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The impact of risk indicators on green and conventional corporate bonds: an empirical analysis from Europe

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The impact of risk indicators on green and conventional corporate bonds: an empirical analysis from Europe

Abstract: This study examines volatility dynamics in the European corporate green bond and conventional bond markets from 1 May 2020 to 24 January 2025, using Granger causality, VAR, and impulse response analysis. VAR results show a negative relationship between bond returns and VIXIE and VSTOXX. No green premium is observed when VIXIE rises, but a premium appears with VSTOXX increases. GVZ and OVX display significant positive links with corporate and green bond returns, respectively; however, only GVZ shocks produce a green premium. Granger causality identifies VIXIE as a key causal driver, with conventional bonds acting as receivers of volatility shocks and transmitters towards green bonds and GVZ. Impulse responses confirm a green premium for VIXIE, VSTOXX, and GVZ shocks, but not for OVX. Green bonds show slightly lower shock susceptibility, suggesting higher collateral quality and greater appeal for risk-conscious investors and lenders.

Keywords: portfolio investment; risk management; VIXIE, EVZ; GVZ; OVX; VSTOXX; green bond; ESG bond; green premium

JEL: G12, G32, G15, Q56

1 Introduction

Since the Paris Agreement was adopted, interest in environmental investments has grown. As a result, companies are now motivated to achieve both financial and non-financial goals. Pursuing these non-financial objectives alongside financial performance can lead to long-term investor returns and positively impact society by shaping corporate behaviour.

Conversely, it is essential to secure capital to fulfil the ecological investment objectives of firms. In the immediate term, sustainability incurs expenses that must be borne. The subsequent inquiry pertains to the methods and parties responsible for bearing these costs. The capital necessary to support green initiatives results in a proliferation of green bond issuances. Green bonds constitute a category of fixed-income securities, whereby the proceeds are allocated to finance projects that yield beneficial environmental outcomes. Similar to conventional bonds, green bonds provide investors with an announced return and a pledge to utilise the proceeds for financing or refinancing sustainable initiatives. As of 2023, thirty-five percent of the total proceeds from green bonds issued between 2014 and 2023 across Europe were allocated to the energy sector. Construction of buildings was the second predominant sector utilising green bond proceeds, representing twenty-five percent of the total (Statista, 2025).

Green bonds assist issuers in reducing financing costs and attracting investors who are interested in sustainable investments and portfolio diversification (Tang & Zhang, 2020; Flammer, 2021). Recently, the green finance movement has gained significant momentum, driven by investors' increasing interest in developing more sustainable investment portfolios. The issuance of green bonds within the European Union has experienced considerable growth from 2014 to 2024, increasing from 0.1% to 6.9% of all bonds issued during this period. This upward trajectory indicates a rising demand for sustainable investments, which has been partially driven by the European Green Deal and the necessity to facilitate the transition towards a low-carbon, environmentally sustainable economy. Corporations have significantly increased their issuance of green bonds, rising from 5.6% of total corporate bonds in 2020 to a peak of 12.8% in 2024. The proportion of green bonds issued by governmental entities increased

from 3.3% in 2020 to 4.2% in 2024. Additionally, corporations accounted for 58.8% of the total value of green bonds issued by both the corporate and government sectors within the European Union, amounting to €33.55 billion in 2024 (EEA, 2025).

This study investigates how green and conventional bonds respond to risk indicators such as the CBOE Euro Currency Volatility (EVZ Index), iTraxx/CBOE Europe Main 1-month Volatility (VIXIE Index), Cboe Crude Oil Volatility Index (OVX Index), CBOE Gold Volatility (GVZ Index) and STOXX 50 Volatility(VSTOXX Index). Such an investigation could be vital for European policymakers to understand how risk indicators influence environmental investments and to devise suitable strategies for encouraging eco-friendly enterprises. Ultimately, the study has significant implications for portfolio managers and investors across diverse investment horizons, enabling them to develop effective cross-market portfolios and formulate risk mitigation strategies.

2 Literature review

Finance literature predominantly focuses on green market price movements to aid participants in comprehending market behaviour and making well-informed investment decisions. Most of this research centres on the yield of the green bond market, specifically examining the presence of green bond premiums compared to other conventional bond options (Dorfleitner et al., 2022). Researchers have identified evidence suggesting that green bonds exhibit a positive premium (Baker et al. 2019; Nanayakkara and Colombage 2019; Zerbib 2019). Conversely, other researchers have failed to substantiate this phenomenon (Larcker and Watts 2020; Flammer 2020). Bachelet et al. (2019) further have observed that green bonds are marginally undervalued, indicating a negative premium.

The connectedness between the green bond market and other financial markets has been examined in numerous studies. According to Inderst et al. (2012), there is limited connectivity between traditional fixed-income instruments and green bonds. Reboredo (2018) argued, however, that the green bond market exhibits moderate connectedness with the stock and energy markets, while maintaining a significant link with the corporate bond and treasury markets. Furthermore, Reboredo and Ugolini (2020) note a strong connection between green bonds and the currency market. In bearish markets, Lee et al. (2021) showed a strong bidirectional causal relationship between oil prices and the Green Bond Index, which weakened as the oil market moved into higher quantiles. In lower quantiles, geopolitical uncertainty was also found to be a strong predictor of Green Bond Index behaviour. According to Ferrer et al. (2021), there is a slight but noteworthy correlation between green bonds and corporate and Treasury bonds, as well as the oil markets. This suggests that investors may profit from diversification (Nguyen et al., 2020; Mensi et al., 2021). In their analysis of the factors influencing the returns on the green bond market, Piñeiro-Chousa et al. (2021) found that investor sentiment was significantly and positively correlated with green bond market returns, while stock and non-renewable energy market returns had a negative impact; the CBOE Volatility Index (VIX) had no discernible effect. According to findings presented by Broadstock and Cheng (2019), macroeconomic factors such as oil prices, economic policy uncertainty, and daily economic activity significantly influence the degree of interconnectedness between green and conventional bonds. Pham (2021) explored the relationship between green bonds and green stocks and discovered that interdependence varies across different time horizons and frequency ranges, showing weaker medium- and long-term relationships, higher short-term interdependence, and increased connections during extreme market conditions. Yi et al. (2021) underscored considerable uncertainty within the green bond market, chiefly attributable to investor concerns regarding credit risk, especially during the COVID-19 pandemic in China. Conversely, Naeem et al. (2021a) indicated that the green bond market offers conventional bond investors effective diversification and demonstrates greater efficiency than the traditional bond market during external shocks. Moreover, Arif et al. (2021) contended that green bonds may function as safe-haven investments across stock, currency, and commodities markets, in addition to the traditional bond market, particularly amid severe shocks.

In comparison with the conventional fixed-income market, there exists comparatively limited research elucidating the characteristics of volatility within the green bond market. By analysing the effects of volatility indices on both traditional and green corporate bond markets, this study makes a significant contribution to the existing body of literature. Naeem et al. (2021b) examined the relationship between metals and green bond markets. On the one hand, the link between precious metals and green bonds generally appears positive, as higher commodity returns tend to lead to higher green bond returns. Although researchers observe mixed results during downturns in gold and silver markets, changes in the returns of precious metals mainly influence green bonds in a similar directional pattern. Since gold and silver are recognised as effective hedges and safe-haven assets, evidence of positive correlations in middle and lower quantiles supports the notion that green bonds share comparable hedging and safe-haven properties. The responsiveness of green investments to oil market shocks was examined by Dutta et al. (2020). According to the research, green assets are more susceptible to volatility in the oil market than to movements in the price of oil. Hietakangas and Dutta (2024) identified a substantial positive correlation between fluctuations in the oil implied volatility index and the observed volatility of green bonds. Conversely, the volatility within the green bond market appears to remain largely unaffected by variations in macroeconomic uncertainties, geopolitical risks, or stock market fluctuations.
Our study analyses how conventional corporate and green bonds react to market shocks. Suppose green bonds are less sensitive to shocks than conventional bonds. In that case, this finding will have a significant impact on collateral management for both lenders and borrowers, indicating a considerable improvement in collateral quality.

3 Data and preliminary analyses

3.1 Data

In this empirical study, the MSCI EUR Corporates IG Climate Change ESG Select Index (hereafter referred to as the Green Bond Index, GBI) and the MSCI EUR Corporates IG Select Index (hereafter referred to as the Conventional Bond Index, CBI) are employed.

