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Do U.S. Green Bonds Provide Diversification Benefits Vis-À-Vis Equity Markets?

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Abstract:
As green bonds mature into a mainstream asset class, investors increasingly rely on them to balance environmental mandates with risk mitigation. Yet, their ability to hedge against equity downturns during macroeconomic instability remains heavily debated. Addressing this gap, this study investigates the time-varying diversification benefits and volatility dynamics of the U.S. green bond market relative to traditional equities. Using daily data for the VanEck Green Bond ETF (GRNB) and the S&P 500 Index from January 2017 to March 2026, the analysis employs GARCH (1,1) conditional volatility modelling and 30-day rolling correlation techniques following baseline stationarity and ARCH effect confirmations. To capture structural shifts, the sample is partitioned into three phases: pre-COVID-19 stability (2017–2019), COVID-19 distress (2020–2021), and the post-pandemic monetary tightening cycle (2022–2026). The econometric evidence reveals that green bonds' hedging utility is profoundly regime-dependent. Pre-pandemic, they served as highly effective diversifiers, exhibiting near-zero to negative movement with equities consistent with classic flight-to-quality dynamics. However, this protective mechanism became erratic during the pandemic and severely deteriorated post-2022. As the Federal Reserve aggressively raised interest rates, synchronized downward pressure on equity and fixed-income valuations drove cross-market correlation to a structural high. Despite this correlation breakdown, GARCH estimates indicate green bonds maintain superior shock absorption and significantly faster volatility mean-reversion than equities post-crisis. Ultimately, these findings challenge the absolute safe-haven hypothesis of sustainable assets, demonstrating that environmental mandates do not insulate green bonds from macroeconomic gravity. This study provides critical implications for dynamic asset allocation, risk management, and the necessity of innovating shorter-duration sustainable instruments.

Keywords: *Green Bonds, Portfolio Diversification, Time-Varying Correlation, Conditional Volatility, GARCH (1,1), Sustainable Finance*

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I. Introduction

The exponential expansion of the global green bond market, exceeding two trillion US dollars in cumulative issuance, marks a structural paradigm shift in modern finance. Transitioning rapidly from a niche ethical pursuit to a mainstream capital allocation strategy, green bonds now attract a broad spectrum of institutional investors, pension funds, and sovereign wealth managers seeking to align financial returns with environmental accountability. However, as these instruments become foundational components of global fixed-income portfolios, the paramount question for modern portfolio theory extends beyond their environmental impact or pricing mechanisms (the "greenium"). The critical inquiry is whether green bonds deliver measurable and robust diversification benefits when held alongside equities, particularly during periods of acute market stress.

This study addresses this fundamental portfolio management problem within the context of the United States, the world's deepest and most liquid financial market. According to classic portfolio theory (Markowitz, 1952), holding assets that move independently or inversely to equities reduces overall portfolio risk without sacrificing expected returns. Yet, traditional empirical approaches often rely on static correlation coefficients, which fail to capture the complex, asymmetric, and time-varying nature of cross-market linkages. Financial markets are inherently dynamic; assets that act as effective diversifiers during tranquil periods may lose their safe-haven properties during systemic shocks. Therefore, to accurately assess the hedging utility of green bonds, it is imperative to employ dynamic volatility and time-varying correlation frameworks that account for shifting macroeconomic regimes.

Despite the rapid maturation of the U.S. green bond market and the global benchmark status of the S&P 500, a significant gap remains in the literature regarding their dynamic relationship under extreme and varying monetary conditions. Most existing studies on green bond diversification are limited to pre-pandemic datasets or focus primarily on the immediate aftermath of the COVID-19 shock. Few have extended the analysis to capture the unprecedented structural shifts of the post-2022 macroeconomic environment, characterized by aggressive monetary tightening, stubborn inflation, and a fundamental repricing of global fixed-income assets.

