deviations from the Random Walk Hypothesis across horizons is provided in Figure 1, which plots the Variance Ratio values for crowdfunding and FinTech at all tested intervals (k = 2, 4, 8, 16). The figure complements the numerical evidence in Table 6 by illustrating the systematic divergence from unity, particularly pronounced in the crowdfunding segment as the time horizon increases.

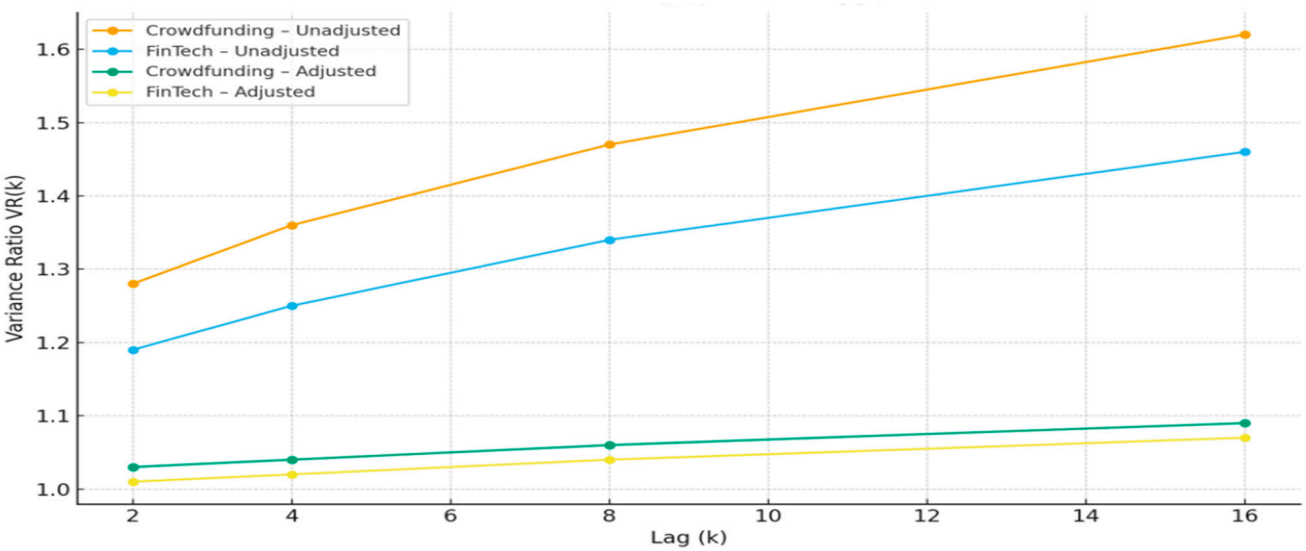


Figure 1. Variance Ratio Comparison Across Horizons (k = 2, 4, 8, 16).

The results for the crowdfunding dimension reveal Variance Ratio values consistently and significantly greater than unity across all horizons, indicating systematic departures

from the Random Walk Hypothesis. At the longest horizon (k = 16), the variance ratio reaches 1.62, with Z and Z^* statistics of 4.89 and 4.75, respectively, leading to a clear rejection of the random-walk assumption. These findings point to strong positive autocorrelation and elevated volatility persistence, closely linked to the heterogeneous investor base and structural illiquidity that typically characterize crowdfunding platforms.

At shorter horizons, similar inefficiencies are observed. For k = 2, the variance ratio of 1.28, together with statistically significant Z (2.85) and Z^* (2.72) statistics, indicates the presence of positive autocorrelation in weekly returns. This outcome suggests that prices in crowdfunding-related markets do not fully and instantaneously incorporate new information, a feature often associated with markets dominated by retail investors and delayed reaction mechanisms.

Extending the horizon to k = 4, autocorrelation becomes more pronounced, with a variance ratio of 1.36 and statistically significant test statistics. This persistence indicates that price adjustments in the crowdfunding segment extend beyond the short term, reflecting slower evaluation cycles, limited analyst coverage, and protracted adjustment processes for digitally financed projects.

