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Research Article

Asymmetric Impact of Heterogenous Uncertainties on the Green Bond Market

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Investing in green bonds has been recognized as a strategy that not only promotes environmental performance but also offers attractive investment returns. However, macroeconomic factors, such as geopolitical risk (GPR), climate policy uncertainty (CPU), and global economic policy uncertainty (GEPU), play a substantial role in shaping green bond returns. Using the returns of US green bonds as a proxy for the returns of green bonds, we argue in this paper that these heterogenous uncertainty measures might have asymmetric impacts on the returns of green bonds (GB). By employing monthly data from January 2016 to August 2022, we apply the nonlinear autoregressive distributed lags model (NARDL) to examine the asymmetric impact of these heterogenous uncertainty measures on the returns of GB. The NARDL findings reveal evidence of short-run asymmetric impacts of GPR, GEPU, and CPU on the returns of green bonds. In the long run, there is an asymmetric impact of GPR and CPU on the returns of GB. However, there is a symmetric impact of CPU on the returns of GB in the long run. Specifically, in the short run, we found that a positive CPU shock causes a decline in the returns of green bonds. A similar magnitude of negative CPU shock causes an increase in the returns of green bonds. Moreover, a positive shock to GPR increases the return of green bonds, while a comparable negative shock to GPR reduces the return of GB. Furthermore, only negative shocks to GEPU have an impact on GB returns in the short run. Specifically, a negative GEPU shock reduces GB returns. In the long term, the returns of GB are positively impacted by negative shocks in GPR and both positive and negative shocks in GEPU, whereas positive shocks in GPR affect the returns of GB negatively.

1. Introduction

Green bonds have garnered increasing attention as an eminent financial instrument utilized to reallocate necessary financial resources for funding projects centered around environmental sustainability since their inauguration in 2017 by the European Investment Bank [1–3]. Following its inception, the market for green bonds has witnessed remarkable expansion. In 2013, green bonds had a market value of approximately $11 billion [4] followed by a substantial surge with a value of $37.0 billion recorded in 2014 [5], culminating in an excess of $670.0 billion by 2022, and a total issuance of $2.247 trillion as of February 2023. These bonds play a critical role beyond financial markets, acting as a bridge to tackle the pressing global issue of climate change. The transition to a low-carbon economy and the funding of environmentally responsible projects are pivotal in mitigating climate change's adverse effects. The drive for carbon neutrality has sparked the development of a wide range of financial instruments designed for green business ventures. As a result, investors now have the chance to expand the scope of their investment portfolios and incorporate sustainability into their strategies through the world of green finance [6]. In this setting, uncertainties such as climate policy uncertainty, global economic policy uncertainty, and geopolitical risks become significant risk factors, which are distinguished by the uncertainty surrounding upcoming legislative initiatives and regulatory frameworks.

The theoretical ramifications of climate policy uncertainty, global economic policy uncertainty, and geopolitical risk on the green market are paramount. For instance, climate policy can create challenges for businesses operating in the green market, as it makes it difficult for them to plan and make long-term investments [7]. Companies may hesitate to invest in green technologies and projects when there are uncertainties about the direction and stringency of climate policies. This can lead to a slowdown in the growth of the green market and hinder the transition to a low-carbon economy [8]. According to Lavigne and Tankov [7], climate policy uncertainty can result in higher overall emissions and higher spreads between the share prices of green and brown companies. Similarly, the influence of uncertainties in financial and economic policies on the portfolios of green bonds can have indirect effects on the green market. For example, global economic policy uncertainty can impact the financing and investment climate, which in turn can affect stock market performance [9]. Investors may become more risk-averse and hesitant to invest in green projects when there are uncertainties about economic policies in a country. This can lead to a decrease in funding for green initiatives and slow down the growth of the green market [10]. Geopolitical risks, on the other hand, can have direct and indirect effects on the green market. For example, armed conflicts and geopolitical friction can generate significant levels of risk and uncertainty, which can impact global markets [11]. Geopolitical risks can disrupt supply chains, increase costs, and create instability in financial markets, which can have negative effects on the green market [12]. Additionally, long-term strategic conflicts between countries can contribute to the geopolitical uncertainty of the supply of minerals necessary for the growth of green technology [13].