Moreover, the CBOE Euro Currency Volatility (EVZ Index), iTraxx/CBOE Europe Main 1-month Volatility (VIXIE Index), Cboe Crude Oil Volatility Index (OVX Index), CBOE Gold Volatility (GVZ Index) and VSTOXX 50 Volatility (VSTOXX Index) data have been utilised as risk indicators.

The study uses bond returns as dependent variables. We employed the following formula to calculate the daily returns.

Return of an asset = $(P_{t+1} - P_t)/P_t$

Where,

P_{t+1}= price of the asset at time t+1

P_t = price of the asset at time t

In investment-grade corporate bond investing, the MSCI EUR Corporates IG Climate Change ESG Select Index (GBI) aims to track the performance of a strategy that systematically includes environmental, social, and governance (ESG) standards, reflecting the opportunities and risks associated with the transition to a lower-carbon economy. It also meets the minimum requirements of the EU Climate Transition Benchmark.
The MSCI EUR Corporates IG Select Index (CBI) serves as the primary benchmark derived from a broad universe of corporate bonds issued in EUR. Its selection process is based on criteria such as country of domicile and security type, considering factors like coupon, seniority, maturity, bond age, credit rating, and bond size. In essence, these two indices are constructed to be comparable in terms of liquidity, credit, and interest rate risk.

The EVZ Index quantifies the implied volatility of the euro or the dollar-euro exchange rate as anticipated by market participants.

The VIXIE Index concentrates on the European corporate bond market, assessing volatility expectations across diverse industries.

The OVX Index serves as an estimate of the anticipated 30-day volatility of crude oil.

The GVZ Index measures the market's expectation of 30-day volatility implicit in the prices of near-term Gold ETF options.

The real-time options prices of the EURO STOXX 50 constitute the foundational data for the VSTOXX Indices. By calculating the square root of the implied variance across all options with a designated expiry, they endeavour to accurately mirror the market's expectations of volatility over both short and long-term periods.

The Daily data used in this analysis, covering the period from May 1, 2020, to January 24, 2025, has been sourced from the Bloomberg database.

3.2 Preliminary analyses

This section includes descriptive and correlation analysis.

Table 1 Descriptive statistics

	CBI1	EVZ	GBI1	GVZ	OVX	VIXIE	VSTOXX
Mean	1.58E-05	8.212160	-8.47E-06	17.10477	41.07149	41.81250	21.07911
Median	0.000000	7.330000	0.000000	16.69000	38.46500	36.03500	19.83000
Maximum	0.014488	533.0000	0.016572	31.70000	115.3900	102.1600	49.64000
Minimum	-0.013219	4.710000	-0.014203	10.22000	23.73000	19.49000	12.12000
Std. Dev.	0.002432	15.06767	0.002707	3.056672	11.33661	18.14655	5.948767

Table 1 shows that the average daily return of CBI is positive(0.0000158); however, the average daily return of GBI is negative (-0.00000847). In this parallel, GBI exhibits a slightly higher standard deviation of returns at 0.0027, while CBI demonstrates a standard deviation of returns at 0.002432. We observe low volatility and symmetric distribution around zero for CBI and GBI returns.

Table 2 Correlation matrix

	CBI1	EVZ	GBI1	GVZ	OVX	VIXIE	VSTOXX
CBI1	1.000000	-0.015901	0.975696	-0.013587	-0.037023	-0.096814	-0.090558
EVZ	-0.015901	1.000000	-0.026461	0.026064	0.036402	0.081509	0.059327
GBI1	0.975696	-0.026461	1.000000	-0.007174	-0.029531	-0.084800	-0.077050
GVZ	-0.013587	0.026064	-0.007174	1.000000	0.544767	0.437699	0.681847

OVX	-0.037023	0.036402	-0.029531	0.544767	1.000000	0.653479	0.783244
VIXIE	-0.096814	0.081509	-0.084800	0.437699	0.653479	1.000000	0.733460
VSTOXX	-0.090558	0.059327	-0.077050	0.681847	0.783244	0.733460	1.000000

Table 2 shows that volatility indices have a positive correlation with each other but a negative correlation with both bond return indices. Positive volatility index correlation coefficients indicate that uncertainties within the analysed market segments typically react similarly to market conditions or there are spillover effects across all sectors (Albers, 2024). Volatility indices have low correlation with bond return indices. The highest correlation is between OVX and VSTOXX among the volatility indices. Meanwhile, the lowest correlation is between EVZ and GVZ.

4 Empirical study

To ensure the validity of the time-series analysis, unit root tests such as the Augmented Dickey-Fuller (ADF) test were conducted. A unit root test is used to determine whether a time series variable is stationary or non-stationary. A stationary series has constant mean and variance over time, which is a key requirement for valid time series analysis. A Vector Autoregression (VAR) model was then estimated to explore the dynamic interrelationships among EVZ, GVZ, OVX, VIXIE and VSTOXX. Following the VAR estimation, Granger causality tests were applied to examine the direction of predictive relationships.

4.1. Time Series Properties and Pre-Estimation Diagnostics

Before conducting the VAR analysis, it is essential to examine the time series properties of the data to avoid spurious regression results. Accordingly, unit root tests were employed to determine the stationarity of each variable. Specifically, the Augmented Dickey-Fuller (ADF) test was applied to all series in levels and first differences. The null hypothesis of the ADF test posits the presence of a unit root (i.e., non-stationarity). If the test statistic is more negative than the critical value at conventional levels (1%, 5%, or 10%), the null hypothesis is rejected, indicating stationarity. The test results indicated that all variables (EVZ, GVZ, OVX, VIXIE and VSTOXX) were integrated of order one, I(1), and became stationary after first differencing. Consequently, the first-differenced series were used in the subsequent VAR modeling to ensure stationarity.

4.2 Vector Autoregression with Exogenous variables of order 2 (VAR(2))

A Vector Autoregression (VAR) model was employed to capture the linear interdependencies among the macroeconomic variables. The VAR model treats all variables as endogenous and specifies each as a function of its own lagged values and the lagged values of other variables in the system. General VARX(2) Model Structure can be represented as:

$$CBI_t = \alpha_{10} + \alpha_{11}CBI_{t-1} + \alpha_{12}CBI_{t-2} + \alpha_{13}GBI_{t-1} + \alpha_{14}GBI_{t-2} + \beta_1 EVZ_t + \beta_2 GVZ_t + \beta_3 OVX_t + \beta_4 VIXIE_t + \beta_5 VSTOXX_t + \varepsilon_{CBI,t} \quad (1)$$

$$GBI_t = \gamma_{10} + \gamma_{11}CBI_{t-1} + \gamma_{12}CBI_{t-2} + \gamma_{13}GBI_{t-1} + \gamma_{14}GBI_{t-2} + \delta_1 EVZ_t + \delta_2 GVZ_t + \delta_3 OVX_t + \delta_4 VIXIE_t + \delta_5 VSTOXX_t + \varepsilon_{GBI,t} \quad (2)$$

where:
CBI_t : Conventional Bond Index return at time t,
GBI_t : Green Bond Index return at time t,
EVZ_t, GVZ_t, OVX_t, $VIXIE_t$, $VSTOXX_t$: Volatility indices (exogenous)
$\varepsilon_{CBI,t}$, $\varepsilon_{GBI,t}$: Error terms

4.3 Granger causality test

To identify predictive causality between variables, Granger causality tests were conducted within the VAR framework. The test evaluates whether lagged values of one variable provide statistically significant information about the future values of another. Specifically, for a bivariate case, if the inclusion of lagged values of variable X in the equation for variable Y significantly improves the model's explanatory power, then X is said to Granger-cause Y. The test is based on the null hypothesis that the coefficients of the lagged values of X in the equation for Y are jointly equal to zero. Rejection of the null hypothesis at conventional significance levels (e.g., 5%) implies the presence of Granger causality. This methodology enables us to determine the direction of causality among macroeconomic indicators, offering insights into their dynamic relationships and potential policy implications. Unrestricted Model (with lags of X and Y):

$$Y_{t=} \alpha_0 + \sum_{i=1}^{p} \alpha_i Y_{t-i} + \sum_{j=1}^{p} \beta_j X_{t-j} + E_t$$

Where:

Y_t = CBI_t , GBI_t
X_t = EVZ_t, GVZ_t, OVX_t, $VIXIE_t$, $VSTOXX_t$
E_t = Error terms

4.4 Impulse Response Functions

We compute Impulse Response Functions (IRFs) to examine the dynamic effects of shocks in one variable on the other.