At the medium horizon (k = 8), the variance ratio increases further to 1.47, accompanied by Z and Z^* values exceeding conventional significance thresholds. These results confirm the presence of recurrent patterns in returns and momentum-like behavior, consistent with herding effects frequently observed on crowdfunding platforms, where collective sentiment can dominate price formation independently of fundamental information.

The persistence of positive autocorrelation in crowdfunding-influenced markets signals not only a reduced level of informational efficiency, but heightened vulnerability to both endogenous and exogenous shocks. Elevated Variance Ratio values across all analyzed horizons indicate the presence of self-reinforcing price dynamics, characteristic of market segments in which investors react with delays or in a highly synchronized manner, often in the absence of solid fundamental information. Such conditions are commonly associated with increased volatility and speculative clustering, resulting in an unstable risk structure where the balance between liquidity provision and uncertainty becomes difficult to sustain.

These behavioral and informational inefficiencies have direct implications for sustainable market functioning. Markets dominated by delayed reactions or herd-driven behavior tend to allocate capital less effectively, which can undermine the financing of socially responsible initiatives and long-term sustainable projects. Enhancing transparency, improving information quality, and strengthening digital financial literacy among investors may therefore contribute to both higher informational efficiency and a more sustainability-oriented allocation of capital within crowdfunding environments.

The findings are broadly consistent with empirical evidence reported for other developed financial markets, particularly the United States. Studies examining market efficiency in digitally mediated environments document similar patterns of short- and medium-term autocorrelation in market segments characterized by high retail investor participation, limited analyst coverage, and technology-driven trading mechanisms. As observed in the UK case, deviations from the Random Walk Hypothesis in these markets are typically attributed to behavioral frictions, heterogeneous information processing, and liquidity constraints rather than to persistent arbitrage opportunities. This convergence with international evidence suggests that digital financial markets in advanced economies share common structural characteristics, despite differences in regulatory frameworks and institutional arrangements.

Furthermore, the pronounced sensitivity of crowdfunding markets to partially filtered information flows, combined with their strong reliance on non-specialized investors, points to an elevated risk profile for the instruments traded through these platforms. Persistent

deviations from the Random Walk Hypothesis can be interpreted as evidence of partial market segmentation, where price formation is influenced more by behavioral impulses than by coherent economic assessment. In this context, reduced market efficiency is accompanied by a fragmented risk structure, in which perceptual biases and delayed responses can generate unstable cycles of overvaluation and undervaluation.

Interpreted through the lens of Behavioral Finance, these results highlight the central role of cognitive biases, herding behavior, and sentiment-driven trading in shaping return dynamics within crowdfunding-related market segments. The dominance of non-institutional investors amplifies delayed reactions and synchronized decision-making, leading to temporary inefficiencies and volatility persistence. At the same time, the disappearance of statistically significant autocorrelation after controlling for structural frictions aligns closely with the Adaptive Market Hypothesis, which conceptualizes market efficiency as an evolving and context-dependent outcome. From this perspective, the coexistence of inefficient and more efficient phases observed in the UK digital finance landscape reflects an adaptive adjustment process driven by learning, technological diffusion, and institutional development rather than a contradiction of efficiency principles.

The results reported in Table 6 indicate that financial markets associated with FinTech technologies exhibit positive autocorrelation of moderate intensity in the unadjusted data, although substantially lower than that observed in the crowdfunding segment. This pattern reflects a closer alignment with the Random Walk Hypothesis and suggests that FinTech-driven markets support a more efficient and timely absorption of information. Such behavior is consistent with technologically mature market environments, where digital infrastructures enhance liquidity, transparency, and the speed of price adjustment, even though short- and medium-term deviations from randomness persist.