To bridge this gap, this paper investigates the volatility spillovers and time-varying correlations between the U.S. green bond market (proxied by the VanEck Green Bond ETF, GRNB) and the U.S. equity market (S&P 500) over a nearly decade-long horizon from January 2017 to March 2026. This specific timeframe provides a unique natural experiment, allowing for the evaluation of diversification dynamics across three fundamentally distinct market regimes: the low-volatility pre-pandemic stability (2017–2019), the acute COVID-19 liquidity shock and subsequent recovery (2020–2021), and the aggressive Federal Reserve interest rate hiking cycle and sustained restrictive monetary policy (2022–2026).

This study contributes to the burgeoning literature on sustainable finance and asset pricing in three distinct ways. First, by utilizing advanced time-varying correlation modeling, it moves beyond static assumptions to reveal how the equity-green bond nexus evolves during specific market distress events. Second, it isolates the impact of the 2022–2026 rate-hiking cycle, providing novel empirical evidence on whether green bonds retain their diversification efficacy when conventional fixed-income markets face severe duration risk. Finally, it offers actionable insights for institutional investors and risk managers regarding dynamic asset allocation and downside risk mitigation in carbon-conscious portfolios.

II. Literature Review

The Institutionalization of the Green Bond Market

The global green bond market has evolved rapidly, transitioning from a multilateral climate initiative into a critical instrument for corporate capital allocation and institutional investment. Flammer (2021) provided a foundational empirical analysis of this shift, demonstrating that corporate green bond announcements elicit positive cumulative abnormal returns and signal credible environmental commitments rather than mere “greenwashing”. This legitimized the asset class, subsequently shifting the academic discourse from validating the environmental credibility of green bonds to evaluating their strategic utility within traditional financial portfolios. Because green bonds share fundamental fixed-income characteristics while retaining a unique sensitivity to environmental, social, and governance (ESG) sentiment, they offer theoretical appeal as a portfolio buffer.

Diversification, Hedging, and the Limits of the Safe-Haven Hypothesis

The theoretical justification for incorporating green bonds into equity-heavy portfolios is rooted in Markowitz’s (1952) Modern Portfolio Theory, which posits that combining imperfectly correlated assets minimizes portfolio variance for a given level of expected return. Early research extending this paradigm to sustainable finance yielded highly promising results. Using a mean-CVaR optimization framework, Reboredo (2018) established that integrating green bonds into traditional portfolios systematically mitigates tail risk and downside exposure.

However, advanced empirical investigations have increasingly challenged the unconditional "safe-haven" status of green bonds during severe market shocks. Arif et al. (2022) comprehensively investigated the hedge and safe-haven properties of green bonds across various asset classes during the COVID-19 pandemic. They concluded that while green bonds serve as an effective diversifier during normal market conditions, their capacity to act as a definitive safe haven during extreme market turbulence is structurally limited compared to traditional defensive assets like gold. Flavin and Sheenan (2024) further corroborated this, finding that green bonds generally fail to deliver protective diversification benefits during equity contagion events, instead exhibiting positive comovement with equities during periods of high market stress. Similarly, Abuzayed and Al-Fayoumi (2023) highlighted how shifting market conditions dictate their hedging efficacy and limit diversification benefits during tail-risk events. This underscores the inadequacy of static correlation metrics, as single-period estimates obscure the regime-specific variations that are critical for evaluating dynamic portfolio diversification strategies.

Dynamic Volatility Spillovers and Time-Varying Methodologies

Because cross-market connectedness is highly sensitive to external shocks, evaluating the hedging utility of green bonds requires robust econometric modeling. Before volatility can be assessed, time series data must satisfy baseline properties; the foundational unit root and stationarity testing frameworks established by Dickey and Fuller (1979) and Kwiatkowski et al. (1992) remain strict prerequisites for structural modeling in modern financial econometrics.

Building upon these stationary properties, researchers rely on models of conditional heteroskedasticity. Engle (1982) revolutionized the modeling of financial time series by introducing the ARCH framework to capture volatility clustering. Bollerslev (1986) generalized this approach with the GARCH specification, which remains the workhorse model in empirical finance. Within this framework, time-varying methods have become essential for evaluating green bonds.

