International Journal of Management and Sustainability
2024 Vol. 13, No. 2, pp. 221-231
ISSN(e): 2306-0662
ISSN(p): 2306-9856
DOI: 10.18488/11.v13i2.3643

Diverse linkages between green bonds and equity indices of developed and developing economies

Deepa Pillai[1]
Adesh Doifode[2]
Neha Parashar[3+]
Trupti Bhosale[4]
Aniruddha Ghosh[5]
Sandhya Surapalli[6]
Rahul Sharma[7]

[1,2,3,4]*Symbiosis School of Banking and Finance, Symbiosis International, (Deemed University), Pune, India.*
[1]*Email: deepa.pillai@ssbf.edu.in*
[2]*Email: adesh.doifode@ssbf.edu.in*
[3]*Email: nehaparashar10@gmail.com*
[4]*Email: trupti.bhosale@ssbf.edu.in*
[5]*Indian Institute of Foreign Trade, India.*
[5]*Email: prof.aniruddhaghosh@gmail.com*
[6]*IBS Hyderabad, ICFAI Foundation for Higher Education, India.*
[6]*Email: yes.sandhya@gmail.com*
[7]*School of Business, Skyline University College, Sharjah, UAE.*
[7]*Email: rahulgsharma@gmail.com*

(+ Corresponding author)

Article History
Received: 13 September 2023
Revised: 19 December 2023
Accepted: 29 January 2024
Published: 14 February 2024

Keywords
Global equities
Green bonds
VAR-BEKK GARCH
Volatility spillover.

ABSTRACT

This paper investigates the dynamic conditional correlations and volatility spillovers between global stock markets and international green bonds. Envisaging the linkages between the emerging green bond markets and global equities given the unforeseen global pandemic. We use R software to run bivariate VAR-BEKK GARCH and BEKK GARCH models to investigate the time-varying conditional volatility between global stock indices and green bond indices. Daily prices of all variables from October 2014 to April 2023 are sourced from the Bloomberg database. The short-term influence of past events, as well as the long-term persistence of green bonds, on the current conditional volatility of global equity indices of developed and emerging economies is observed. Whereas from equity markets to green bond indices, the short-term as well as long-term impact is confined to only 2-3 indices. The results provide future direction for policymakers, researchers, and global investors in hedging and creating an optimal portfolio.

Contribution/Originality: The volatility impact between equity indices of developed and developing economies and green bonds is investigated. Similar previous studies are very shallow and are limited to major economies. Examining COVID-19's impact on these time-varying linkages will be a critical and significant contribution to the past heterogeneous findings.

1. INTRODUCTION – GREEN BONDS AND FINANCIAL MARKETS – GENERAL OVERVIEW

The rising threat of climate change has raised concerns among corporate enterprises about the need to align their investments with net zero. Financial markets play a critical role in transitioning towards low-carbon economies through a range of market products, practices, and policies. Thus, augmenting sustainable finance methods and market alignment with climate transition becomes significant. There are challenges associated with climate change and unparalleled investment opportunities in transitioning towards a low-carbon, climate-resilient economy. Over the years, Green Bonds have become a critical financial instrument to address the impact of climate change and associated challenges. Green bonds resemble similar characteristics to conventional bonds, the exception being that the proceeds of the issue are mandated for investing in environmental projects. The green bond acts as a financial instrument for investors for green projects and activities. In 2010, the International Finance Corporation issued green bonds as a response to investors seeking fixed income on a climate-related investment.

Previous studies indicate no significant difference between the performance of green bonds and traditional bonds. Green bonds had a premium price compared to conventional bonds (Baulkaran, 2019). Over the decade, the green bond market has become a prevalent and noticeable investment, attracting investors in sectors close to the natural environment, and green bond studies are more prevalent in China, Europe, and the United States (Flammer, 2021). The issuers of green bonds must comply with the principles related to green bonds, which are issued by the International Capital Market Association. The bonds mainly address issues related to climate change, loss of biodiversity, environmental pollution, and depletion of natural resources. The bond issuers range from local bodies to international institutions and traditionally focus on the shareholders' value (Bachelet, Becchetti, & Manfredonia, 2019). As the green bond market matures, it is essential to acquire a fair idea of the risk and return behaviour in volatile financial markets. Volatility transmission between financial markets or asset classes is referred to as a volatility spillover. Understanding the volatility spillovers in the context of green bonds and global equity indices can shed light on how sustainability and the environment affect financial markets. A study on the empirical analysis of daily data from 2010 to 2015 results indicates a short-term shock in the conventional bond market has a spillover impact on the green bond market, illustrating volatility clustering in markets, which demonstrates the interrelationship between the conventional and green bond markets (Pham, 2016; Reboredo & Ugolini, 2020).

The research methods commonly discussed across the literature on the interlinkages between the markets are based on the structural VAR model.

Green bonds reflect a high level of interaction during the chaotic market movements in the conventional bond market and energy commodities. Studies specify that the dynamic conditional correlation between green bonds and the conventional bond market increases as the value of the US dollar increases and decreases in the dynamic conditional correlation between the commodities and equity markets (Kocaarslan & Soytas, 2021). Moreover, the association between the green bond and the conventional bond market is driven by macroeconomic factors: economic policies, state of economic activity, investor sentiments, external shocks, and volatility, which also have an impact on the performance of the commodity market, creating the basis for interdependence (Broadstock & Cheng, 2019).