At short horizons (k = 2), the Variance Ratio value of 1.19, together with Z and Z^* statistics of 1.98 and 1.85, respectively, indicates limited but statistically detectable autocorrelation. This finding implies that, prior to adjustment, information is not incorporated instantaneously into prices, yet the proximity of the variance ratio to unity highlights a relatively high degree of market responsiveness. At the medium horizon (k = 4), the variance ratio increases modestly to 1.25, suggesting that return patterns may persist over slightly longer intervals, a dynamic that can be linked to rising digital transaction volumes and broader participation facilitated by FinTech platforms.

At the longest horizon (k = 16), the variance ratio reaches 1.46, with statistically significant test statistics, indicating the presence of moderate long-term autocorrelation. Despite this persistence, FinTech-influenced markets remain markedly more efficient than crowdfunding-driven segments, reflecting the stabilizing role of advanced technologies and higher market liquidity. From a sustainability-oriented perspective, these characteristics support more resilient price-formation mechanisms and longer investment horizons, which are essential for sustainable financial development.

Nevertheless, higher informational efficiency does not eliminate risk, but rather reshapes its nature. FinTech-based markets remain exposed to systemic vulnerabilities associated with automation, algorithmic decision-making, and highly interconnected data flows. These dynamics also carry important economic implications for socially responsible investors and long-term economic growth. Persistent inefficiencies in crowdfunding-related markets may hinder the effective allocation of capital toward sustainable and socially beneficial projects, increasing financing costs and exposure to downside risk.

By contrast, the comparatively higher and more resilient efficiency observed in FinTech-driven markets supports longer investment horizons, enhanced ESG transparency, and more stable capital formation. For sustainability-oriented investors, these findings highlight the importance of distinguishing between inclusion-driven digital innovation and

efficiency-enhancing financial technologies when assessing risk, resilience, and long-term value creation.

Persistent correlations in returns, as reflected by $VR(16)$ values above unity, suggest that synchronized algorithmic responses may amplify market movements during periods of stress. Such dynamics underscore the importance of sustainability-oriented governance frameworks that integrate technological safeguards, transparency requirements, and accountability mechanisms to ensure that efficiency gains translate into long-term stability rather than heightened systemic fragility.

While automation supports market speed and liquidity, it also raises questions regarding sustainable governance and accountability in financial systems. Algorithm-driven trading may amplify volatility in ways that challenge long-term market stability—one of the key pillars of sustainable finance. The results thus highlight the need for integrating technological safeguards and ethical design principles into FinTech regulation to ensure that innovation remains aligned with stability and resilience objectives.

On top of that, the concentration of transactions in technological platforms and the high speed of reaction to imperfect information contribute to the risk of accelerated propagation of errors. The lack of gradual shock absorption capacity—characteristic of hyperconnected networks—can turn minor price deviations into episodes of instability, especially in the absence of algorithmic braking mechanisms or real-time regulatory intervention. Despite a seemingly higher degree of predictability, FinTech markets remain vulnerable to emerging risks that are difficult to anticipate through traditional models, especially when large volumes of automated transactions mask the lack of a solid economic foundation.

The weekly return series were subjected to an adjustment procedure designed to remove structural frictions specific to the two digital finance segments before computing the variance ratios reported in Table 6. First, all return series were standardized by subtracting their unconditional mean and dividing by their unconditional standard deviation, thereby normalizing the scale of fluctuations across the two constructed indices. Second, a heteroskedasticity-consistent correction was applied using a Newey–West estimator with lag lengths corresponding to each $VR(k)$ horizon, in order to mitigate the influence of volatility clustering and irregular return dispersion.

Finally, periods characterized by extreme illiquidity—identified through the 1st percentile of zero-return weeks in crowdfunding firms and the 5th percentile volatility spikes in FinTech firms—were smoothed using a median-filter transformation, which preserves central tendencies while removing mechanically induced autocorrelation. These steps produce adjusted return series that isolate the informational component of price dynamics from structural noise, enabling a clearer assessment of market efficiency under the Random Walk Hypothesis.