5 Findings

5.1 Unit root test results

The CBI, GBI, and all other volatility indices are stationary. The ADF unit root test results for the CBI and GBI indices are shown in Table 3. Results for the volatility indices are available upon request.

Table 3 ADF unit root test results

Null Hypothesis: CBI1 has a unit root

Exogenous: Constant

Lag Length: 0 (Automatic - based on SIC, maxlag=22)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-33.03097	0.0000
Test critical values:	1% level	-3.435436	
	5% level	-2.863674	

	10% level	-2.567956

*MacKinnon (1996) one-sided p-values.

Null Hypothesis: GBI1 has a unit root

Exogenous: Constant

Lag Length: 0 (Automatic - based on SIC, maxlag=22)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-34.07246	0.0000
Test critical values:	1% level	-3.435436	
	5% level	-2.863674	
	10% level	-2.567956	

*MacKinnon (1996) one-sided p-values.

5.2 VAR analysis

Table 4 VAR model results for the conventional bond index return and green bond index return

	CBI	GBI
CBI(-1)	0.097060 (0.13424) [0.72305]	0.391740 (0.14942) **[2.62171]*****
CBI(-2)	0.174823 (0.13338) [1.31075]*	0.250624 (0.14846) [1.68811]**
GBI(-1)	-0.051366 (0.12051) [-0.42624]	-0.331137 (0.13414) [-2.46857]***
GBI(-2)	-0.117620 (0.12019) [-0.97866]	-0.186758 (0.13378) [-1.39600]*
C	-0.000121 (0.00041) [-0.29654]	-0.000225 (0.00045) [-0.49614]
EVZ	-7.83E-07 (4.6E-06) [-0.17091]	-2.63E-06 (5.1E-06) [-0.51632]
GVZ	5.79E-05 (3.1E-05) [1.85817]**	6.03E-05 (3.5E-05) [1.73610]**
OVX	2.01E-05 (1.0E-05)	1.95E-05 (1.2E-05)

	[1.94095]**	[1.69352]**
VIXIE	-8.85E-06 (5.8E-06) [-1.53742]*	-8.93E-06 (6.4E-06) [-1.39299]*
VSTOXX	-6.20E-05 (2.5E-05) [-2.52013]***	-5.85E-05 (2.7E-05) [-2.13797]**

Note: Standard errors in ( ) & t-statistics in [ ], Significance levels: ***p < 0.01, **p < 0.05, *p < 0.10.

Table 4 depicts that a significant positive relationship exists between the lag of CBI return and the GBI return. If the lag of CBI return increases by 1%, the GBI return increases by 39%. Corporate bonds typically exhibit higher liquidity and receive closer attention from investors. Price movements in corporate bonds may precede responses to changes in credit spreads, interest rates, or economic outlooks before green bonds react. In other words, this finding may be due to the spillover effect.

A significant negative relationship exists between the lag of the GBI return and the GBI return itself. If the lag of GBI return increases by 1%, the GBI return decreases by 33%. This finding could be due to an overreaction to news, which might push prices too high, and then correct in the next period.

A significant positive relationship exists between the GVZ index and the CBI return and the GBI return, respectively. When the GVZ index rises, it often signals increased market uncertainty and inflation concerns (commodity spikes), which lead to looser monetary policy. Consequently, bond returns tend to increase. If the GVZ index increases by 1%, the CBI return increases by 0.00579%. On the other hand, if the GVZ index rises by 1%, the GBI return increases by 0.006%, which is slightly higher than the CBI return. This result is similar to that of Naeem et al (2021) in the literature.

A significant positive relationship exists between the OVX index and the CBI return and the GBI return, respectively. Similar to the GVZ and bond return relationship, a positive OVX and bond return relationship exists because oil volatility signals increased macroeconomic and financial uncertainty, leading to flight-to-safety flows into bonds and expectations of looser monetary policy because of recession fears, both of which boost bond returns. If the OVX index increases by 1%, then the CBI return increases by 0.002%. On the other hand, if the OVX index increases 1%, then the GBI return increases 0.00195%, which is slightly less than the CBI return. This result is similar to Hietakangas and Dutta (2024) in the literature.

A negative relationship between volatility indices (VIXIE and VSTOXX) and bond returns occurs when volatility indicates risks related to inflation, fiscal policies, geopolitical issues, or currency fluctuations, or when bonds issued by European countries fail to serve as a safe haven. In these circumstances, investors divest from both equities and bonds, leading to a decline in bond returns as the VIXIE and VTOXX increase. For example, inflation surged after the pandemic in 2021 and 2022, leading the European Central Bank to tighten monetary policy. Consequently, bond returns fall. In addition, the Russia-Ukraine war and the resulting energy shock in Europe raise inflation fears, which trigger higher yield demands by investors, and thus bond returns fall.

There is a significant inverse relationship between the VIXIE index and the CBI return and the GBI return, respectively. If the VIXIE index rises by 1%, then the CBI return decreases by 0.000885%. On the other hand, if the VIXIE index rises by 1%, then the GBI return decreases by 0.000893%, which is slightly more than the CBI return. We do not observe a green premium when volatility increases for the bonds in GBI. This result is similar to Larcker and Watts (2020), Flammer (2020), Bachelet et al. (2019) in the literature section.

A significant inverse relationship exists between the VSTOXX index and both the CBI return and the GBI return. When the VSTOXX index increases by 1%, the CBI return decreases by 0.0062%. Similarly,

a 1% rise in the VSTOXX index results in a decrease in GBI return by 0.00585%. Notably, this decline in GBI return is slightly less than that of CBI return, suggesting the presence of an ignorable green premium. This result is similar to Baker et al. (2019), Nanayakkara and Colombage (2019), and Zerbib (2019) in the literature.

A significant positive relationship exists between the lag of CBI return and the GBI return. Additionally, the volatility index of gold exhibits a positive relationship with bond returns. However, bond and stock volatility indices show a negative relationship with bond returns.

5.3 Granger causality test results

Granger causality is a statistical concept of causality based on prediction. It states that if a signal X1 "Granger-causes" (or "G-causes") a signal X2, then the previous values of X1 should be able to predict X2 more accurately than X2's past values alone.

Table 5 Causality test results between the EVZ index and CBI and GBI returns

Null hypothesis:	F-statistics	Prob.
EVZ does not Granger-cause CBI	0.10147	0.9035
CBI does not Granger-cause EVZ	0.35695	0.6999
EVZ does not Granger-cause GBI	0.01367	0.9864
GBI does not Granger-cause EVZ	0.14112	0.8684

Table 5 reports F-statistic values (F = 0.10147 for EVZ → CBI and F = 0.35695 for CBI → EVZ), indicating that neither relationship is statistically significant. As the corresponding p-values exceed the conventional 5% significance level, the null hypothesis of no Granger causality cannot be rejected in either direction. This suggests that past values of EVZ do not provide additional predictive power for current values of CBI, and past values of CBI do not aid in forecasting EVZ. Consequently, there is no evidence of Granger causality between EVZ and CBI.

The causality between EVZ and GBI is the same as that between EVZ and CBI.

Table 6 Causality test results between the GVZ index and CBI and GBI returns

Null hypothesis:	F-statistics	Prob.
GVZ does not Granger-cause CBI	2.89234	0.0558
CBI does not Granger-cause GVZ	3.28689	0.0377
GVZ does not Granger-cause GBI	1.80597	0.1648
GBI does not Granger-cause GVZ	3.15620	0.0429

Table 6 shows the values of the F-statistic (F = 2.89234 for GVZ → CBI, and F = 3.28689 for CBI → GVZ), which suggest statistically significant causality at the 10% and 5% levels, respectively. This indicates that past values of GVZ have predictive power for current values of CBI at the 10% significance level, while past values of CBI aid in predicting current values of GVZ at the 5% significance level. However, neither relationship is significant at the more stringent 1% level. Thus, there is evidence of bidirectional Granger causality between GVZ and CBI, but only at the 10% and 5% significance thresholds. There is a two-way relationship. GVZ shocks can lead bond returns via “risk aversion” channels. Bond returns can lead to GVZ via the real interest rate–gold demand channel. The strength of causality depends on the macro-regime (crisis vs stable periods). The values of the F-statistic (F = 1.80597 for GVZ → GBI, and F = 3.15620 for GBI → GVZ) indicate that GVZ does not Granger-cause GBI, whereas GBI Granger-causes GVZ at the 5% significance level. This suggests that

historical values of GBI provide predictive insight into current values of GVZ, although this relationship does not reach significance at the more rigorous 1% level.