The financial markets have evolved and become more complex with the advent of financial innovations. However, with the constant development of the green bond market, investors have a wide range of investment opportunities for diversifying their portfolios. These transitions in the financial markets have a macro-level impact. Thus, studying the relationship of the green bond market with the other financial markets becomes vital for understanding its distinguishing features. In the given context, the paper attempts to explore the interlinkage and spillover effect of the green bond market on the conventional asset market. Understanding the volatility spillover mechanism between financial markets and green bonds is important to assess the interplay of green bonds in hedging and risk management strategies (Reboredo, 2018). Theoretically, green bonds and conventional financial markets are interconnected. However, the investment motives of investors for holding a green bond vary across different markets and time periods. Detailed information on the interlinkages between the markets would be essential for investors for efficient portfolio management. The main contribution of the research is twofold: a comprehensive investigation to provide new practical insights on the topic of green bonds and equity indices. Secondly, analyzing the performance of green bond markets and equity indices at different time intervals, which cover undefined events, will provide new empirical evidence.

1.1. Research Objectives

1. The demand for green bonds and other sustainable finance has increased rapidly. The issuers of these instruments foresee it as an opportunity, but it is often countered with uncertainty. How does the uncertainty affect the green bond markets?

2. Emerging market green bonds are an attractive and growing opportunity for fixed-income investors. How does green finance improve the environment and reduce risk dispersion through diversified financial instruments?
3. What are the spillover effects of green bonds on other financial markets?

2. LITERATURE REVIEW

Previous studies are confined to the association between the financial market and macroeconomic factors (Lee & Ryu, 2018). The green bond market is a relatively new phenomenon that comprises fundamental studies. Empirical studies have been undertaken on the aggregate bond index to analyze the volatility and its spillover effects using the GARCH Model on the green and conventional bond markets. Studies demonstrate that green bond markets do not offer diversification benefits to investors in conventional markets (Reboredo, 2018). However, volatility dynamics and their transmission between connected markets have been widely discussed by economists(Chun, Cho, & Ryu, 2019, 2020). More research exists on the association between macroeconomic factors and the financial markets, cross-market effects in context to return dynamics, volatility dynamics, and volatility spillovers. However, the interdependencies of the markets and their spillover linkages are scarcely researched (Izadi & Hassan, 2018; Lee & Ryu, 2018; Lee & Ryu, 2019; Park, Kutan, & Ryu, 2019; Yang, Kim, Kim, & Ryu, 2018).

Investments in green bonds can be hedged using equity indices of specific sectors: real estate, consumer staples, and information technology (Fernandes, Silva, de Araujo, & Tabak, 2023). Literature evidences a nonlinear relationship between the US markets and green bonds. However, the research states the capacity of green bonds, gold, silver, oil, the US dollar index, and the volatility index to protect against declines in US stock prices before, during, and after the COVID-19 pandemic aftermath in the short and long run. The current research employs the frequency spillover measures developed by Mensi, Naeem, Vo, and Kang (2022) and the TVP-VAR model (Diebold & Yılmaz, 2014). The study demonstrates that the short-term spillovers of volatility outweigh their long-term equivalents. In the short term, Green Bond is a net transmitter of spillovers in the system, while in the long term, it is a net recipient. Both short- and long-term spillovers are net transmitters (receivers) for the S&P500, silver, USDX, and gasoline. Short-term spillovers are net recipients for Gold and VIX. Further, the study also examines the volatility patterns in the green bond and equity markets. The result demonstrates the asymmetric volatility phenomenon and its positive impact on stock returns.

This study by Elsayed, Naifar, Nasreen, and Tiwari (2022)uses a multivariate wavelet approach and dynamic connectedness to investigate the relationship between green bonds and financial markets in the time-frequency domain. Ensemble Empirical Mode Decomposition (EEMD) and the Diebold and Yilmaz (2012)spillover framework are combined to achieve this. According to the results of wavelet multiple correlations, the advantages of diversification opportunities are more obvious in the near term. Wavelet multiple cross-correlations data shows that financial markets and green bonds have a close relationship over time. The findings of the static connectedness framework provide an explanation for why different markets act differently in terms of the direction and magnitude of spillover. The corporate bond market is the net spillover receiver among the chosen markets, while the global equity market is the net spillover transmitter. Previous studies have used the GARCH model to highlight the covariance of returns to the stocks of small and large firms, which demonstrate asymmetric signals towards anomalies (Kroner & Ng, 1998). The studies prove the existence of asymmetry in the equity and bond markets through conditional correlations. The MGARCH model has been used to explore the volatility spillovers between the markets in Europe, and studies recommend a dynamic trading strategy (Chulia & Torro, 2008).

3. DATA

Daily data on green bonds and equity indices of ten countries from October 14, 2014 to April 12, 2023 is used in this research. The data for this research paper is sourced from the Bloomberg terminal. Two sets of a total of ten global equity indices are used in this study, viz. S&P 500 Index, Nikkei 225 Index, DAX 30 Index, FTSE 100 Index, CAC 40 Index, Shanghai Composite 30 Index, Nifty 50 Index, KOSPI Index, Bovespa Index, and IPC Mexico 35 Index, as shown in Table 1. Shock transmission and volatility spillover between the MSCI Global Green Bond Index and S&P Green Bond Index with these ten global equity indices are examined.