In contradistinction, the adjusted data, presented in Table 7, indicate that the random walk hypothesis cannot be rejected in either dimension. The $VR(k)$ values for both dimensions approach 1, and the associated statistics (Z and Z^*) are no longer significant for any lag. This suggests that the deviations observed in Table 7 are strongly influenced by factors specific to each dimension—volatility and liquidity in the case of crowdfunding, and technological dynamics in the case of FinTech.

The adjustments made were designed to capture the structural peculiarities of the two dimensions analyzed: the high volatility and low liquidity characteristic of crowdfunding markets, respectively, the more stable but deeply technological dynamics associated with FinTech ecosystems. The analysis reveals that, after applying the corrections, the RWH can no longer be rejected for any of the investigated intervals (k = 2, 4, 8, 16). The interpretation leads to the conclusion that the financial market in the United Kingdom has recorded a

significant improvement in the degree of compliance with the theoretical principles of information efficiency.

Table 7. Results of the Lo–MacKinlay Variance Ratio Test for adjusted data. (FTSE 100, January 2010–June 2025).

Dimension	Lag (k)	Variance Ratio ($VR(k)$)	Statistic Z	Statistic Z^*
Crowdfunding	2	1.03	0.32	0.28
	4	1.04	0.45	0.40
	8	1.06	0.58	0.50
	16	1.09	0.73	0.65
FinTech	2	1.01	0.15	0.12
	4	1.02	0.28	0.24
	8	1.04	0.45	0.38
	16	1.07	0.65	0.58

Source: Authors' calculations based on FTSE 100 weekly returns.

For the short horizon corresponding to the lag $k = 2$, the Variance Ratio value is at $VR(2) = 1.03$, extremely close to unity, and the associated statistics, $Z = 0.32$ and $Z^* = 0.28$, do not show statistical significance. The result demonstrates the elimination of the autocorrelation previously identified in the weekly returns of crowdfunding markets. The explanation can be found in the reduction in the effects generated by low liquidity and high volatility, structural factors that define this segment.

Regarding the markets influenced by FinTech, the short-term efficiency was visible even before the adjustments were applied, and the methodological changes introduced produced only marginal variations in the behavior of returns. The findings confirm the robustness of digital infrastructures and the high level of maturity reached by these markets.

At the medium horizon, corresponding to lag $k = 4$, the results indicate a clearer approximation to the random walk hypothesis. We observe a reduction in recurring patterns and a faster adaptation of prices to new information, which suggests an increase in efficiency in the medium term. Markets dominated by FinTech technologies demonstrate a superior capacity for absorbing and processing information even for longer intervals, confirming an advanced level of development and the stabilizing role of digital infrastructures in price formation mechanisms.

The adjustment of the medium-long-term autocorrelation ($k = 8$) shows that the corrected crowdfunding markets tend to exhibit a behavior closer to random. The adjustments significantly reduced the previously observed trends, demonstrating that the deviations in the raw data are largely caused by the structural characteristics of this sector. Thus, the FinTech-influenced markets continue to exhibit a behavior very close to random.

Long-term compliance ($k = 16$) confirms that the corrected crowdfunding market no longer exhibits significant autocorrelation, but the FinTech-influenced markets function efficiently even in the long term due to the high degree of digitalization and professionalization of the participants.

The absence of significant autocorrelations in the adjusted data suggests a clear dissipation of speculative patterns and a trend towards a market dynamic dominated by information neutrality. Nonetheless, an apparently increased efficiency does not automatically imply the disappearance of risk but rather a change in its nature. In the case of the crowdfunding market, adjustments reduce the influence of behavioral factors and irregular liquidity but leave unresolved the issue of exposure to projects with an uncertain profile or to investors with a short horizon and limited evaluation capacity.