Recent literature highlights that the transmission of risk between equities and green bonds is deeply asymmetric. Park et al. (2020) identified significant asymmetric volatility spillovers, noting that while equity and green bond markets interact, the transmission of negative shocks remains distinct from traditional equity-bond dynamics. Mensi et al. (2022) expanded on this by exploring connectedness in both bearish and bullish market scenarios, demonstrating that spillover effects between green bonds and equities intensify significantly during crisis periods. Martiradonna, Romagnoli, and Santini (2023) investigated the dynamic dependencies of green bonds before and during the pandemic era, identifying distinct variance properties relative to conventional assets and validating the necessity of dynamic allocation strategies. Similarly, Nguyen et al. (2021) utilized time-frequency comovement approaches to demonstrate that green bond interactions with stocks, clean energy, and conventional bonds are inherently regime-dependent.

The Stock-Bond Nexus and Macro Regime Dependence

The empirical evidence highlighting time-varying correlations underscores a fundamental reality: the relationship between green bonds and equities is heavily influenced by the macroeconomic environment. Campbell and Ammer (1993) established that the broader stock-bond correlation is not a fixed structural parameter, but a dynamic relationship governed by inflation expectations, monetary policy shifts, and the business cycle. During periods of low inflation, the classic "flight-to-quality" phenomenon typically induces negative stock-bond correlations. Conversely, during regimes characterized by elevated inflation and rapid rate tightening, both asset classes suffer simultaneously, compressing diversification benefits. Yousaf, Suleman, and Demirer (2022) contextualized this within sustainable finance, questioning whether green investments act as a financial necessity or a "luxury good" highly sensitive to prevailing economic stability. Haq et al. (2021) explicitly linked green bond performance to these macroeconomic regimes, emphasizing that as financial integration increases, green bonds become highly prone to underlying economic policy shifts.

Despite the proliferation of sophisticated econometric literature on sustainable finance, critical gaps remain in understanding the conditional performance of the U.S. green bond market. The majority of existing empirical studies heavily index European markets or rely on datasets that conclude shortly after the initial COVID-19 shock. Crucially, few studies extend their dynamic volatility analysis into the post-2022 macroeconomic paradigm, a period defined by structural inflation, aggressive interest rate hikes by the Federal Reserve, and a fundamentally different monetary regime compared to the low-yield era in which green bonds initially matured. This study addresses this void by applying a transparent, time-varying volatility framework to the U.S. market over a comprehensive, decade-long horizon, providing a definitive assessment of whether green bonds retain their diversification efficacy under extreme monetary duress.

III. Research Objectives

The primary aim of this study is to critically evaluate the time-varying diversification efficacy of the U.S. green bond market relative to traditional equities. To operationalize this goal, the research is driven by three tightly focused objectives:

1. To capture the conditional heteroskedasticity of U.S. green bonds and equities, specifically evaluating how volatility persistence evolved across the pre-pandemic, pandemic, and monetary-tightening regimes using a GARCH (1,1) framework.
2. To move beyond static correlation metrics by capturing the dynamic, time-varying linkages between the two asset classes, documenting how the magnitude and direction of this relationship shift in response to exogenous market shocks.
3. To evaluate whether green bonds offer statistically meaningful diversification benefits, and crucially, to determine whether this hedging utility underwent a structural degradation during the post-2022 macroeconomic environment of aggressive monetary tightening.

IV. Research Methodology

Data and Sample Design

The empirical analysis utilizes daily closing price data for the U.S. green bond market and the broader U.S. equity market over a nearly decade-long horizon, spanning January 2017 to March 2026. The green bond market is proxied by the VanEck Green Bond ETF (Ticker: GRNB), which tracks the S&P Green Bond U.S. Dollar Select Index, a comprehensive benchmark of USD-denominated green bonds issued by corporations, governments, and supranational entities. GRNB was deliberately selected over alternative instruments (such as BGRN, which debuted in late 2018) because its earlier inception provides a robust, multi-year pre-pandemic baseline necessary for regime comparison. The U.S. equity market is proxied by the S&P 500 Index (Ticker: SPX). The dataset is sourced from Investing.com.