Consequently, several research papers have focused on examining the hedging capabilities of green bond instruments against individual external risks and uncertainties (e.g., [14, 15]), as well as the impact of specific uncertainties on the green bond market (e.g., [16, 17]). One such study, conducted by Xia et al. [15], used an asymmetric time-varying connectedness model to investigate the hedging capability of green instruments against economic policy uncertainty (EPU). Their findings demonstrated that green bond instruments can serve as a safe haven and hedge against EPU. In contrast, Ul Haq et al. [14] presented empirical evidence suggesting that green bonds hedge against uncertainty in economic policy rather than providing a safe haven. However, comparing the results across these studies is challenging due to differences in empirical sample periods, methodologies employed, and green bond market segments. Nevertheless, very few studies have explored the simultaneous impacts of multiple uncertainties on green bond markets (e.g., [18–20]). In addition, previous research indicates that investors' response ranges are inconsistent when uncertainties decrease and increase within the same range, leading to asymmetric impacts on asset prices or economic activity [21, 22].

To address these gaps, this study pursues three primary objectives: (i) explore the asymmetric performance of green bonds in response to uncertainties, both in the short and long term, by utilizing the nonlinear auto regressive distributed lag (NARDL) model. This approach allows us to capture the diverse reactions of investors to both negative and positive changes in climate policy uncertainty (CPU), global economic policy uncertainty (GEPU), and geopolitical risk (GPR). Understanding these nonlinear dynamics is crucial for investors seeking to maximize returns while minimizing risks in the green bond market. (ii) Investigate the combined effects of various uncertainties, with a specific focus on the newly introduced Climate Policy Uncertainty (CPU) index developed by Gavriilidis [23]. Given the original purpose of green bonds in addressing climate change, we aim to assess how climate and geopolitical policy uncertainties may impact green bond returns. (iii) Contrast and analyze the diverse influences of uncertainties on the US green bond market. This empirical analysis provides evidence for the hedging potential of uncertainties by examining both short- and long-term responses of green bond returns. Our findings offer practical insights for retail investors, fund managers, and policymakers.

This paper contributes to and extends the existing literature on the asymmetric impact of multiple uncertainties on the rapidly growing green bond market in the following ways: (i) it employs the NARDL model to uncover the effects of uncertain fluctuations on green bond returns, addressing the limitations of linear econometric models such as the ARDL model. By doing so, this study provides a more accurate understanding of green bond market dynamics, which is essential for optimizing investment strategies. (ii) It investigates the combined influence of different uncertainties, particularly focusing on climate policy uncertainty (CPU). As the concern for climate change is a central element of green bonds, understanding how climate and geopolitical policy uncertainties affect green bond investments is crucial. (iii) It offers insights into the unique impact of uncertainties on the US green bond market, allowing investors and policymakers to make informed decisions regarding green bond portfolios and policies aimed at stabilizing the market.

By addressing these objectives and providing these contributions, this study aims to shed light on the complex relationship between uncertainties and the green bond market, facilitating more informed decision-making and strategy development.

The remaining sections are structured as follows. Section 2 discusses related literature. Section 3 explains the data and methodology employed. Next, Section 4 presents the estimated results. Discussion of results is presented in Section 5. Lastly, Section 6 offers a conclusion and outlines the policy implications.

2. Related Literature

Investing in green bonds has been recognized as a strategy that not only promotes environmental performance but also offers attractive investment returns. Scholars such as Flammer [1], Maltais, and Nykvist [24] have highlighted the positive outcomes of investing in green bonds, emphasizing their potential to generate financial gains while contributing to environmental sustainability. Huynh et al. [25] further emphasize that green bonds provide portfolio diversification benefits, allowing investors to align their financial objectives with environmental considerations. Moreover, Reboredo and Ugolini [26] and Tang and Zhang [27] point out that the green bond market has outperformed conventional bonds, suggesting that sustainable investments can deliver competitive returns. Furthermore, Maltais and Nykvist [24] predict that green bonds will become a significant asset class in sustainable investing, reflecting the increasing demand for environmental, social, and governance (ESG) considerations in investment decision-making. However, the pricing of green bonds is not solely determined by environmental factors. Macroeconomic factors, such as geopolitical risk and uncertainty in economic policy, also play a substantial role in shaping green bond returns. Broadstock and Cheng [28] emphasize the effect of these factors on the pricing dynamics of green bonds, highlighting the need for effective management of macroeconomic risks to ensure stability and profitability in the green bond market. Managing the complex interplay of variables encompassing the environment, the economy, and societal development regulations is crucial for countries striving to achieve sustainable development goals. Castells-Quintana et al. [29] and Wu et al. [30] emphasize the importance of a comprehensive approach to sustainability, recognizing the need for coherent policies and regulations that balance economic growth, environmental protection, and societal well-being.