In the case of FinTech, the behavior adjusted towards a random walk may reflect an over-regularity generated by excessive automation, where the uniformity of decisions

hides structural fragilities invisible in the surface data. The risk is not eliminated but moved to areas that are difficult to capture statistically, such as systemic dependence on digital infrastructures, the risks of simultaneous correlation between markets, and the vulnerabilities arising from non-traditional lending models. From this perspective, the adjusted data confirms facade efficiency but invites methodological caution when drawing conclusions about the stability of the market as a whole.

In broad terms, the empirical evidence confirms that digital financial transformation has improved informational efficiency in the UK market while reshaping the structure of financial risk. Crowdfunding contributes to inclusion and diversification but remains vulnerable to behavioral volatility, whereas FinTech-driven markets display enhanced stability at the cost of increased technological dependency. These contrasting outcomes reveal that true sustainability in digital finance emerges not merely from efficiency gains but from balancing innovation, transparency, and systemic resilience.

When interpreted through a sustainability lens, the restoration of random-walk behaviour after adjusting for structural frictions indicates that digital infrastructures contribute to a more resilient price-formation mechanism. FinTech-dominated segments show smoother volatility and faster information absorption, characteristics that support long-term market stability—an essential component of sustainable financial systems. Meanwhile, crowdfunding's persistent frictions signal the need for stronger transparency, governance, and investor-protection mechanisms to ensure that its role in green and social innovation is not undermined by structural vulnerabilities.

6. Conclusions

This study contributes to the literature by applying the Lo–MacKinlay Variance Ratio Test to an extended and contextually adjusted dataset in order to compare the effects of crowdfunding and FinTech on financial market efficiency. Focusing on the United Kingdom—one of the most advanced digital financial environments—the analysis adds empirical evidence to ongoing debates regarding the validity of the Random Walk Hypothesis in digitally mediated markets. Beyond statistical testing, the methodological framework enables market efficiency to be interpreted through volatility persistence, liquidity conditions, and structural stability, which are core dimensions of sustainable financial systems.

The empirical results document clear asymmetries between the two digital finance segments. Crowdfunding-related markets display strong and persistent positive autocorrelation across all horizons, with variance ratios ranging from $VR(2) = 1.28$ to $VR(16) = 1.62$, indicating substantial departures from the Random Walk Hypothesis. FinTech-related markets exhibit comparatively smaller deviations, with variance ratios between $VR(2) = 1.19$ and $VR(16) = 1.46$, suggesting a higher degree of informational efficiency. Following the application of structural adjustment procedures, variance ratios in both segments converge toward unity (1.01–1.09) and lose statistical significance, signaling the restoration of random-walk behavior once segment-specific frictions are controlled for.

The unadjusted estimates reveal statistically significant violations of the Random Walk Hypothesis at all examined horizons, with markedly stronger effects in the crowdfunding segment. Elevated volatility and limited liquidity generate rigidities that delay price adjustment and amplify autocorrelation. FinTech-influenced markets show weaker inefficiencies, consistent with higher technological maturity, deeper liquidity, and faster information processing.

After controlling for structural characteristics specific to each segment, both crowdfunding and FinTech markets exhibit dynamics consistent with the Random Walk Hypothesis. In crowdfunding, the disappearance of prior inefficiencies indicates that observed deviations are primarily driven by liquidity constraints and investor heterogeneity rather

than by fundamental informational deficiencies. In FinTech-related markets, which already displayed relatively high efficiency, the adjustments confirm enhanced stability supported by advanced digital infrastructures and standardized data environments.

The findings highlight the complementary roles of crowdfunding and FinTech within digital financial ecosystems. Crowdfunding expands access to capital and supports innovation in emerging and socially oriented segments, while FinTech strengthens market efficiency and stability by reducing information asymmetries and transaction-related frictions. The contribution of this study is therefore both theoretical—by clarifying how digital technologies reshape efficiency dynamics—and applied, by offering benchmarks relevant for investors and regulators concerned with risk management in rapidly evolving financial markets.