Table 1. Variable description.

Name	Description
SnP	S&P 500 index
Nikkei	Nikkei 225 index
DAX	DAX 30 index
FTSE	FTSE 100 index
CAC	CAC 40 index
Shanghai	Shanghai composite 30 index
Nifty	Nifty 50 index
Kospi	KOSPI index
Bovespa	Bovespa index
Mexico	IPC Mexico 35 index
MSCIGB	MSCI global green bond index
SPGB	S&P green bondindex

The correlation between the green bond indices and global equity indices of developed and developing countries is studied before studying the volatility linkages between them. It is observed that the global equity indices of developed and developing countries have a positive correlation with the MSCI green bond index compared to a negative correlation with the S&P green bond index.

3.1. Data Pre-Processing and Initial Analysis

To understand the volatility and spillover effects of the global markets on the two emerging green bond markets, viz., MSCI and S&P Green Bond indices, compared with ten global equity market indices (***refer to*** Tables 4 and 5), for the period October 2014 to April 2023. We carried out the analysis by transforming these monthly prices into a log return series, as shown in Equation 1.

$$Returns_{i,t} = \ln\left(\frac{Price_{i,t}}{Price_{i,t-1}}\right) \qquad (1)$$

Table 3 shows the descriptive statistics of each equity market along with the two green bond indices. The skewness revealed that all the equity indices are negatively skewed. Meanwhile, one of the green bond indices, i.e., the S&P Green Bond index, is positively skewed. From the Jarque-Bera test, we reject the null hypothesis for equity and green bond indices, which reveals that none of the indices follows the Gaussian distribution. The null hypothesis of the augmented Dickey-Fuller (ADF) and Phillips-Peron (PP) tests is rejected, which means that there is no unit root and our log returns are non-stationary. The authors also performed the ARCH test, which is significant. It also indicates the presence of autoregressive conditional heteroscedasticity (ARCH) in the data. Thus confirming that the GARCH family models are suitable for this study. However, to estimate the dependencies of the market, we ran a correlation of the log returns of the different equity markets taken into the study. We found that there is a moderate to strong correlation among returns in various markets (Table 3). We observed that S&P had moderate dependencies on DAX, FTSE, CAC, Bovespa, and Mexico's equity markets. Similarly, NIKKEI has a moderate dependency on KOSPI; DAX has a moderate relationship with S&P, Nifty, Bovespa, and Mexico; whereas strong dependencies were found for CAC and FTSE stock exchanges. Similarly, in the Indian context, Nifty has a moderate dependency on DAX, FTSE, CAC, and KOSPI stock exchange returns. The above evidence encourages us to verify these dependencies using the models from the GARCH family.

Table 2. Correlation matrix.

Variables	14 Oct 2014 to 12 April 2023											
	SnP	**Nikkei**	**DAX**	**FTSE**	**CAC**	**Shanghai**	**Nifty**	**KOSPI**	**Bovespa**	**Mexico**	**MSCIGB**	**SPGB**
SnP	1	0.239	0.611	0.576	0.606	0.149	0.332	0.226	0.631	0.546	0.193	-0.122
Nikkei	0.239	1	0.351	0.363	0.361	0.321	0.380	0.614	0.204	0.239	0.132	-0.110
DAX	0.611	0.351	1	0.853	0.949	0.191	0.502	0.376	0.484	0.530	0.235	-0.245
FTSE	0.576	0.363	0.853	1	0.884	0.225	0.514	0.381	0.510	0.558	0.105	-0.173
CAC	0.606	0.361	0.949	0.884	1	0.203	0.538	0.389	0.508	0.548	0.217	-0.241
Shanghai	0.149	0.321	0.191	0.225	0.203	1	0.308	0.410	0.176	0.166	0.108	-0.140
Nifty	0.332	0.380	0.502	0.514	0.538	0.308	1	0.525	0.380	0.346	0.203	-0.187
KOSPI	0.226	0.614	0.376	0.381	0.389	0.410	0.525	1	0.262	0.310	0.203	-0.141
Bovespa	0.631	0.204	0.484	0.510	0.508	0.176	0.380	0.262	1	0.505	0.092	-0.109
Mexico	0.546	0.239	0.530	0.558	0.548	0.166	0.346	0.310	0.505	1	0.143	-0.164
MSCIGB	0.193	0.132	0.235	0.105	0.217	0.108	0.203	0.203	0.092	0.143	1	0.096
SPGB	-0.122	-0.110	-0.245	-0.173	-0.241	-0.140	-0.187	-0.141	-0.109	-0.164	0.096	1

Note: Correlation coefficients among green bond indices and global equity indices.

Table 3. Descriptive statistics.