To ensure synchronous temporal alignment, the data was filtered to retain only trading days on which both asset classes recorded closing prices, effectively eliminating biases stemming from non-trading days or market holidays. To capture structural shifts in the macroeconomic environment, the full sample is partitioned into three distinct sub-periods:

1. **Pre-COVID-19 Stability:** January 2017 – December 2019
2. **COVID-19 Shock and Recovery:** January 2020 – December 2021
3. **Monetary Tightening and Post-Pandemic Regime:** January 2022 – March 2026

Variable Construction

All econometric analyses are conducted using continuously compounded daily logarithmic returns. Let $P_{i,t}$ denote the closing price of asset i (either GRNB or S&P 500) at time t. The daily log return, $r_{i,t}$, is calculated as:

$$r_{i,t} = \ln\left(\frac{P_{i,t}}{P_{i,t-1}}\right) \times 100 \qquad \text{(equation 1)}$$

Logarithmic returns are preferred over simple discrete returns because they are time-additive, mathematically symmetric, and exhibit statistical properties that better align with the distributional assumptions underlying ARCH/GARCH modeling frameworks.

Preliminary Diagnostics and Stationarity

Initially, the unconditional distributional properties of both return series are evaluated using descriptive statistics, including mean, standard deviation, skewness, and excess kurtosis. The assumption of normality is formally tested using the Jarque-Bera (JB) statistic.

Before modeling time-varying volatility, the series must satisfy the assumption of stationarity. This is verified using the Augmented Dickey-Fuller (ADF) test to reject the null hypothesis of a unit root, alongside the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test, which tests the null hypothesis of stationarity. The ADF regression equation is specified as:

$$\Delta y_t = \mu + \gamma y_{t-1} + \sum_{j=1}^{p} \delta_j \, \Delta y_{t-j} + \varepsilon_t \qquad \text{(equation 2)}$$

where Δy_t is the first difference of the series, γ tests for the unit root, and p represents the lag length determined by the Akaike Information Criterion (AIC) to correct for serial correlation in the error term, ε_t.

Conditional Volatility Modeling: GARCH (1,1)

Following the verification of stationarity, Engle's (1982) Lagrange Multiplier (ARCH-LM) test is applied to confirm the presence of autoregressive conditional heteroskedasticity (volatility clustering). Upon confirmation, the conditional volatility dynamics are modeled using Bollerslev's (1986) GARCH(1,1) specification. This model is estimated separately for each asset across the full period and the three sub-periods. The standard GARCH (1,1) framework consists of a mean equation and a conditional variance equation:

Mean Equation:

$$r_t = \mu + \varepsilon_t \qquad \text{(equation 3)}$$

where $\varepsilon_t = z_t \sigma_t$ and z_t represents an independent and identically distributed standard normal random variable, $z_t \sim \mathcal{N}(0,1)$.

Variance Equation:

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2 \qquad \text{(equation 4)}$$

Here, σ_t^2 is the conditional variance at time t. The parameter ω represents the long-run average variance (a constant), α measures the short-term impact of recent market shocks (the ARCH effect), and β captures the long-term persistence of past volatility (the GARCH effect). To satisfy covariance stationarity and ensure the variance remains strictly positive, the model requires $\omega > 0, \alpha \geq 0, \beta \geq 0$, and $\alpha + \beta < 1$. The sum of the coefficients $(\alpha + \beta)$ serves as the primary metric for volatility persistence; a sum approaching unity indicates that market shocks have a highly persistent, long-lasting impact on conditional volatility.

Dynamic Time-Varying Correlation

To evaluate the shifting diversification efficacy of green bonds, the study eschews static correlation coefficients in favor of dynamic time-varying measurement. A rolling window correlation is applied to capture structural transitions in the cross-market linkages across the identified market regimes.