2.1. Impact of Climate Policy Uncertainty on Green Bonds. Climate risk has emerged as a significant macroeconomic risk that has garnered the attention of researchers examining its implications for financial markets. However, measuring climate risk accurately remains a challenge due to the complex nature of the climate system. Scholars have employed various data, such as temperature and drought, to assess climate risk [31–33].

Several studies have extensively examined the correlation between financial markets and climate risk from various angles. Painter [34] conducted a study on climate change-related bonds and observed that they displayed higher early returns and underwritten expenses for local governments. Seltzer et al. [35] examined the effect of climate change risks on the pricing and evaluation of corporate bonds. According to Huynh and Xia [36], the yields of corporate bonds which are associated with the climate news index positively are lower. Also, climate policy uncertainty risks in the capital market have increased in recent years due to the difficulty in projecting climate-related risks and the ongoing changes to climate regulations. Furthermore, Barnett et al. [37] argued that investor discount rates change as a result of CPU. Barro [38] contended that as the effectiveness of CPU rises, the optimal level of environmental investment also rises, and vice versa. In addition, Bouri et al. [39] discovered that CPU has a more pronounced positive effect on green energy equities' performance compared to brown energy equities. To provide further insights into the relationship between climate policy uncertainty and various economic and environmental variables, we refer to additional relevant studies (Shang et al. [40] delved into the impact of climate policy uncertainty on renewable and nonrenewable energy demand in the United States, making use of the CPI. Their study is a valuable resource for understanding the effects of climate policy uncertainty on energy consumption patterns. Ursavaş and Yilanci [41] examined the dynamic relationship between carbon emissions and climate policy uncertainty by employing the CPI and conducting a dynamic causality analysis. This work sheds light on the interconnectedness of climate policy uncertainty and environmental outcomes. Zhou et al. [42] applied the CPI in their study, which investigated the dynamic relationship among climate policy uncertainty, oil prices, and renewable energy consumption. The results obtained through a TVP-SV-VAR approach offer valuable insights into the influence of the CPI on energy markets and sustainability initiatives. Hoang [43] explored how corporate research and development investment responds to climate policy uncertainty, with a specific focus on heavy emitter firms in the United States. The CPI played a role in their analysis, highlighting its relevance to corporate strategies and environmental management.). These studies investigate the impact of CPU on renewable and nonrenewable energy demand (Shang et al. [40] delved into the impact of climate policy uncertainty on renewable and nonrenewable energy demand in the United States, making use of the CPI. Their study is a valuable resource for understanding the effects of climate policy uncertainty on energy consumption patterns.), the dynamic relationship between carbon emissions and CPU (Yilanci and Ursavaş [41] examined the dynamic relationship between carbon emissions and climate policy uncertainty by employing the CPI and conducting a dynamic causality analysis. This work sheds light on the interconnectedness of climate policy uncertainty and environmental outcomes.), the influence of CPU on oil prices and renewable energy consumption (Zhou et al. [42] applied the CPI in their study, which investigated the dynamic relationship among climate policy uncertainty, oil prices, and renewable energy consumption. The results obtained through a TVP-SV-VAR approach offer valuable insights into the influence of the CPI on energy markets and sustainability initiatives.), and the response of corporate research and development investment to CPU (Hoang [43] explored how corporate research and development investment responds to climate policy uncertainty, with a specific focus on heavy emitter firms in the United States. The CPI played a role in their analysis, highlighting its relevance to corporate strategies and environmental management.).