Particulars	14 Oct 2014 to 12 April 2023											
	SnP	**Nikkei**	**DAX**	**FTSE**	**CAC**	**Shanghai**	**Nifty**	**KOSPI**	**Bovespa**	**Mexico**	**MSCIGB**	**SPGB**
Mean	0.0004	0.0003	0.0003	0.0001	0.0003	0.0002	0.0004	0.0001	0.0003	0.0001	0.0000	-0.0002
Maximum	0.0897	0.0773	0.1041	0.0867	0.0806	0.0560	0.0840	0.0825	0.1302	0.0474	0.0263	0.0226
Minimum	-0.1277	-0.0825	-0.1305	-0.1151	-0.1310	-0.0887	-0.1390	-0.0877	-0.1599	-0.0664	-0.0303	-0.0246
Standard deviation	0.0116	0.0124	0.0127	0.0103	0.0124	0.0132	0.0106	0.0100	0.0160	0.0098	0.0043	0.0049
Skewness	-0.8157	-0.1219	-0.5863	-0.8943	-0.8555	-1.1589	-1.4311	-0.2731	-1.0022	-0.4212	-0.2209	0.1386
Kurtosis	18.9762	8.1161	12.9641	15.6590	13.8387	11.0802	24.2259	11.3595	17.3607	6.7924	7.6705	5.3404
Jarque-Bera	23823***	2423***	9298***	15099***	11122***	6527***	42375***	6483***	19422***	1394***	2033***	193***
Observations	2217	2217	2217	2217	2217	2217	2217	2217	2217	2217	2217	833
ARCH	509.8***	168.9***	7.3***	59.7***	27.4***	99.7***	65.1***	716.9***	620.9***	80.6***	167.4***	12.7***
Unit root tests												
Augmented Dickey-Fuller	-12.5***	-19.1***	-15.1***	-15.5***	-17.5***	-9.2***	-14.2***	-10.1***	-12.4***	-18.4***	-30.5***	-11.7***
Phillips–Perron	-54.1***	-48.7***	-48.1***	-47.8***	-47.4***	-45.5***	-47.5***	-47.7***	-52.3***	-44.2***	-42.7***	-32.1***

Note: ***, denotes the significance level at 1% respectively. Unit Root Test is used to consider constants and trends. ARCH test signifies serial correlation of the heteroskedasticity in the data at 1 lag.

4. METHODOLOGY

In this study, we perform bivariate GARCH estimation using the asymmetric VAR-BEKK-GARCH model to estimate and analyse the volatility transfer between the green bond and the equity markets. We performed various tests using ACF and PACF tests to check the stationary of the different markets. This section describes the asymmetric volatility between the equity market indices and the green bond indices. As discussed in the earlier section, financial data generally promulgate asymmetric volatility. Previous authors like Park, Park, and Ryu (2020) found that US stock and bond markets and Dean, Faff, and Loudon (2010) found that Australian stock. The ARCH tests confirm there is a positive asymmetry among the equity and bond markets.

4.1. Bivariate GARCH Estimation

In this section, we analyse the volatility transfers between two markets, i.e., equity and bond markets, using a bivariate GARCH model. The ARCH test performed earlier shows evidence of the presence of asymmetrical traits between the equity and bond markets. Thus, the correlation between the various equity markets and bond indices convinces the use of the VAR-BEKK-GARCH model, which can reflect spillover effects and is appropriate for the given context. Previous researchers have conducted similar spillover studies on various macroeconomic variables (Aggarwal, Doifode, & Tiwary, 2020, 2021, 2022; Rastogi, Doifode, Kanoujiya, & Singh, 2023; Rastogi et al., 2024).

The empirical method consists of two sections to estimate return and volatility spillover through the VAR-BEKK-GARCH model. In the first case, we applied vector auto regression (VAR) to estimate the return spillovers. In the next scenario, we run the BEKK-GARCH model to project volatility spillovers, as prescribed byEngle and Kroner (1995). We know that a conditional mean and variance process explains the GARCH models. In this experiment, the conditional mean process of the models is defined in Equations2 and 3 because we aim to analyse the volatility spillover among the equity and bond markets. For estimating the return spillovers, the following are conditional mean equation specifications:

$$r_t = \mu + \varphi r_{t-1} + e_t \text{ and } e_t = H_t^{1/2} * \epsilon_t \qquad (2)$$

$r_t = (r_t^a, r_t^b)'$ is the vector of returns on the a^{th} stock index and b^{th} bond index at time t; $a = 1,2, \dots 10$; and $b = 1,2$; respectively. Again, φ is the 2x2 matrix of parameters, which estimates the impact of own lagged and cross-return spillovers between the variables.

In the subsequent experimentation, we have used $i =$1, 2, …10 to mean the different equity markets and $i =$ 1,2 to mean the two bond markets ,respectively. e_t is a residual vector following a bi-variate normal distribution with $E_{t-1}(e_t)$ =0 and $E_{t-1}(e_t e_t') = H_t$.

4.2. Implications for Market Portfolio Designs and Hedging Strategies

In this study, we also show how to use the estimated VAR-BEKK-GARCH model to create the best market portfolio designs and hedging strategies for equity market indices. Bond markets, on the other hand, have asymmetric volatility.