Table 7 Causality test results between the OVX index and CBI and GBI returns

Null hypothesis:	F-statistics	Prob.
OVX does not Granger-cause CBI	1.42015	0.2421
CBI does not Granger-cause OVX	0.04119	0.9597
OVX does not Granger-cause GBI	1.09937	0.3334
GBI does not Granger-cause OVX	0.11061	0.8953

Table 7 presents the F-statistic values (F = 1.42015 for OVX → CBI and F = 0.04119 for CBI → OVX), indicating that neither relationship is statistically significant. Consequently, the null hypothesis of no Granger causality cannot be rejected in either direction, implying that past values of OVX do not help predict current CBI, and vice versa. Similarly, no causality is observed between OVX and GBI, indicating that OVX does not Granger-cause GBI, nor does GBI Granger-cause OVX. Accordingly, there is no evidence of Granger causality between OVX and either CBI or GBI.

Table 8 Causality test results between the VIXIE index and CBI and GBI returns

Null hypothesis:	F-statistics	Prob.
VIXIE does not Granger-cause CBI	9.64055	7.E-05
CBI does not Granger-cause VIXIE	0.40747	0.6654
VIXIE does not Granger-cause GBI	7.11109	0.0009
GBI does not Granger-cause VIXIE	0.06353	0.9385

Table 8 shows F-statistic values (F = 9.64055 for VIXIE → CBI and F = 0.40747 for CBI → VIXIE), indicating that VIXIE Granger-causes CBI at the 1% significance level, whereas no reverse causality is observed. This implies that past values of VIXIE have substantial predictive power for current CBI values. A similar pattern is observed for GBI, where VIXIE Granger-causes GBI but not vice versa. These findings suggest that VIXIE Granger-causes bond returns, consistent with the notion that volatility spikes frequently precede shifts in risk appetite and subsequent variations in bond demand.

Table 9 Causality test results between the VSTOXX index and the CBI and GBI returns

Null hypothesis:	F-statistics	Prob.
VSTOXX does not Granger-cause CBI	8.01476	0.0003
CBI does not Granger-cause VSTOXX	2.89859	0.0555
VSTOXX does not Granger-cause GBI	6.65378	0.0013
GBI does not Granger-cause VSTOXX	2.59665	0.0749

Table 9 presents the F-statistic values (F = 8.01476 for VSTOXX → CBI, and F = 2.89859 for CBI → VSTOXX), indicating that VSTOXX Granger-causes CBI at the 1% significance level, whereas CBI Granger-causes VSTOXX at the 10% significance level. This denotes a bidirectional relationship, with stronger evidence supporting causality from VSTOXX to CBI. A comparable causality pattern is observed between VSTOXX and GBI. From an economic perspective, an increase in VSTOXX signals expectations of higher stock market volatility, often leading to a flight to safety, where investors shift capital from equities to government bonds or highly rated corporate bonds. Conversely, a significant rise in bond yields may indicate tighter financial conditions, which can subsequently result in higher equity market volatility, with bond market dynamics potentially Granger-causing variations in the VSTOXX index.

Table 10 Causality test results among volatility indices(EVZ, GVZ, OVX, VIXIE and VSTOXX)

Null hypothesis:	F-statistics	Prob.
GVZ does not Granger-cause EVZ	0.68167	0.5060
EVZ does not Granger-cause GVZ	0.22210	0.8009
OVX does not Granger-cause EVZ	4.04178	0.0178
EVZ does not Granger-cause OVX	0.64181	0.5265
VIXIE does not Granger-cause EVZ	4.54746	0.0108
EVZ does not Granger-cause VIXIE	0.65243	0.5210
VSTOXX does not Granger-cause EVZ	2.78574	0.0621
EVZ does not Granger-cause VSTOXX	2.00878	0.1346
OVX does not Granger-cause GVZ	0.33734	0.7137
GVZ does not Granger-cause OVX	4.71744	0.0091
VIXIE does not Granger-cause GVZ	9.29773	0.0001
GVZ does not Granger-cause VIXIE	1.67550	0.1876
VSTOXX does not Granger-cause GVZ	4.91890	0.0075
GVZ does not Granger-cause VSTOXX	3.77147	0.0233
VIXIE does not Granger-cause OVX	13.5114	2.E-06
OVX does not Granger-cause VIXIE	5.27246	0.0052
VSTOXX does not Granger-cause OVX	17.4943	3.E-08
OVX does not Granger-cause VSTOXX	0.98733	0.3729
VSTOXX does not Granger-cause VIXIE	0.15286	0.8583
VIXIE does not Granger-cause VSTOXX	6.68937	0.0013

Table 10 shows the values of the F-statistic, which suggest that GVZ Granger-causes OVX, VIXIE Granger-causes GVZ, VSTOXX Granger-causes GVZ, VIXIE Granger-causes OVX, OVX Granger-causes VIXIE, VSTOXX Granger-causes OVX, and VIXIE Granger-causes VSTOXX at 1% significance level. Volatility indices (VIXIE, VSTOXX, OVX, GVZ) demonstrate a network of causal influences, signalling interconnectedness within markets.

Table 11 Causality test results between the CBI and GBI returns

Null hypothesis:	F-statistics	Prob.
GBI does not Granger-cause CBI	0.78526	0.4562
CBI does not Granger-cause GBI	5.19383	0.0057

Table 11 presents the F-statistic values (F = 0.78526 for GBI → CBI and F = 5.19383 for CBI → GBI), indicating that GBI does not Granger-cause CBI, whereas CBI Granger-causes GBI at the 1% significance level. This suggests that past values of CBI provide significant predictive power for current values of GBI. Therefore, evidence of unidirectional Granger causality exists from CBI to GBI. This finding aligns with Reboredo (2018) in the literature. Conventional corporate bonds are older, more liquid, and better reflect credit market conditions. Green bonds are a subset of the corporate bond market, so shocks to the wider corporate bond market (such as spread widening or risk-off sentiments) should naturally affect green bonds.

VIXIE is a key "causal driver" that imposes Granger causality over several variables, including CBI, EVZ, GBI, GVZ, OVX, and VSTOXX. Additionally, CBI primarily acts as a "receiver" from VIXIE and VSTOXX, while also serving as a causative factor for GBI and GVZ. Moreover, no causality has been found between EVZ and CBI, or GBI, in either direction.

5.3 Impulse response test results

Within the framework of a Vector Autoregression (VAR) model, the impulse response function (IRF) serves as a crucial instrument for analysing the dynamic consequences of a shock (or innovation) to a specific variable on the other variables within the system across temporal horizons. An impulse response function delineates the impact of a singular shock to one of the variables in the VAR system on both the current and subsequent values of all variables involved.