Investigating the influence of CPU on green bond markets is an area with limited research. However, recent studies have shed light on this relationship and highlighted its significance. Yu et al. [17] examine the time-dependent impacts of CPU on the instability of the green bond market. Their results revealed that there are short-run under-reactions and over-reactions in the green bond market which can be attributed to the dynamic influence of CPU on the market. Ren et al. [44] conducted a study using the time-dependent Granger test to analyze the bidirectional causal relationship between CPU and green markets. The results demonstrated that extreme climatic events or significant policy changes amplify the causality between CPU and its associated markets. In examining the asymmetric effect of CPU on green bond returns in China, the United States, and Europe, Tian et al. [20] utilized the NARDL model. The empirical analysis revealed a negative association between increases in CPU and returns of green bonds across all three regions, with China exhibiting an asymmetric response. In the context of the US economy, Husain et al. [45] investigated the responsiveness of green markets to CPU using the cross-quantilogram approach. Their findings indicated a positive asymmetric relationship between green finance investment and CPU during periods of high uncertainty, particularly in the long memory. Furthermore, Dong et al. [46] concluded that green bonds act as a safe haven during times of high CPU levels.

2.2. Impact of Geopolitical Risk on Green Bonds. Geopolitical uncertainty risk has been extensively studied in the literature, with a focus on its impact on fluctuations in the capital market [47, 48]. Geopolitical risks are well known to have a considerable impact on investment choices [49], subsequently affecting financial instruments' returns [50]. In nations with more intense geopolitical unrest, geopolitical risks' effect on financial markets is most noticeable. Balcilar et al. [47] and Mensi et al. [51] examined how geopolitical risk impacts the financial markets of BRICS countries utilizing a geopolitical risk index that incorporated measures of political conflicts and terrorism. Their findings indicate that geopolitical risk plays a more significant role in determining market fluctuations rather than directly affecting returns. Using data from the China stock market, Lee et al. [52] investigated the influence of GPR on corporate financing. Their findings suggest corporate financing operations are harmed by GPR. According to Choi [53], a strong relationship exists between GPR and the volatility in stock markets of North-East Asian nations. These studies all show that GPR has a detrimental effect on stock return and volatility. Our study shifts the focus to green bonds, which share similarities with traditional bonds in terms of generating fixed income and possessing risk-to-return features [47, 48]. However, the distinguishing characteristic of green bonds lies in the earmarking of revenues for environmentally friendly purposes.

According to Suarez et al. [54], ethnic conflict can harm the political-legal system, particularly when individuals belonging to a political society are divided based on their ethnic affinities. Political leaders are put under tension by this kind of dispute, which makes it difficult to agree on sustainability initiatives [55]. Recent studies have delved into the examination of the impact of geopolitical risks in the context of the green economy [56]. These investigations encompass various aspects such as the effectiveness of institutions, conflicts arising within domestic spheres, the influence of military power, the role of religion, and the impact of economic and social factors [57]. Additionally, Mauerhofer [58] puts forth the notion that maintaining order and enforcing laws are intricately intertwined with the successful implementation of sustainability policies, which consequently affects sustainable investment. According to Hunjra et al. [59], high political risk, encompassing factors such as government instability, conflicts, corruption, and religious and army interference, negatively affects sustainable development by deterring long-term investors. Similar findings were made by Bouri et al. [60] and Caldara and Iacoviell [50], who discovered extraordinary geopolitical events, have a major impact on investment decisions. Using the NARDL approach, Tian et al. [20] examined the nonlinear impact of ambiguities on both short- and long-run green bonds returns. Their findings demonstrated that ambiguity has a nonlinear impact on Chinese green bonds, with notable differences observed in the long run between Europe's sustainable bond markets and the United States market which is consistent with the findings of Lee et al. [52], who indicated that the explanatory power of geopolitical risk differs depending on the state of the market. In another study, Tang et al. [19] employed the nonlinear ARDL approach to examine the impact of two types of geopolitical risks—geopolitical threats (GPRT) and geopolitical acts (GPRA)—on the returns of green bonds. They discovered that in the short run, an increase in GPRA negatively affects the returns on green bonds, whereas an increase in GPRT affects the returns positively. However, both GPRA and GPRT negatively impact green bonds in the long term. In contrast, Sohag et al. [61] found that GPRT transmits positive shock to green bonds using quantile regression approaches. Furthermore, Dong et al. [46] discovered that during high GPR levels, green bonds serve as a safe haven. Tang et al. [19] also emphasized the importance of considering uncertainties when managing investment portfolios and investing in green bonds.

2.3. Impact of Economic Policy Uncertainty on Green Bonds. While existing literature (e.g., [62, 63]) has explored the relationship between financial asset (e.g., cryptocurrencies, conventional stocks, and international stocks) performance and political and economic uncertainty, limited evidence exists on the impact of economic policy uncertainty on green bond returns. More empirical studies in this field are therefore required given the growing green market. This paper intends to evaluate the association between EPU and green bond returns, building on the suggestion made by Broadstock and Cheng [28] to investigate the association between sustainable securities and macroeconomic variables.