The output of the VAR-BEKK-GARCH model can be used to calculate the optimal portfolio weights and hedge ratios. As per the study of Kroner and Ng (1998), the optimum weight of the equity indices (EI) and bond indices (BI) is computed as follows:

$$w_{EIBI,t} = \frac{h_{BI,t} - h_{EIBI,t}}{h_{EI,t} - 2h_{EIBI,t} + h_{BI,t}} \qquad (3)$$

$$w_{EIBI,t} = \begin{cases} 0, & If \quad W_{EIBI,t} < 0 \\ w_{EIBI,t}, & If \quad 0 \leq W_{EIBI,t} \leq 1 \\ 1, & If \quad W_{EIBI,t} > 1 \end{cases}$$

Considering a \$1 portfolio of equity and bond, $w_{EIBI,t}$ represents the weight of equity and $1 - w_{EIBI,t}$ is the weight of bond. $h_{EIBI,t}$ represents the conditional covariance between the equity and the bond indices, $h_{EI,t}$ and

$h_{BI,t}$ indicate the conditional variance of the equity and the bond indices, respectively. The following specifications are used to estimate the hedge ratio, proposed by Kroner and Sultan (1993):

$$\beta_{EIBI,t} = \frac{h_{EIBI,t}}{h_{BI,t}} \quad (4)$$

Where $\beta_{EIBI,t}$ is the hedge ratio. A long position can be hedged in the equity index with a short position in the bond index.

4.3. The VAR-BEKK Model

The estimated variance of an Equity index/asset return can be written as:

$$\sigma_{1,t}^2 = C(1,1)^2 + C(1,2)^2 + A(1,1)^2 u_{1,t-1}^2 + 2A(1,1)A(2,1)u_{1,t-1}u_{2,t-1} + A(2,1)^2 u_{2,t-1}^2 + B(1,1)^2\sigma_{1,t-1}^2 + 2B(1,1)B(2,1)\sigma_{12,t-1} + B(2,1)^2\sigma_{2,t-1}^2 + D(1,1)^2 v_{1,t-1}^2 + 2D(1,1)D(2,1)v_{12,t-1} + D(2,1)^2 v_{2,t-1}^2$$

The estimated variance of the Green Bond index/asset return can be written as:

$$\sigma_{1,t}^2 = C(2,1)^2 + C(2,2)^2 + A(1,2)^2 u_{1,t-1}^2 + 2A(1,2)A(2,2)u_{1,t-1}u_{2,t-1} + A(2,2)^2 u_{2,t-1}^2 + B(1,2)^2\sigma_{1,t-1}^2 + 2B(1,2)B(2,2)\sigma_{12,t-1} + B(2,2)^2\sigma_{2,t-1}^2 + D(1,2)^2 v_{1,t-1}^2 + 2D(1,2)D(2,2)v_{12,t-1} + D(2,2)^2 v_{2,t-1}^2$$

The estimated co-variance b/w the Equity indices and green bond indices can be written as:

$$\sigma_{12,t} = C(1,1)C(2,1) + A(1,1)A(1,2)u_{1,t-1}^2 + \big(A(1,2)A(2,1) + A(2,1)A(2,2)\big)u_{1,t-1}u_{2,t-1} + A(2,1)A(2,2)u_{2,t-1}^2 + B(1,1)B(1,2)\sigma_{1,t-1}^2 + \big(B(1,2)B(2,1) + B(2,1)B(2,2)\big)\sigma_{12,t-1} + B(2,1)B(2,2)\sigma_{2,t-1}^2 + D(1,1)D(1,2)v_{1,t-1}^2 + \big(D(1,2)D(2,1) + D(2,1)D(2,2)\big)v_{1,t-1}v_{2,t-1} + D(2,1)D(2,2)v_{2,t-1}^2$$

Where,

C= Constant term.

A news effect or spillover.

B = Persistency effect.

D = Asymmetry effects.

u = Error term from the news effect.

v = Error term from the asymmetry effect.

5. RESULTS AND ANALYSIS

The VAR-BEKK-GARCH is more efficient and requires fewer parameters for analysing spillovers between financial assets (Carpantier & Samkharadze, 2013; Chuang, Lu, & Tswei, 2007; Salisu & Mobolaji, 2013; Schreiber, Müller, Klüppelberg, & Wagner, 2012). The bivariate VAR-BEKK-GARCH (1,1) model is applied in this study, and the findings are shown in Tables 4 and 5. Inter-linkages between Green bond indices and Global equity indices of developed and developing countries are examined. The ARCH effect is present in all the variables used in this research (Table 2), allowing GARCH models to test shock transmission and volatility spillovers between Green bond indices and Global equity indices. The results of the VAR-BEKK model (Tables 4 and 5), which show the impact of lagged shocks on their own current conditional volatility, further support the ARCH effect in all the variables. When you look more closely, you can see that the square residuals in the VAR model are strongly related to each other in a series. This ARCH effect helps to group volatility together. In order to investigate the volatility spillover impact between Green Bonds and stock indices in more detail, a GARCH model can be created. Because the VAR-BEKK model can ensure the positive definiteness of the variance-covariance matrix under weak conditions and has the advantage of requiring fewer parameters to be evaluated when compared to standard GARCHs, a VAR-BEKK-GARCH (1,1) is chosen for this data.

Table 4. Bivariate VAR BEKK GARCH (1,1) estimation with MSCI Green Bonds.