Figure 1 Response of VIXIE to CBI return

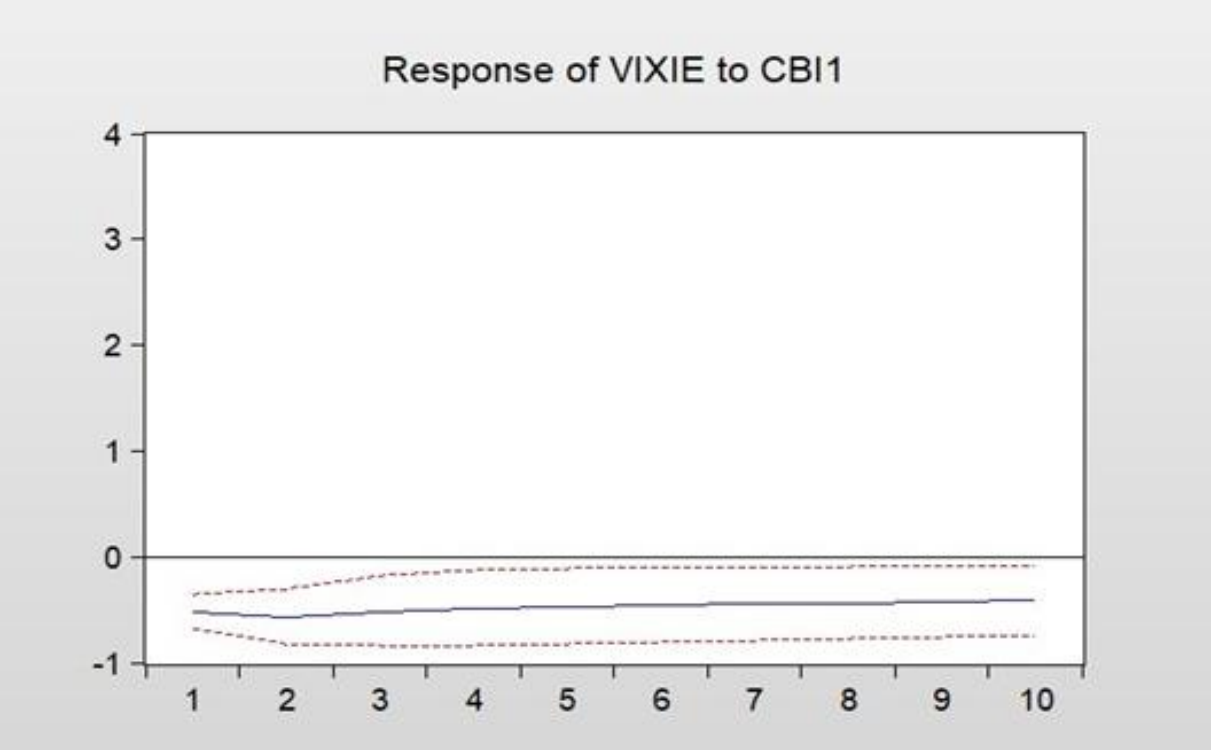


Figure 1 illustrates that a one-standard-deviation shock to the CBI return leads to an immediate decline in the VIXIE index during periods 1 and 2, indicating a short-term negative response. In periods 3 and 4, the response becomes slightly less negative but remains below zero. From period 5 onward, the VIXIE index remains relatively stable in the negative region. This suggests that shocks to CBI returns are correlated with a persistent decrease in market volatility expectations, both in the short term and the long term. The findings imply that when bond markets perform favourably, investor sentiment tends to improve, thereby diminishing the demand for volatility protection instruments such as VIXIE. During periods of high volatility, bond investors tend to sell their bonds and reallocate their investments into liquid instruments that are exempt from interest rate risk.

Figure 2 Response of VIXIE to GBI return

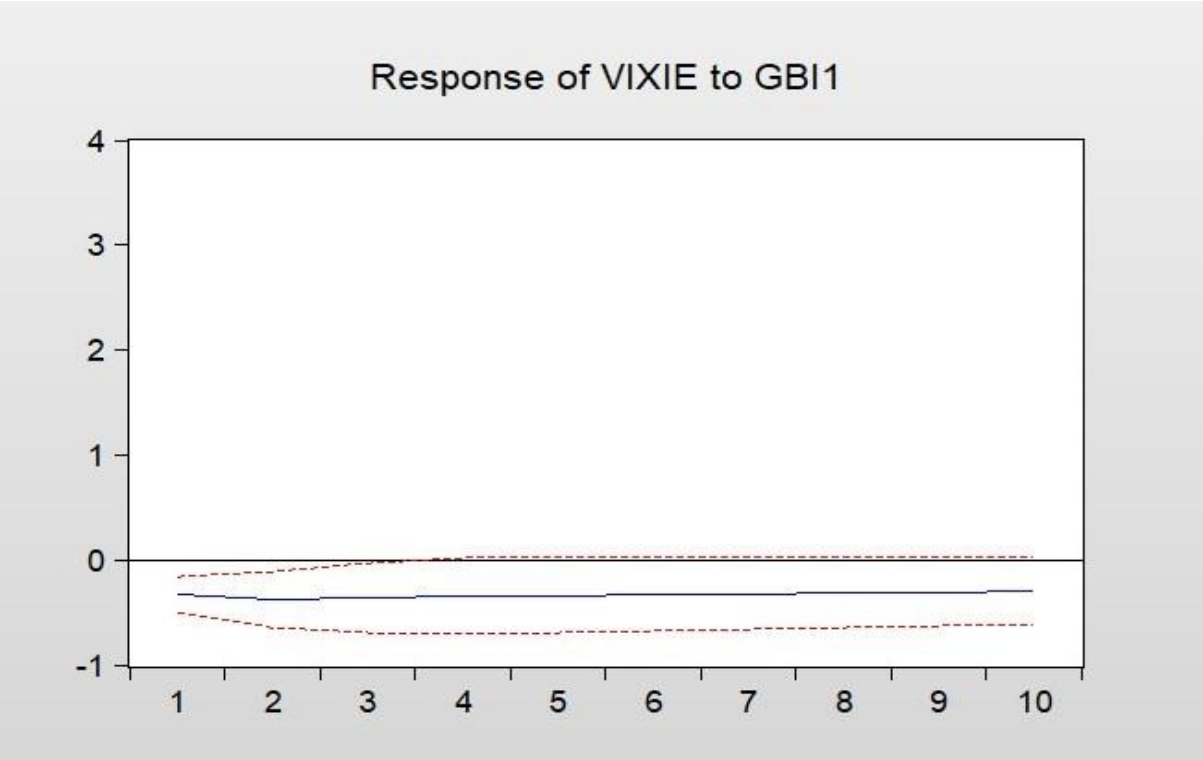


Figure 2 depicts the impulse response of VIXIE to a one-standard-deviation shock in GBI returns. The graph demonstrates that VIXIE initially responds negatively during periods 1 and 2, indicating that a shock to GBI diminishes market volatility in the short term. In periods 3 and 4, the response becomes marginally more negative. From period 5 onward, VIXIE consistently remains in the negative zone, signifying a sustained negative effect until period 10. This pattern suggests that shocks to GBI returns reduce market volatility, possibly because investor sentiment shifts towards safer or more sustainable investments during uncertain times. Investors may reallocate capital into green bonds, perceiving them as safer or more resilient, particularly during high-volatility phases. The return of CBI is more substantially affected by the shock than that of GBI, indicating the presence of a green premium during volatile periods. This finding is consistent with previous research such as Baker et al. (2019), Nanayakkara and Colombage (2019), and Zerbib (2019), which emphasise the stabilising role of green finance during turbulent periods.

Figure 3 Response of VSTOXX to CBI return

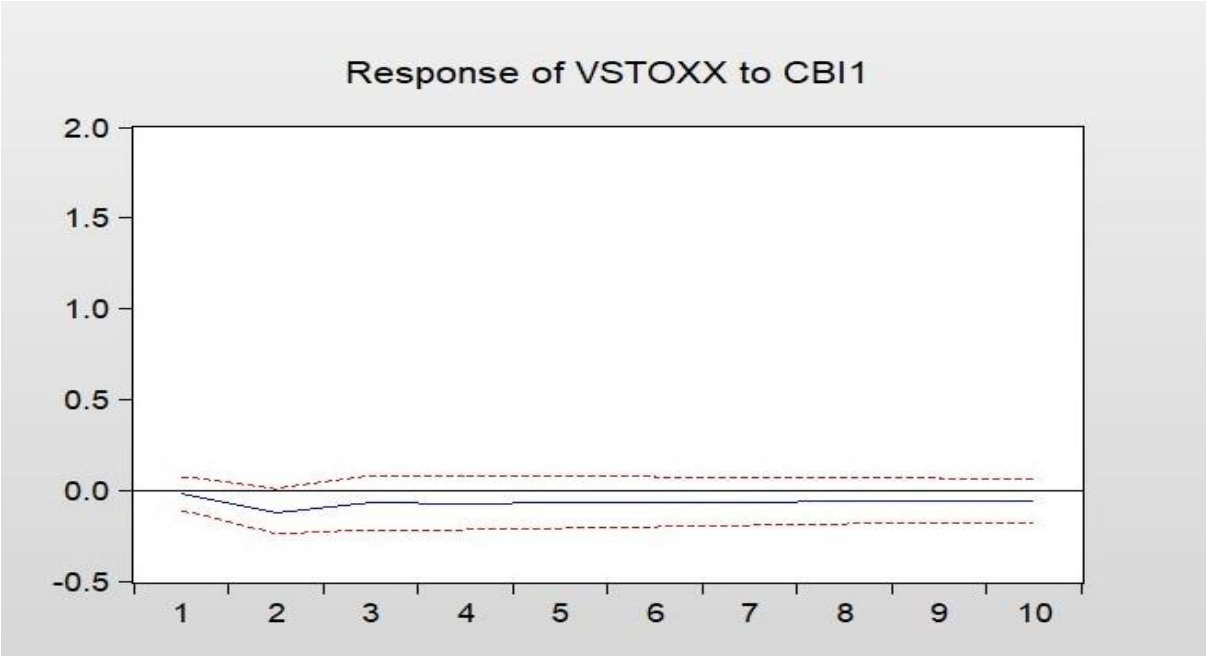


Figure 3 illustrates the impulse response of the VSTOXX index to a one-standard-deviation shock in CBI returns. The findings indicate that the VSTOXX responds negatively during the initial two periods, implying that an increase in CBI returns initially diminishes market volatility within the Eurozone. In periods three and four, the effect marginally reverses but remains near zero. From the fifth period onwards, the response persists in the negative domain, suggesting a sustained suppressive impact on volatility over the medium to long term.