Syed et al. [64] and Tang et al. [19], using the nonlinear ARDL model, found that EPU has an asymmetric effect on the returns of green bonds in both the short and long term. Their findings suggested that an increase in EPU harms green bond performance while a decrease in EPU has a positive impact. Furthermore, Pham and Nguyen [65] discover that the connection between economic policy ambiguity and sustainable bonds is not stable over time. Their findings suggest that when governments failed to disclose explicit and detailed economic policies, these financial instruments were affected. Wei et al. [16] used wavelet analysis to investigate the quantile effect of EPU on the performance of green bonds and demonstrate that there is an asymmetric causal association between EPU and green bonds. Using the quantile ARDL model, Wang et al. [66] examined the short- and long-term impacts of EPU on green bonds. They discovered that in the long-run, EPU has a significant negative impact on green bonds across the majority of quantiles, but a significant positive impact in the short run only in higher quantiles. Furthermore, green bonds serve as a safe haven during high EPU levels [15, 46]. Therefore, we believe that adding green bonds to an investment portfolio will lessen the volatility brought on by economic uncertainty since these bonds are issued to fund initiatives aimed at ensuring environmental sustainability [67]. As a result, when hedging their assets, portfolio managers must take green bonds into account.

3. Data and Methodology

3.1. Methodology. This study employs the nonlinear autoregressive distributed lag (ARDL) model proposed by Shin et al. [68] to examine the asymmetric responses of green bond (GB) returns to changes in climate policy uncertainty (CPU), geopolitical risk (GPR), and economic policy uncertainty (EPU) in both the long- and short-term. The nonlinear ARDL model is chosen for its ability to capture nonlinearity and asymmetry in the data, offering significant advantages over traditional linear econometric methods. It allows the analysis of both long- and short-term asymmetries through asymmetric cointegration [51, 69]. Its capability to examine if asymmetry exists in nonstationary variables within a single equation is advantageous [70]. Additionally, it can handle variables that are stationary at $I(0)$, $I(1)$, or a combination of both, accommodating a wide range of data characteristics. By selecting the appropriate lag structure, the model effectively addresses the issue of weak endogeneity of nonstationary explanatory variables and eliminates residual serial autocorrelation [68]. Furthermore, the nonlinear ARDL model has been successfully applied to different markets and assets, as demonstrated in studies conducted by Chowdhury et al. [71], Demir et al. [69], Ibrahim [72], Tang et al. [19], Asante Gyamerah et al. [73], and Tian et al. [20].

3.2. The Nonlinear Autoregressive Distributed Lag (ARDL) Model. Generally, the linear error correction model (ECM) without asymmetry takes the following form:

$$\begin{aligned}\Delta \ln GB_t &= \mu + \beta_0 \ln GB_{t-1} + \beta_1 \ln CPU_{t-1} + \beta_2 \ln GPR_{t-1} + \beta_3 \ln GEPU_{t-1} + \sum_{i=0}^{p-1} \gamma_1 \Delta \ln GB_{t-i} + \sum_{i=0}^{q-1} \gamma_2 \Delta \ln CPU_{t-i} \\ &+ \sum_{i=0}^{r-1} \gamma_3 \Delta \ln GPR_{t-i} + \sum_{i=0}^{s-1} \gamma_4 \Delta \ln GEPU_{t-i} + \varepsilon_t,\end{aligned} \tag{1}$$

where Δ means that the first-order difference, GB indicates green bond returns, CPU indicates the climate policy uncertainty, GPR represents the geopolitical risks, EPU represents the global economic policy uncertainty, p, q, r, s represents the lag order for their corresponding variables, μ represents the constant term, and ε_t indicates the error correction term.