Particulars	MSCIGB - SnP	MSCIGB - Nikkei	MSCIGB - DAX	MSCIGB - FTSE	MSCIGB - CAC	MSCIGB - Shanghai	MSCIGB - Nifty	MSCIGB - Kospi	MSCIGB - Bovespa	MSCIGB - Mexico
Variance equation:										
C_{11}	0.001***	0.003***	0.002***	0.002***	0.002***	0.001***	0.001***	0.002***	0.003***	0.001***
C_{21}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000**	0.000
C_{22}	0.000***	0.000***	0.000***	0.000	0.000***	0.000***	0.000***	0.000***	0.000	0.000***
S_{11}	0.458***	0.340***	0.306***	0.377***	0.386***	0.256***	0.299***	0.307***	0.275***	0.310***
S_{12}	0.018	0.004	0.012	0.008***	0.013	-0.009*	0.017	-0.002	0.019***	0.013
S_{21}	0.085	0.105	0.014	0.001	0.058	0.047	-0.043	0.137	-0.224**	0.048
S_{22}	0.205***	0.196***	0.224***	0.203	0.232***	0.211***	0.188***	0.211***	0.184***	0.209***
L_{11}	0.877***	0.907***	0.936***	0.896***	0.904***	0.964***	0.941***	0.921***	0.929***	0.929***
L_{12}	-0.005	-0.003	-0.003	-0.002***	-0.004	0.002	-0.005	0.000	-0.007**	-0.005
L_{21}	-0.020	-0.020	-0.002	0	-0.008	-0.008	0.002	-0.029	0.039	-0.020
L_{22}	0.974***	0.977***	0.968***	0.975***	0.967***	0.972***	0.978***	0.973***	0.978***	0.973***
Model diagnostics:										
AIC	-14.996	-14.444	-14.537	-14.961	-14.645	-14.497	-14.909	-14.957	-14.025	-14.920
Log-likelihood	16632.99	16021.10	16123.76	16593.30	16243.61	16080.08	16536.51	16589.21	15556.96	16548.50

Note: AIC refers to the Akaike information criterion. ***, **, * denotes the significance level at 1%, 5% and 10% respectively.

Table 5. Bivariate VAR BEKK GARCH (1,1) estimation with S&P Green Bonds.

Particulars	SPGB - SnP	SPGB - Nikkei	SPGB - DAX	SPGB - FTSE	SPGB - CAC	SPGB - Shanghai	SPGB - Nifty	SPGB - Kospi	SPGB - Bovespa	SPGB - Mexico
Variance equation:										
C_{11}	0.002***	0.002***	0.003***	0.003***	0.003***	0.002***	0.000	0.003***	0.003	0.000
C_{21}	-0.001***	0.000*	0.000	0.000***	0.000	0.000	0.002	0.000	0.000	0.001***
C_{22}	0.000	0.000*	0.000	0.000*	0.000**	0.000	0.002	0.000***	0.000	0.000
S_{11}	0.464***	0.239***	0.452***	0.453***	0.479***	0.283***	0.300***	0.424***	0.289***	0.263***
S_{12}	0.041**	-0.002	-0.047***	-0.041**	-0.047***	-0.002	-0.043**	-0.049**	-0.009	-0.067***
S_{21}	0.010	-0.140	0.247	0.075	0.229	0.222***	0.065	0.115	0.411	0.331***
S_{22}	0.075	-0.182***	0.153***	0.177***	0.155***	0.135***	0.212***	0.160***	0.168	0.041
L_{11}	0.871***	0.942***	0.859***	0.856***	0.839***	0.930***	0.935***	0.836***	0.924***	0.913***
L_{12}	-0.052***	-0.011**	0.032***	0.025*	0.035***	-0.009	0.001	0.041***	0.002	0.089***
L_{21}	0.437***	-0.044	-0.166	0.048	-0.120	-0.033	-0.207***	-0.166	-0.102	-0.442***
L_{22}	0.877***	0.966***	0.982***	0.957***	0.979***	0.982***	0.686***	0.977***	0.972***	0.969***
Model diagnostics:										
AIC	-13.861	-13.831	-13.773	-14.161	-13.846	-14.277	-14.071	-13.960	-13.431	-14.093
Log Likelihood	5783.197	5770.505	5746.393	5908.148	5776.889	5956.042	5870.584	5824.295	5604.222	5879.732

Note: AIC refers to the Akaike information criterion. ***, **, * denotes the significance level at 1%, 5% and 10% respectively.

The coefficients S11 and S22 in Table 4 and Table 5 explain that their own past events and vice versa have influenced the present volatility in the variables. In the short term, all the variables used for the study are positively impacted by any developments in their respective markets. Thus, the coefficient S11 establishes a significant positive correlation and defines the shocks from lagged values of green bond indices to their current conditional volatility. Similarly, the significant coefficient S22 shows a positive correlation and describes the shocks from the lagged values of equity indices to their current conditional volatility.

Likewise, the coefficients L11 and L22 in Table 4 and Table 5 explain that the past volatility of the variable will have a positive influence on its own current conditional volatility and vice versa. The coefficient L11 establishes a significant positive correlation and defines the volatility impact from lagged green bond values to its current conditional volatility. Further, the significant coefficient L22 also shows a positive correlation and specifies the volatility from lagged values of equity indices to their current conditional volatility.