Figure 4 Response of VSTOXX to GBI return

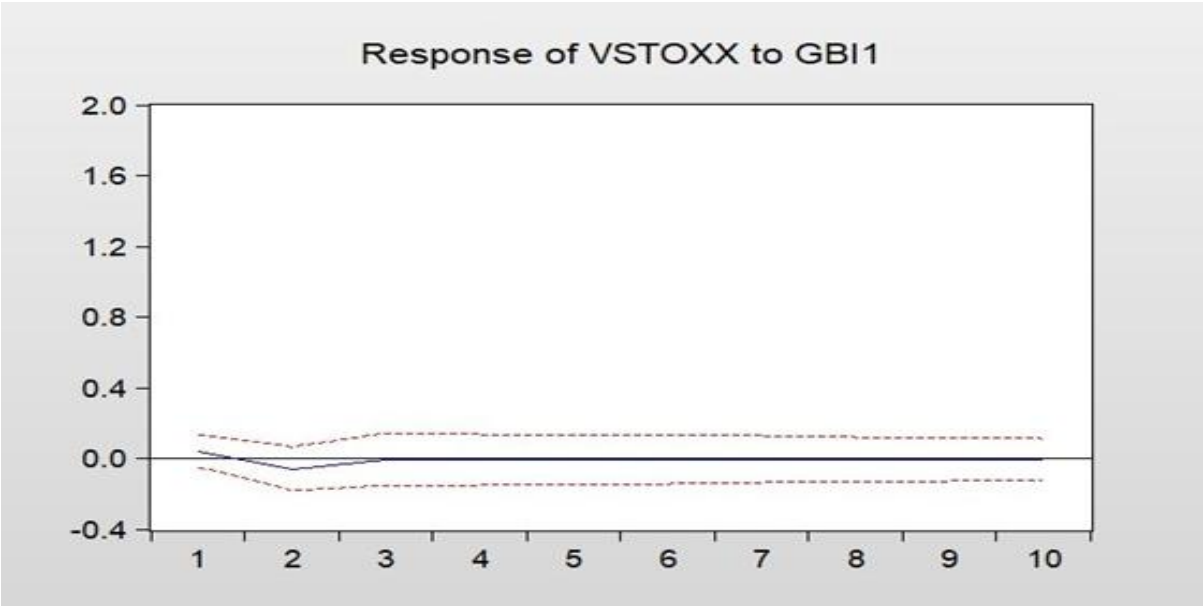


Figure 4 illustrates the impulse response of the VSTOXX index to a one-standard-deviation shock in GBI returns. The graph demonstrates that a positive shock to GBI return initially causes a slight decline in the VSTOXX during the first two periods, followed by a modest increase in the third period. Subsequently, after the fourth period, the response stabilises and remains proximate to zero through the tenth period. This pattern indicates that GBI returns exert a mild, short-lived negative influence on Eurozone market volatility, as measured by the VSTOXX index. Significantly, this decline in GBI returns is less pronounced than that observed in CBI. The return to pre-volatility levels occurs within three periods, implying the existence of a green premium during volatile times. The smaller magnitude and rapid reversion to baseline suggest that GBI return is less responsive to market sentiment, or that investors perceive it as a more stable and less risky asset class. This finding aligns with the results of Baker et al. (2019), Nanayakkara and Colombage (2019), and Zerbib (2019) in the existing literature.

Figure 5 Response of GVZ to CBI return

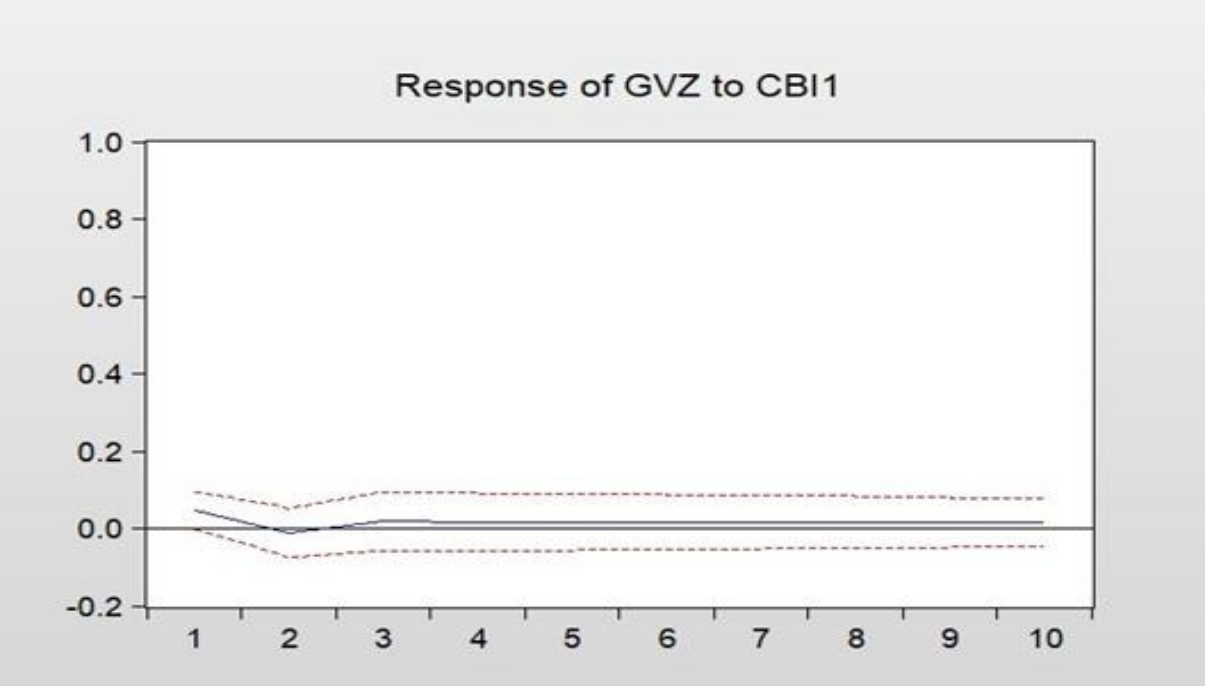


Figure 5 shows that a one-standard-deviation shock to CBI return initially lowers GVZ in periods 1 and 2, crosses the negative region, and then increases it in periods 3 and 4. Beyond the 5th period, GVZ remains flat in the positive region until period 10. Shocks to CBI return have a positive impact on GVZ both in the short run and long run. When the GVZ index rises, it often signals increased market uncertainty and inflation concerns (commodity spikes), which lead to looser monetary policy. Consequently, bond returns tend to increase. This result is similar to that of Naeem et al (2021) in the literature.