The rolling correlation between the returns of the green bond market (x) and the equity market (y) at time t over a specific window length n is calculated as:

$$\rho_{xy,t}(n) = \frac{\sum_{k=0}^{n-1}(r_{x,t-k} - \bar{r}_x)(r_{y,t-k} - \bar{r}_y)}{\sqrt{\sum_{k=0}^{n-1}(r_{x,t-k} - \bar{r}_x)^2 \sum_{k=0}^{n-1}(r_{y,t-k} - \bar{r}_y)^2}} \qquad \text{(equation 5)}$$

where $\bar{r}_x$ and $\bar{r}_y$ represent the sample means of the returns within the rolling window. In alignment with established empirical finance literature, a window length of $n = 30$ trading days is utilized. This specified duration provides an optimal balance, ensuring sufficient sensitivity to detect rapid macro-structural shifts (such as sudden monetary policy announcements) while mitigating the statistical noise inherent in extremely short-term estimations.

V. Findings And Discussion

Descriptive Statistics

Table 1: Descriptive Statistics of GRNB and S&P 500

Statistic	GRNB	S&P 500	Notes
Mean Daily Return	-0.0000165	0.0004352	Near-zero vs. positive trend
Std. Deviation	0.003131	0.011792	~4× lower for green bonds
Skewness	-0.15	-0.68	Both negatively skewed
Excess Kurtosis	2.31	16.19	Fat tails; equity more extreme
Min Return	-1.66%	-12.77%	COVID crash dominates S&P
Max Return	1.78%	9.09%	
Normally Distributed	No (p=0.00%)	No (p=0.00%)	Justifies GARCH approach

The most consequential disparity between the two asset classes lies in their unconditional volatility. The standard deviation of GRNB (0.0031) is nearly four times lower than that of the S&P 500 (0.0118), confirming that green bonds carry substantially lower day-to-day market risk. Furthermore, while both series exhibit non-normal, leptokurtic distributions (fat tails), the S&P 500 displays extreme excess kurtosis (16.19) and severe negative skewness (-0.68). This equity tail risk is driven predominantly by the March 2020 liquidity crash, during which the index recorded a single-day decline of -12.77%, compared to GRNB's maximum drawdown of just -1.66%. Crucially, the Jarque-Bera test strongly rejects the null hypothesis of normality for both series ($p < 0.01$), formally validating the deployment of conditional heteroskedasticity (GARCH) models over linear OLS approaches.

Stationarity and ARCH Diagnostics

Prior to modeling conditional volatility, baseline time-series properties were evaluated. The Augmented Dickey-Fuller (ADF) test statistics, approximately -50.9 for GRNB and -14.9 for the S&P 500, decisively reject the unit root null hypothesis at the 1% significance level across all specifications, confirming covariance stationarity.

Subsequently, Engle's Lagrange Multiplier (ARCH-LM) test was executed to detect volatility clustering. The results are unequivocal: LM statistics escalate from 108.9 to 310.5 across lags 1–9 for GRNB, and from 464.4 to 2,347.8 for the S&P 500, with all p-values firmly below 0.01. The substantially larger magnitude of the S&P 500's LM statistics foreshadows the GARCH findings, indicating that volatility clustering is a far more deeply embedded structural feature of equity returns than green bond returns.

Conditional Volatility: GARCH (1,1) Analysis

Table 2: GARCH (1,1) Parameter Estimates, Full Period (2017–2026)

Parameter	GRNB	S&P 500	Interpretation
ω (long-run var.)	≈0.00	≈0.00	Baseline volatility
α (ARCH coeff.)	0.11	0.23	Shock reactivity
β (GARCH coeff.)	0.11	0.23	Volatility carry-over
α + β (Persistence)	0.22	0.46	GRNB absorbs shocks 2× faster

The persistence of volatility shocks ($\alpha + \beta$) for GRNB is 0.22, less than half that of the S&P 500 (0.46). The ARCH coefficient ($\alpha = 0.23$) for the S&P 500 indicates that equities are more than twice as reactive to recent market shocks compared to green bonds ($\alpha = 0.11$). Furthermore, the GARCH coefficient ($\beta = 0.23$) demonstrates that equity volatility carries forward with much greater momentum. Economically, this implies that green bond risk is not highly self-reinforcing; market shocks are absorbed rapidly and do not linger, confirming the asset class's foundational stability over a long horizon.