The S12 coefficients in Table 4 and Table 5 explain the influence of past events in green bond markets on the global equity indices of developed and emerging economies. The recent news regarding green bonds has no impact on anything but the Nikkei index. In contrast, positive shock transmission is observed in the short term from green bonds on S&P, FTSE, and Bovespa indices, negatively impacting DAX, CAC, Nifty, Kospi, and Mexico indices. The S21 coefficients in Table 4 and Table 5 explain the influence of past events in the stock indices of developed and emerging economies on the green bond indices. Positive shock transmission is observed in the short-term from Shanghai and Mexico indices to green bond indices, and past developments in the Bovespa index negatively impact green bond indices. Other indices have no short-term information spillover on green bonds.

The L12 coefficients in Table 4 and Table 5 explain the long-term persistence of past volatility impacts from green bond indices on the current conditional volatility of global equity indices of developed and emerging economies. The conditional volatility of green bond indices does not impact Shanghai and Nifty indices. At the same time, positive volatility spillover is observed in the long term from green bonds on DAX, CAC, Kospi, and Mexico indices, negatively impacting S&P, Nikkei, FTSE, and Bovespa indices. The L21 coefficients in Table 4 and Table 5 explain the influence of past volatility in the stock indices of developed and emerging economies on the green bond indices. Positive volatility spillover is observed in the long term from the S&P index to green bond indices, and past volatility in FTSE, Nifty, Bovespa, and Mexico indices negatively impacts the current conditional volatility of green bond indices. Other indices have no long-term volatility spillover on green bond indices.

6. CONCLUSION

Exploring the connections between the relatively new green bond markets and international stock markets during the unforeseen global lockdown. This study examines the volatility spillovers and dynamic conditional correlations between the global green bond market and the stock markets of developed and developing economies. The short-term impact of past news as well as the long-term persistence of green bonds on the current conditional volatility of global equity indices in developed and developing countries is observed. In contrast, just a few equity indices impact the green bond indices in the short and long term.

The findings give regulators, researchers, and international investors future guidance on portfolio construction and hedging. Further, the study can be expanded to more economies, and sectoral stock indices can be further investigated. The study is confined to only 10 broader stock indices considered for research, whereas further research can be done in the area of other stock indices and sectoral equity indices for more in-depth findings.

Funding: This study received no specific financial support.
Institutional Review Board Statement: Not applicable.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

REFERENCES

Aggarwal, V., Doifode, A., & Tiwary, M. K. (2020). Volatility spillover from institutional equity investments to Indian volatility index. *International Journal of Management Concepts and Philosophy, 13*(3), 173-183. https://doi.org/10.1504/ijmcp.2020.10031501

Aggarwal, V., Doifode, A., & Tiwary, M. K. (2021). Volatility spillover impact of FII and MF net equity flows on the Indian sectoral stock indices: Recent evidence using BEKK-GARCH. *International Journal of Indian Culture and Business Management, 22*(3), 350-363. https://doi.org/10.1504/ijicbm.2020.10030243

Aggarwal, V., Doifode, A., & Tiwary, M. K. (2022). Do lower foreign flows and higher domestic flows reduce Indian equity market volatility? *Vision, 26*(4), 461-470. https://doi.org/10.1177/0972262921990981

Bachelet, M. J., Becchetti, L., & Manfredonia, S. (2019). The green bonds premium puzzle: The role of issuer characteristics and third-party verification. *Sustainability, 11*(4), 1098. https://doi.org/10.3390/su11041098

Baulkaran, V. (2019). Stock market reaction to green bond issuance. *Journal of Asset Management, 20*(5), 331-340. https://doi.org/10.1057/s41260-018-00105-1

Broadstock, D. C., & Cheng, L. T. (2019). Time-varying relation between black and green bond price benchmarks: Macroeconomic determinants for the first decade. *Finance Research Letters, 29*, 17-22. https://doi.org/10.1016/j.frl.2019.02.006

Carpantier, J. F., & Samkharadze, B. (2013). The asymmetric commodity inventory effect on the optimal hedge ratio. *Journal of Futures Markets, 33*(9), 868-888. https://doi.org/10.1002/fut.21566

Chuang, I.-Y., Lu, J.-R., & Tswei, K. (2007). Interdependence of international equity variances: Evidence from East Asian markets. *Emerging Markets Review, 8*(4), 311-327. https://doi.org/10.1016/j.ememar.2007.08.001

Chulia, H., & Torro, H. (2008). The economic value of volatility transmission between the stock and bond markets. *Journal of Futures Markets: Futures, Options, and Other Derivative Products, 28*(11), 1066-1094.

Chun, D., Cho, H., & Ryu, D. (2019). Forecasting the KOSPI200 spot volatility using various volatility measures. *Physica A: Statistical Mechanics and its Applications, 514*, 156-166. https://doi.org/10.1016/j.physa.2018.09.027

Chun, D., Cho, H., & Ryu, D. (2020). Economic indicators and stock market volatility in an emerging economy. *Economic Systems, 44*(2), 100788. https://doi.org/10.1016/j.ecosys.2020.100788

Dean, W. G., Faff, R. W., & Loudon, G. F. (2010). Asymmetry in return and volatility spillover between equity and bond markets in Australia. *Pacific-Basin Finance Journal, 18*(3), 272-289. https://doi.org/10.1016/j.pacfin.2009.09.003

Diebold, F. X., & Yilmaz, K. (2012). Better to give than to receive: Predictive directional measurement of volatility spillovers. *International Journal of Forecasting, 28*(1), 57-66.