Figure 6 Response of GVZ to GBI return

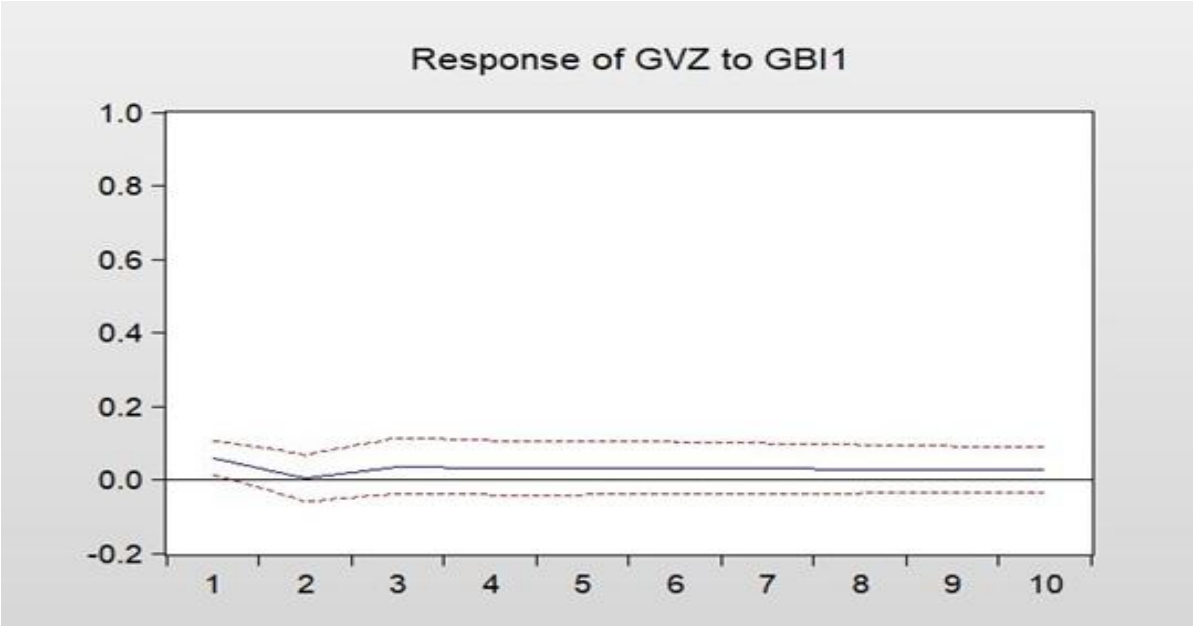


Figure 6 shows that a one-standard-deviation shock to GBI return first lowers GVZ in periods 1 and 2 until the X-axis, and then increases it in period 3. Beyond the 4th period, GVZ remains flat in the positive region until period 10. Shocks to GBI return have a positive impact on GVZ both in the short run and long run. CBI return is affected slightly less by the shock compared to GBI return, indicating a premium.

Figure 7 Response of OVX to CBI return

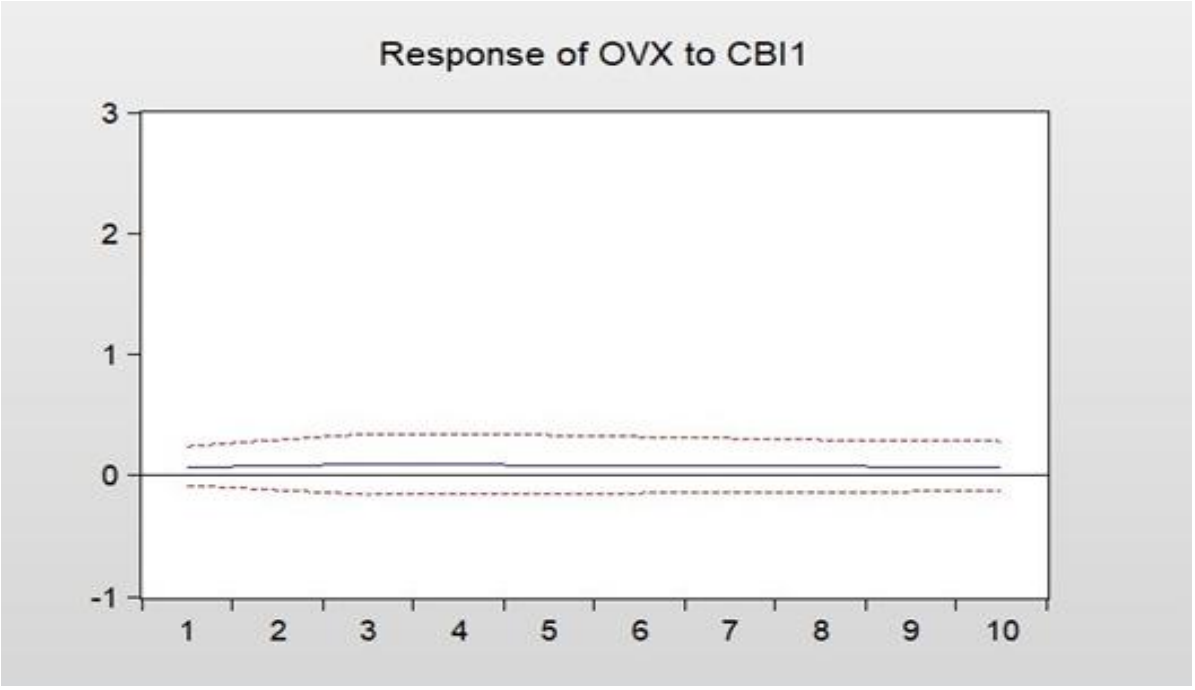


Figure 7 shows that a one-standard-deviation shock to CBI return first increases OVX in periods 1 and 2 in the positive region, and then remains flat in periods 3 and 4. Beyond the 5th period, OVX falls slightly and stays flat in the positive region until period 8. Once more, it falls slightly in 8 and remains flat till period 10. Shocks to CBI return will have a positive impact on OVX both in the short run and

the long run. Oil volatility signals increased macroeconomic and financial uncertainty, leading to flight-to-safety flows into bonds and expectations of looser monetary policy because of recession fears, both of which boost bond returns. This result is similar to Hietakangas and Dutta (2024) in the literature.

Figure 8 Response of OVX to GBI return

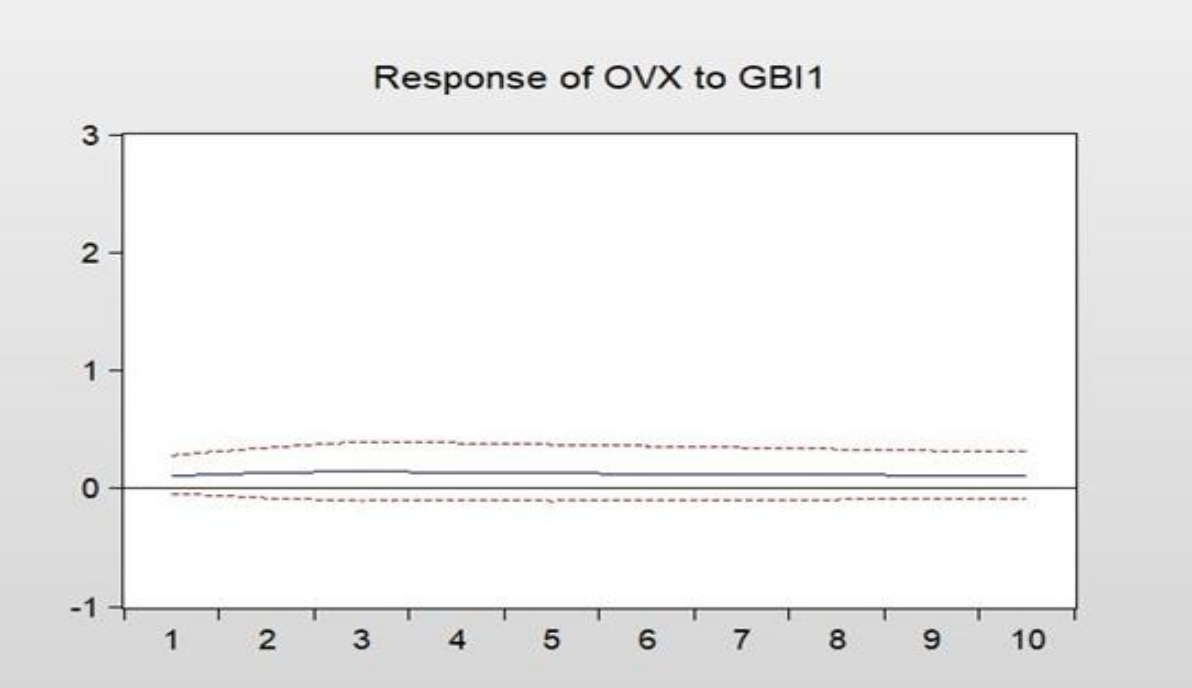


Figure 8 shows that a one-standard-deviation shock to GBI return first increases OVX in periods 1 and 2 in the positive region, and then stays flat in periods 3 and 4. Beyond the 5th period, OVX falls slightly and stays flat in the positive territory until period 8. Once more, it falls slightly in 8 and remains flat till period 10. Shocks to GBI return have a positive effect on OVX both in the short run and long run. The GBI return is affected less than the CBI return.