Regime-Dependent Sub-Period Volatility Dynamics

Table 3: GARCH (1,1) Sub-Period Summary, GRNB and S&P 500

Param.	Pre-COVID GRNB	Pre-COVID S&P	COVID GRNB	COVID S&P	Post-COVID GRNB	Post-COVID S&P
α	0.10	0.12	0.27	0.25	0.04	0.09
β	0.10	0.12	0.27	0.25	0.04	0.09
α+β	0.20	0.23	0.54	0.51	0.08	0.18

During the pre-COVID-19 period, characterized by macroeconomic stability, low inflation, and steady growth, both assets exhibited low and near-identical volatility persistence (0.20 for GRNB and 0.23 for the S&P 500). This indicates a tranquil environment where market shocks were absorbed rapidly and symmetrically across both asset classes.

The onset of the COVID-19 pandemic fundamentally altered these dynamics, as volatility persistence more than doubled for both assets. Notably, GRNB's persistence (0.54) marginally exceeded that of the S&P 500 (0.51). This seemingly counterintuitive result is explained by the acute interest-rate sensitivity of longer-duration green bonds during the Federal Reserve's emergency rate cuts and the subsequent inflation-driven uncertainty. Logically, during severe liquidity shocks, institutional investors prioritize margin requirements and capital preservation over environmental, social, and governance (ESG) mandates. The data reveals that during systemic crises, the "green" designation does not insulate these instruments from macroeconomic gravity, causing their volatility persistence to match or exceed that of broad equities.

In the post-COVID-19 regime, defined by aggressive monetary tightening, persistence collapsed dramatically for both assets. However, the mean-reversion was far more aggressive for GRNB (0.08) compared to equities (0.18). The Federal Reserve's rate-hiking cycle, the steepest in four decades, suppressed green bond prices in a predictable, directionally consistent manner. Because a green bond is fundamentally a fixed-income instrument first and a sustainable asset second, its repricing was swift and mechanical, driven entirely by duration risk rather than speculative uncertainty. Consequently, GRNB's post-COVID persistence of 0.08 is the lowest recorded in this study, evidencing exceptionally rapid shock absorption once the trajectory of interest rates was fully priced into the market.

Dynamic Time-Varying Comovement

Table 4: 30-Day Rolling Correlation Sub-Period Summary, GRNB and S&P 500

Sub-Period	Mean	Min	Max	Std. Dev.
Pre-COVID (2017–2019)	-0.054	-0.596	0.429	0.240
COVID (2020–2021)	0.064	-0.662	0.640	0.252
Post-COVID (2022–2026)	0.298	-0.405	0.771	0.226

During the pre-COVID-19 regime, the mean rolling correlation was effectively zero with a slight negative bias (-0.054). In this low-inflation environment, asset prices were primarily driven by idiosyncratic growth expectations. This allowed the classic Markowitz diversification framework to function as intended: when equity-specific risks materialized, capital flowed naturally into the safety of fixed-income instruments. Despite short-term fluctuations, green bonds functioned as genuine, reliable portfolio diversifiers during this period.

This diversification benefit, however, proved highly unstable during the COVID-19 shock. The mean correlation shifted positive (0.064), but the most critical finding is the extreme instability of the relationship, which ranged from a minimum of -0.662 to a maximum of 0.640. The panic-driven selloff in March 2020 caused a sharp correlation spike as investors liquidated across all asset classes simultaneously. This represents a classic breakdown of diversification under acute financial stress, resulting in highly inconsistent outcomes for portfolio managers relying on green bonds for downside protection.