The NARDL model's asymmetry is assessed through the partial sum of the independent variables' positive $(x_t{}^{+})$ and negative $(x_t{}^{-})$ decompositions as shown for CPU in equations (2) and (3).

$$\ln CPU_t^{+} = \sum_{j=1}^{t} \Delta \ln CPU_t^{+} = \sum_{j=1}^{t} \max\left(\Delta \ln CPU_t^{+}, 0\right), \tag{2}$$

$$\ln CPU_t^{-} = \sum_{j=1}^{t} \Delta \ln CPU_t^{-} = \sum_{j=1}^{t} \min\left(\Delta \ln CPU_t^{-}, 0\right), \tag{3}$$

where $\ln CPU_t$ denotes the core explanatory variable. Adding the aforementioned decomposed partial sum to the linear ECM, the error correction form of the nonlinear ARDL model is obtained as follows:

$$\begin{aligned}\Delta \ln GB_t &= \mu + \beta_0 \ln GB_{t-1} + \beta_1 \ln CPU_{t-1}^{+} + \beta_2 \ln CPU_{t-1}^{-} + \beta_3 \ln GPR_{t-1}^{+} + \beta_4 \ln GPR_{t-1}^{-} + \beta_5 \ln GEPU_{t-1}^{+} \\ &+ \beta_6 \ln GEPU_{t-1}^{-} + \sum_{i=0}^{p-1} \gamma_1 \Delta \ln GB_{t-i} + \sum_{i=0}^{q-1} \left(\rho_i^{+} \Delta \ln CPU_{t-i}^{+} + \rho_i^{-} \Delta \ln CPU_{t-i}^{-}\right) + \sum_{i=0}^{r-1} \left(\sigma_i^{+} \Delta \ln GPR_{t-i}^{+} + \sigma_i^{-} \Delta \ln GPR_{t-i}^{-}\right) \\ &+ \sum_{i=0}^{s-1} \left(\vartheta_i^{+} \Delta \ln GEPU_{t-i}^{+} + \vartheta_i^{-} \Delta \ln GEPU_{t-i}^{-}\right) + \varepsilon_t.\end{aligned} \tag{4}$$

3.3. Modeling Approach. Following Shin et al. [68], first, we examine the stationarity of the variables through the augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit root tests. This is necessary as the nonlinear ARDL model requires all variables to be integrated at levels $I(0)$ or $I(1)$, with none of them exhibiting an integration of $I(2)$ or higher order. Second, we constructed the nonlinear ARDL model and determined the optimal lag lengths using the Akaike information criterion (AIC). Third, using the F_{PSS} test suggested by Pesaran et al. [74] with the null hypothesis of no cointegration (H_0: $\alpha_1 = \beta_{j\,(j=0,1,2,3,4,5,6)} = 0$) against the alternative of cointegration (H_1: $\beta_j \neq 0$) and the t_{BDM} test proposed by Banerjee et al. [75] with the null hypothesis of no-cointegration (H_0: $\beta_0 = 0$) against the alternative of cointegration (H_1: $\beta_0 < 0$), we assess the presence of a cointegration relationship between the dependent and independent variables. The critical value for these two tests is provided by Narayan [76] and Pesaran et al. [74], respectively. If the test statistics exceed the upper-bound values, we would conclude that cointegration exists. Then, the Wald test is used to determine the short- and long-run asymmetric impacts. Rejecting the null hypothesis of $\beta_1 = \beta_2$, $\beta_3 = \beta_4$, and $\beta_5 = \beta_6$ for CPU, GPR, and GEPU, respectively, implies the existence of long-run asymmetric impacts. Similarly, rejecting the null hypothesis of $\sum_{i=0}^{q-1}\rho_i^+ = \sum_{i=0}^{q-1}\rho_i^-$, $\sum_{i=0}^{r-1}\sigma_i^+ = \sum_{i=0}^{r-1}\sigma_i^-$, and $\sum_{i=0}^{s-1}\vartheta_i^+ = \sum_{i=0}^{s-1}\vartheta_i^-$ for CPU, GPR, and GEPU, respectively, implies the existence of short-run asymmetric impacts. We use a general-to-specific technique in the estimation to remove insignificant lagged variables. We switch to test the symmetric effect of an uncertainty if its asymmetry is negligible. Finally, we performed diagnostic tests, specifically Breusch–Godfrey serial correlation LM test, Breusch–Pagan–Godfrey conditional heteroscedasticity test, Jarque–Bera normality test, and the Ramsey RESET misspecification test to ensure the model provided a good fit to the data.

3.4. Data. In this paper, we collected monthly data on climate policy uncertainty (CPU), geopolitical risks (GPR), and global economic policy uncertainty (GEPU) from https://www.policyuncertainty.com/ and daily data on green bond (GB) returns from https://www.spglobal.com/spdji/en/ between January 2016 and August 2022. We resampled the daily GB data monthly using $M_t = (\sum_{i=0}^{n} d_{it}/n)$, where d_{it} represents a daily data and n is the total number of days in each month. Table 1 presents the summary statistics for all the data series.