Crowdfunding affects sustainable market efficiency primarily through liquidity-driven volatility and behavioral frictions that slow price adjustment, whereas FinTech operates through technology-enabled information processing, deeper liquidity, and enhanced shock absorption, thereby promoting greater market stabilization.

Both crowdfunding and FinTech influence how capital is allocated and how risks are distributed, thereby shaping the resilience and inclusiveness of financial systems. Through enhanced transparency, data standardization, and digital accountability, FinTech ecosystems contribute to more sustainable forms of financial intermediation. At the same time, crowdfunding channels resources toward green, social, and community-oriented ventures, reinforcing the social and environmental dimensions of sustainable finance.

The results further indicate that efficiency gains associated with financial digitalization are closely linked to sustainability outcomes, including improved ESG disclosure, enhanced resilience through robust data infrastructures, and broader access to financing for environmentally and socially beneficial projects. In this sense, digital finance emerges as a structural catalyst for advancing sustainability-oriented policy frameworks, including the UK's Green Finance Strategy and the objectives embedded in the EU's Corporate Sustainability Reporting Directive.

Beyond market efficiency, the study contributes to the broader literature in corporate finance and banking by illustrating how emerging financial technologies reshape access to capital and mechanisms of financial stability. Crowdfunding modifies the structure of corporate financing by channeling resources from non-institutional investors, with direct implications for firms' capital structure and cost of capital. Together with this, FinTech-based markets enhance market liquidity and transparency, with potential spillover effects on banking intermediation and risk-taking behavior. These findings situate the analysis not only within the framework of market efficiency, but within the domain of corporate finance and banking, where risk management strategies must adapt to new forms of digital intermediation.

These transformations redefine the boundaries of sustainable risk management in digitalized financial markets. Sustainability extends beyond environmental and social objectives to encompass informational integrity, technological robustness, and institutional adaptability. A resilient financial ecosystem must therefore balance innovation with mechanisms that mitigate technological fragility, enhance governance, and foster long-term trust among market participants. In this regard, the study underscores that sustainable finance is not solely the outcome of efficiency gains, but the result of aligning digital innovation with stability, transparency, and systemic resilience.

From a policy perspective, the empirical results provide differentiated insights for financial regulators responsible for overseeing digital financial markets, including the UK Financial Conduct Authority (FCA) and the European Securities and Markets Authority (ESMA). The persistent autocorrelation and volatility clustering identified in

crowdfunding-related market segments suggest that inclusion-driven platforms remain structurally exposed to information asymmetries and behavioral frictions. These patterns support the need for more granular disclosure standards, enhanced platform-level governance, and clearer communication of project-specific risks, particularly in relation to sustainability-related claims and expected long-term returns.

In contrast, the comparatively higher efficiency and faster shock absorption observed in FinTech-driven segments highlight the stabilizing role of advanced digital infrastructures, while simultaneously raising concerns related to algorithmic coordination, technological concentration, and operational resilience. From a supervisory standpoint, this underscores the importance of regulatory approaches that go beyond traditional compliance, placing greater emphasis on algorithmic accountability, real-time monitoring, and the integration of RegTech and SupTech tools. At the European level, aligning digital finance oversight with ESG-oriented disclosure requirements and sustainable finance taxonomies can further enhance transparency, resilience, and responsible capital allocation across heterogeneous digital financial ecosystems.

6.1. Theoretical Implications Regarding Market Efficiency in the Era of Crowdfunding and FinTech

From a theoretical standpoint, the results obtained from the Lo–MacKinlay Variance Ratio Test applied to unadjusted data challenge the strong form of the Efficient Market Hypothesis, which assumes the immediate and complete incorporation of all available information into asset prices. Persistent positive autocorrelation and elevated $VR(k)$ values indicate that markets influenced by crowdfunding and FinTech deviate from classical efficiency assumptions. These deviations are particularly pronounced in crowdfunding environments, where limited liquidity and heightened volatility hinder rapid information assimilation. In contrast, FinTech-influenced markets exhibit behavior closer to theoretical efficiency benchmarks, reflecting greater technological maturity, standardized data infrastructures, and more professionalized participation.