Figure 9 Response of EVZ to CBI return

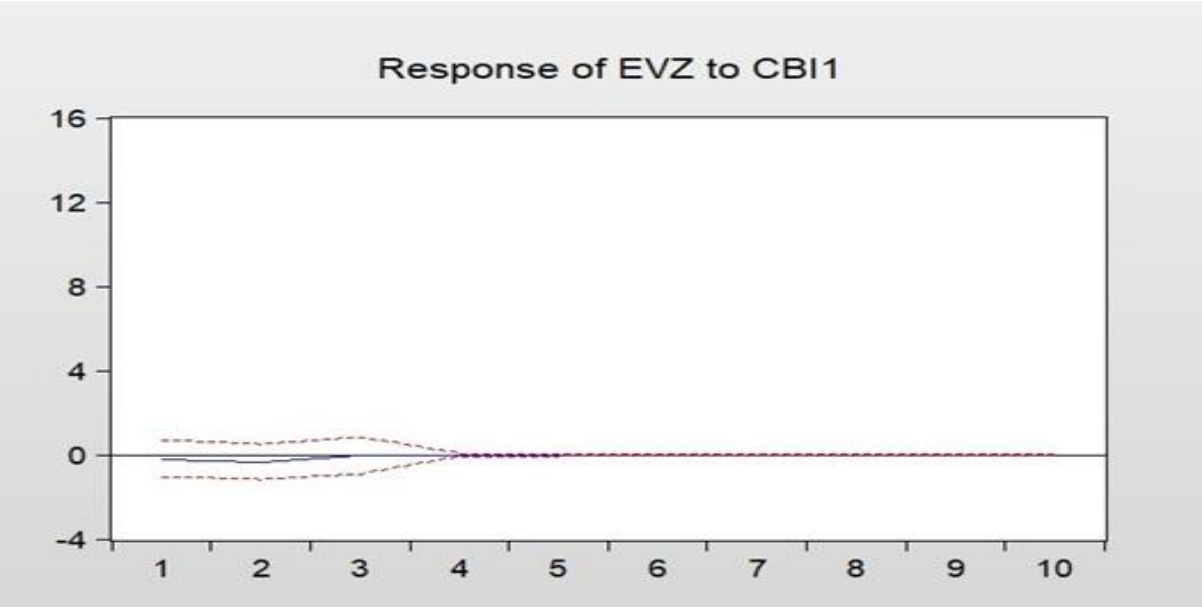


Figure 9 shows that a one-standard-deviation shock to CBI returns first lowers EVZ in periods 1 and 2, and then raises it in period 3. Beyond the 4th period, EVZ remains flat on the X axis until period 10.

Figure 10 Response of EVZ to GBI return

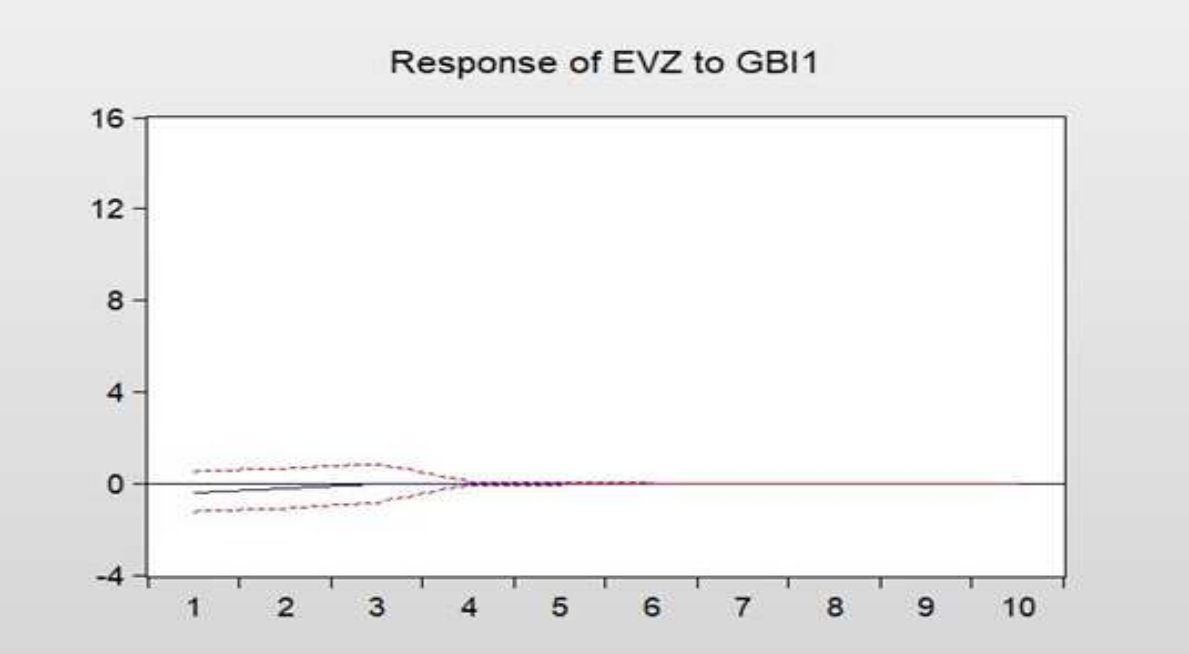


Figure 10 shows that a one-standard-deviation shock to GBI returns first increases EVZ in periods 1, 2, and 3 in the negative region. Beyond the 4th period, EVZ remains flat on the X axis until period 10.

6 Conclusions

This research aims to provide insights into the volatility dynamics of both the green bond market and the conventional bond market in Europe by employing Granger causality, Vector Autoregression (VAR), and impulse response models.

The MSCI EUR Corporates IG Climate Change ESG Select Index (GBI) and the MSCI EUR Corporates IG Select Index (CBI) have been employed to represent the green bond market and the conventional bond market, respectively. Moreover, the EVZ, VIXIE, OVX, GVZ and VSTOXX indices have been utilised as risk indicators.

The VAR model reveals a negative relationship between green bonds and volatility indices (VIXIE and VSTOXX), similar to that observed for traditional bonds. If the VIXIE index increases, the GBI return diminishes slightly more than the CBI return, indicating that there is no green premium. On the other hand, if the VSTOXX index increases, the decline in GBI return is slightly less than that of CBI return, suggesting the presence of a green premium. A significant positive relationship exists between the volatility indices (GVZ and OVX) and the CBI return and the GBI return, respectively. If the GVZ index increases, the GBI return rises slightly more than the CBI return, indicating a premium. Conversely, if the OVX index rises, the GBI return increases slightly less than the CBI return, not suggesting a premium. The VAR model detects a small green premium on green bonds compared to conventional bonds for VSTOXX and GVZ; however, no green premium is observed for VIXIE and OVX indices during periods of volatility.

The Granger Causality model reveals that VIXIE is a key "causal driver" that imposes Granger causality over several variables, including CBI, EVZ, GBI, GVZ, OVX, and VSTOXX. Additionally, CBI primarily acts as a "receiver" from VIXIE and VSTOXX, while also serving as a causative factor for GBI and GVZ. Moreover, no causality has been found between EVZ and CBI, or GBI, in either direction. Volatility indices (VIXIE, VSTOXX, OVX, GVZ) demonstrate a network of causal

influences, signalling interconnectedness within markets. It is worth testing the interconnectedness and spillover effect using the same data for the European bond market.

The impulse response figure for VIXIE to CBI and GBI returns shows that CBI is more affected by the shock than GBI, indicating a green premium during volatile periods. In addition, the impulse response figure for VSTOXX to CBI and GBI returns indicates that CBI is more affected by the shock compared to GBI, suggesting the presence of a green premium during volatile periods. Moreover, the impulse response figure for GVZ to CBI and GBI return shows that CBI is affected slightly less by the shock compared to GBI, indicating a premium. However, the impulse response figure for OVX to CBI and GBI returns shows that the GBI return is affected less than the CBI return, indicating no premium.

Corporate green bonds in Europe exhibit a lower susceptibility to shocks compared to conventional corporate bonds, thereby confirming the presence of a green premium. This finding has significant implications for collateral management among lenders and borrowers, as increased resilience to volatility shocks indicates a considerable improvement in collateral quality.

ETHICAL APPROVAL:

This article does not contain any studies with human participants performed by any of the authors

INFORMED CONSENT:

This article does not contain any studies with human participants performed by any of the authors

Key Statement:

1. There are no competing interests.
2. Ethical approval is not required. This article does not contain any studies with human participants performed by any of the authors.
3. The data used in this study were obtained from the Bloomberg Database, which is a proprietary commercial database requiring institutional or individual subscription access. Therefore, we are unable to provide a direct public access link to the dataset. Access to these data requires registration and subscription/payment through Bloomberg. The data can be accessed at: https://www.bloomberg.com/professional/solution/bloomberg-terminal/, but we have downloaded the data and included it in the supplementary file.
4. The research receives no funding.

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- result25.08.2025.docx
- resultVectorAutoregressionEstimates.docx