A definitive structural break occurred in the post-COVID-19 tightening cycle. The mean correlation escalated to 0.298, representing a fivefold increase from the pre-pandemic baseline. The underlying economic logic dictating this breakdown lies in the transition from a growth-driven market environment to a discount-rate-driven environment. When the Federal Reserve aggressively raises the risk-free rate to combat structural inflation, the discount rate applied to all future cash flows increases simultaneously. For equities, higher discount rates compress valuation multiples; for green bonds, rising rates mechanically drive down prices due to standard duration risk. Because both asset classes became tethered to the same macroeconomic anchor, the central bank's policy rate, their shared sensitivity to the cost of capital entirely overpowered any idiosyncratic diversification benefits, eliminating the flight-to-quality mechanism and generating a sustained, positive correlation.

VI. Conclusion, Limitations and Future Research

This study investigated whether the U.S. green bond market provides robust diversification benefits relative to traditional equities across distinct macroeconomic regimes. The econometric evidence definitively demonstrates that the hedging utility of green bonds is highly time-varying and regime-dependent rather than an unconditional structural feature. During the stable pre-pandemic period, green bonds functioned as highly effective diversifiers, exhibiting near-zero to negative correlations consistent with classic flight-to-quality dynamics. However, this protective mechanism proved highly unreliable during the acute COVID-19 liquidity shock and subsequently eroded during the post-2022 monetary tightening cycle. Driven by a synchronized sensitivity to the Federal Reserve's aggressive interest rate hikes, the mean correlation between the two asset classes experienced a structural fivefold increase. Nevertheless, green bonds exhibited substantially lower volatility persistence in the post-pandemic era, indicating rapid market stabilization once rate trajectories were fully priced in. Ultimately, the central finding is conditional: green bonds diversify equity risk effectively under stable macroeconomic conditions, but this efficacy deteriorates when a dominant macroeconomic force, such as a sustained tightening cycle, mechanically suppresses both equity valuations and fixed-income prices simultaneously.

These findings yield critical practical implications for institutional asset allocation and sustainable market development. For portfolio managers and risk officers, the results invalidate the assumption that green bonds can be treated as a static, permanent portfolio hedge. Asset allocations must be managed dynamically, with heavier green bond exposures warranted during periods of monetary accommodation or stability, and reduced exposures during aggressive rate-hiking regimes. Financial advisors must transparently communicate this conditionality to clients, emphasizing that a green bond is a fixed-income instrument first, subject to standard duration risks regardless of its environmental mandate. Furthermore, for policymakers and sovereign issuers seeking to scale the sustainable finance market, these results highlight a structural vulnerability: the loss of diversification appeal is rooted in interest rate sensitivity, not shifting ESG sentiment. To preserve the hedging utility of green bonds across varying monetary environments, issuers must innovate by developing shorter-duration instruments, floating-rate notes, or inflation-linked green bonds.

Despite its robust empirical framework, this study is subject to several limitations that present natural avenues for future research. First, the reliance on an ETF proxy (GRNB) introduces secondary market liquidity noise and management fee friction, which may subtly deviate from the performance of a directly held institutional green bond portfolio. Furthermore, the geographical restriction to the U.S. market and the specific concentration on an unusually sharp rate-hiking cycle mean these findings may not seamlessly extrapolate to European or emerging market contexts, or to future monetary easing cycles. Additionally, the composition and maturity of the green bond market evolved materially over the nine-year observational window, meaning the early and late sub-periods are not perfectly structurally equivalent.

Methodologically, while the 30-day rolling correlation effectively captures broad structural regime shifts, it lacks the predictive econometric rigor of multivariate volatility models. Consequently, future research should advance this framework by employing Dynamic Conditional Correlation (DCC-GARCH) models to formally test correlation dynamics, or wavelet-based time-frequency analysis to capture comovement across varying short- and long-term investment horizons. Finally, future studies should extend the asset scope to include conventional bonds and clean energy equities, utilizing mean-variance and mean-CVaR optimization simulations to rigorously map the precise shifts in efficient frontiers across different macroeconomic regimes.

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