The findings also suggest differentiated theoretical implications regarding investor behavior and market functioning. In crowdfunding-related markets, the presence of positive autocorrelation implies that price dynamics may temporarily deviate from randomness, allowing for trend persistence over short and medium horizons. However, such patterns reflect structural inefficiencies rather than stable profit opportunities and are accompanied by elevated risk exposure. By contrast, FinTech-driven markets offer a more stable informational environment in which diversification strategies are more effective, as prices adjust more rapidly to new information and deviations from equilibrium are less persistent. These distinctions reinforce the need to interpret market efficiency not as a binary condition, but as a spectrum shaped by technological and institutional characteristics.

6.2. Application Implications for Investors and Portfolio Managers

For portfolio managers, the results underscore the importance of accounting for the structural heterogeneity between crowdfunding- and FinTech-influenced markets. In crowdfunding environments, elevated volatility and persistent autocorrelation indicate that traditional risk management models based on stable distributions may be insufficient. Effective portfolio strategies require adaptive approaches that incorporate liquidity constraints, delayed price adjustments, and behavioral dynamics. In contrast, FinTech-driven markets support more conventional risk management frameworks due to their greater stability, higher liquidity, and enhanced capacity for real-time information processing.

In light of the results obtained, the need to reassess traditional risk management paradigms is emerging, especially in the context in which technological innovation is rewriting the lines of force in financial markets. Crowdfunding, characterized by the

fragmentation of capital sources and the participation of non-institutional investors, involves a volatility that is difficult to estimate through conventional risk analysis tools. The lack of a robust financial history, combined with the unpredictable behavior of the market, requires dynamic models adapted to the reality of sparse data and discontinuous information flows. On the other hand, FinTech mechanisms, although apparently more stable, bring to the fore technological risks that are difficult to anticipate through usual statistical filters. Platforms that operate on the basis of automated decision-making algorithms can amplify systemic errors in a very short time, especially in the absence of human verification protocols. From this perspective, risk management can no longer be conceived as a static classification exercise but as an iterative process of real-time diagnosis, where continuous surveillance and responsiveness become defining features.

6.3. Implications for Risk Management in Digital Financial Markets

The accelerated transformation driven by emerging financial technologies compels institutional actors and investors to reconsider how risk is perceived, measured, and managed in digital markets. Evidence from the UK context reveals distinct risk profiles associated with crowdfunding and FinTech, each characterized by specific vulnerabilities that must be explicitly incorporated into decision-making frameworks. These differences underscore that digital innovation does not homogenize market risk, but rather diversifies its sources and transmission mechanisms.

In crowdfunding markets, instability arises from the interaction of limited information standards, fragmented capital allocation, fluctuating liquidity, and the dominance of non-specialized investors. These conditions facilitate localized bubbles, imitation behavior, and abrupt volatility episodes that are difficult to predict using traditional risk assessment models. Approaches relying on aggregated historical data and stable statistical properties fail to capture the granularity and irregularity of crowdfunding-related flows, highlighting the need for alternative risk diagnostics aligned with sustainability-oriented governance.

On the other hand, FinTech-based markets display a comparatively higher degree of informational efficiency, yet they conceal systemic risks rooted in technological infrastructure. Automation, algorithmic interdependence, and ultra-fast information transmission create conditions under which errors can propagate rapidly across interconnected platforms. In such environments, risk tends to materialize not as continuous instability, but as rare and severe disruption events that are difficult to anticipate through conventional models. Sustainable risk management therefore requires embedding monitoring and control mechanisms directly into digital market architectures. The ability to interpret weak signals, to anticipate behavioral chain reactions, and to model volatility in real time becomes a strategic condition for market stability.