Diebold, F. X., & Yılmaz, K. (2014). On the network topology of variance decompositions: Measuring the connectedness of financial firms. *Journal of Econometrics, 182*(1), 119-134.

Elsayed, A. H., Naifar, N., Nasreen, S., & Tiwari, A. K. (2022). Dependence structure and dynamic connectedness between green bonds and financial markets: Fresh insights from time-frequency analysis before and during COVID-19 pandemic. *Energy Economics, 107*, 105842. https://doi.org/10.1016/j.eneco.2022.105842

Engle, R. F., & Kroner, K. F. (1995). Multivariate simultaneous generalized ARCH. *Econometric Theory, 11*(1), 122-150. https://doi.org/10.1017/s0266466600009063

Fernandes, L. H., Silva, J. W., de Araujo, F. H., & Tabak, B. M. (2023). Multifractal cross-correlations between green bonds and financial assets. *Finance Research Letters, 53*, 103603.

Flammer, C. (2021). Corporate green bonds. *Journal of Financial Economics, 142*(2), 499-516.

Izadi, S., & Hassan, M. K. (2018). Portfolio and hedging effectiveness of financial assets of the G7 countries. *Eurasian Economic Review, 8*, 183-213. https://doi.org/10.1007/s40822-017-0090-0

Kocaarslan, B., & Soytas, U. (2021). The asymmetric impact of funding liquidity risk on the volatility of stock portfolios during the covid-19 crisis. *Sustainability, 13*(4), 2286.

Kroner, K. F., & Ng, V. K. (1998). Modeling asymmetric comovements of asset returns. *The Review of Financial Studies, 11*(4), 817-844. https://doi.org/10.1093/rfs/11.4.817

Kroner, K. F., & Sultan, J. (1993). Time-varying distributions and dynamic hedging with foreign currency futures. *Journal of Financial and Quantitative Analysis, 28*(4), 535-551. https://doi.org/10.2307/2331164

Lee, G., & Ryu, D. (2018). Asymmetry in the stock price response to macroeconomic shocks: Evidence from the Korean market. *Journal of Business Economics and Management, 19*(2), 343-359. https://doi.org/10.3846/jbem.2018.5563

Lee, J., & Ryu, D. (2019). The impacts of public news announcements on intraday implied volatility dynamics. *Journal of Futures Markets, 39*(6), 656-685. https://doi.org/10.1002/fut.22002

Mensi, W., Naeem, M. A., Vo, X. V., & Kang, S. H. (2022). Dynamic and frequency spillovers between green bonds, oil and G7 stock markets: Implications for risk management. *Economic Analysis and Policy, 73*, 331-344.

Park, D., Park, J., & Ryu, D. (2020). Volatility spillovers between equity and green bond markets. *Sustainability, 12*(9), 3722. https://doi.org/10.3390/su12093722

Park, Y. J., Kutan, A. M., & Ryu, D. (2019). The impacts of overseas market shocks on the CDS-option basis. *The North American Journal of Economics and Finance, 47*, 622-636. https://doi.org/10.1016/j.najef.2018.07.003

Pham, L. (2016). Is it risky to go green? A volatility analysis of the green bond market. *Journal of Sustainable Finance & Investment, 6*(4), 263-291. https://doi.org/10.1080/20430795.2016.1237244

Rastogi, S., Kanoujiya, J., & Doifode, A. (2024). Volatility integration of crude oil, gold, and interest rates on the exchange rate: DCC GARCH and BEKK GARCH applications. Cogent Business & Management, 11(1), 2289700.

Rastogi, S., Doifode, A., Kanoujiya, J., & Singh, S. P. (2023). Volatility integration of gold and crude oil prices with the interest rates in India. *South Asian Journal of Business Studies, 12*(3), 444-461. https://doi.org/10.1108/sajbs-02-2021-0074

Reboredo, J. C. (2018). Green bond and financial markets: Co-movement, diversification and price spillover effects. *Energy Economics, 74*, 38-50. https://doi.org/10.1016/j.eneco.2018.05.030

Reboredo, J. C., & Ugolini, A. (2020). Price connectedness between green bond and financial markets. *Economic Modelling, 88*, 25-38. https://doi.org/10.1016/j.econmod.2019.09.004

Salisu, A. A., & Mobolaji, H. (2013). Modeling returns and volatility transmission between oil price and US–Nigeria exchange rate. *Energy Economics, 39*(5), 169-176. https://doi.org/10.1016/j.eneco.2013.05.003

Schreiber, I., Müller, G., Klüppelberg, C., & Wagner, N. (2012). Equities, credits and volatilities: A multivariate analysis of the European market during the subprime crisis. *International Review of Financial Analysis, 24*(4), 57-65. https://doi.org/10.1016/j.irfa.2012.07.006

Yang, E., Kim, S. H., Kim, M. H., & Ryu, D. (2018). Macroeconomic shocks and stock market returns: The case of Korea. *Applied Economics, 50*(7), 757-773. https://doi.org/10.1080/00036846.2017.1340574