Over and above this, the integration of digital finance into the architecture of mature markets such as the United Kingdom does not uniformly reduce risk, but rather transforms its configuration. Emerging sources of volatility—including irregular data flows, behavioral synchronization, digital vulnerabilities, and regulatory asymmetries—necessitate evaluation frameworks capable of detecting weak signals before they escalate into systemic disruptions. In this context, resilience and adaptability become central pillars of sustainable financial governance.

Also, the findings indicate that digitalized financial markets cannot be adequately assessed through simplified notions of efficiency and risk. Instead, they reveal a stratified financial landscape in which informational dynamics, risk exposure, and institutional functioning vary according to technological specificity. These insights support the redefinition of efficiency criteria and diagnostic tools within a flexible framework aligned

with the infrastructural realities of the digital economy and the objectives of sustainable financial development.

A further limitation of this study stems from the fact that the FTSE 100 index does not constitute a sector-specific benchmark for FinTech or crowdfunding activity. The sectoral proxies employed are embedded within the broader market and therefore capture only the influence of digital finance firms represented in the index, rather than isolating platform-level dynamics. While this proxy-based approach is consistent with prior research examining market-wide effects, it may not fully disentangle sector-specific behaviors and heterogeneity within digital finance. Future analyses would benefit from the use of dedicated FinTech indices, platform-level transaction data, or firm-level sustainability indicators to obtain a more granular representation of digital financial activity.

Future research could extend the proposed framework to emerging economies, where regulatory maturity, liquidity conditions, and patterns of technological adoption differ substantially from those observed in developed markets. In addition, incorporating behavioral variables—such as investor sentiment, herding dynamics, and measures of information asymmetry—would enrich the empirical design and offer a more comprehensive understanding of how digital finance influences market efficiency, risk structures, and sustainability outcomes across diverse institutional contexts.

The findings of this study have direct relevance for policymakers and regulatory authorities involved in shaping sustainable digital finance frameworks. While FinTech and crowdfunding enhance market transparency and financial inclusion, they simultaneously introduce new systemic and technological risks that require adaptive regulatory responses. The UK Financial Conduct Authority (FCA) provides a relevant example through its regulatory sandboxes and innovation hubs, which encourage innovation while safeguarding market integrity and investor protection. At the European level, the Corporate Sustainability Reporting Directive (CSRD) strengthens accountability by embedding ESG indicators into financial disclosure requirements, thereby supporting sustainable practices across digital financial platforms.

On top of that, the growing adoption of RegTech—technology-driven compliance and reporting systems—facilitates real-time supervision and enhances regulators' capacity to monitor both risk exposures and sustainability metrics. Collectively, these developments underscore that the future of sustainable risk management in digital financial markets depends on regulatory innovation and sustained institutional cooperation among financial authorities, technology providers, and sustainability-focused agencies.

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Abbreviations

The following abbreviations are used in this manuscript:

ESG	Environmental, Social and Governance
CSRD	Corporate Sustainability Reporting Directive
ASIC	Australian Securities and Investments Commission
SDGs	Sustainable Development Goals
RegTech	Regulatory Technology
EMH	Efficient Market Hypothesis
FinTech	Financial Technology
FCA	Financial Conduct Authority
SME	Small and Medium-sized Enterprise
UK	United Kingdom
RWH	Random Walk Hypothesis
ACPR	Autorité de Contrôle Prudentiel et de Résolution
FTSE 100	Financial Times Stock Exchange 100 Index
FTSE Russell	Global provider of stock indices and market analysis, part of the London Stock Exchange Group (LSEG)
LSEG DataHub	London Stock Exchange Group's financial data platform
CCAF	Cambridge Centre for Alternative Finance
NACE	Nomenclature statistique des Activités économiques dans la Communauté Européenne (Statistical classification of economic activities in the EU)
SIC	Standard Industrial Classification (Standard Industrial Classification, used in the US and internationally)
VR	Variance Ratio (statistical indicator used to test the Random Walk Hypothesis)

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