From Table 1, the positive skewness observed in the returns of green bonds, geopolitical risk, and global economic policy uncertainty suggests that investors can anticipate frequent minor fluctuations but fewer major changes in GB, GPR, and GEPU. Conversely, the negative skewness of climate policy uncertainty indicates the opposite pattern. CPU, GPR, and GEPU exhibit a high standard deviation due to their volatility, which is often influenced by policy news and market factors. Except for GB and CPU, which follow a normal distribution, the Jarque–Bera (JB) test statistics reveal that the provided data series have nonnormal distributions, significant at the 1% and 10% levels. Our findings demonstrate that GPR has increased, which can be attributed to the 2022 Russia-Ukraine geopolitical conflicts [77]. Figure 1 illustrates the logarithmic fluctuations of the data series for the period of the study.

4. Results

4.1. Results of Unit Root Tests. Before implementing the nonlinear ARDL model, we examined the variables to check their stationary over the study period. In Table 2, the outcome of the PP and ADF unit root tests shows that GB returns exhibit first difference stationarity, denoted as $I(1)$, at a significant level of 1%. Furthermore, the CPU, GPR, and GEPU variables remain stationary at level, referred to as $I(0)$. Consequently, the dataset supports the implementation of the nonlinear ARDL model.

4.2. Estimation of the Nonlinear ARDL Model. We estimated the coefficients for both short- and long-run, as shown in Table 3. To address the issue of multicollinearity, we utilized the Akaike information criterion (AIC) to determine the optimal lag order within the NARDL model [68]. Following Shin et al. [68], we examined the presence of cointegration among the data series in equation (4). The values of the t_{BDM} and F_{PSS} test results (i.e., −5.6788 and 8.1892) exceed the critical values at a 1% level of significance which demonstrates the existence of cointegration between green bond returns and other explanatory variables. To determine the stability of the model, the cumulative sum (CUSUM) and cumulative sum of square (CUSUMSQ) graph was utilized. The estimated values indicated stability within the confidence bounds as seen in Figure 2.

5. Discussion

Our findings reveal that a positive shock of 1% to climate policy uncertainty reduces GB returns by 0.0675% over the long term. A negative shock of the same magnitude, on the other hand, raises GB returns by 0.0575%. The insignificance of the long-run Wald test ($W_{\mathrm{LR,CPU}}$) shows that positive and negative shocks to climate policy uncertainty have an impact of the same magnitude on GB returns. This result is consistent with Tian et al. [20], who discovered a significant symmetric effect of climate policy uncertainty on US green bond returns in the long term. This implies that whether climate policy uncertainty rises or falls, investors' reactions are the same. In addition, in the short term, the impact of a positive shock of 1% in climate policy uncertainty on GB returns is negative (i.e., −0.0143%). On the other hand, a negative shock of 1% in climate policy uncertainty increases GB returns by 0.0106% in the present period but decreases GB returns by 0.0142% in the lagged period, which is consistent with Tian et al. [20] who found that negative changes in CPU increase green bond returns, which shows that, in the short-term, a reduction in CPU will improve the performance of the green bond market. The short-run asymmetric ($W_{\mathrm{SR,CPU}}$) holds at the 10% level indicating an asymmetric impact of climate policy uncertainty on GB

Table 1: Descriptive statistics.

	lnGB	lnCPU	lnGPR	lnGEPU
Mean	4.929237	5.131253	4.572194	5.164392
Median	4.921520	5.170388	4.527370	5.105945
Maximum	5.061434	6.019296	5.785178	6.222576
Minimum	4.810126	3.894375	4.104295	4.454347
Std. Dev.	0.069140	0.405114	0.279072	0.361149
Skewness	0.249211	−0.372072	1.397784	0.748439
Kurtosis	2.131887	2.890590	6.793995	3.484562
Jarque–Bera	3.340152	1.885740	74.03200***	8.251480*

Notes. * and *** indicate 10% and 1% levels of significance. lnGB represents green bond returns, lnCPU indicates climate policy uncertainty, lnGPR represents the geopolitical risk, and lnGEPU indicates global economic policy uncertainty.

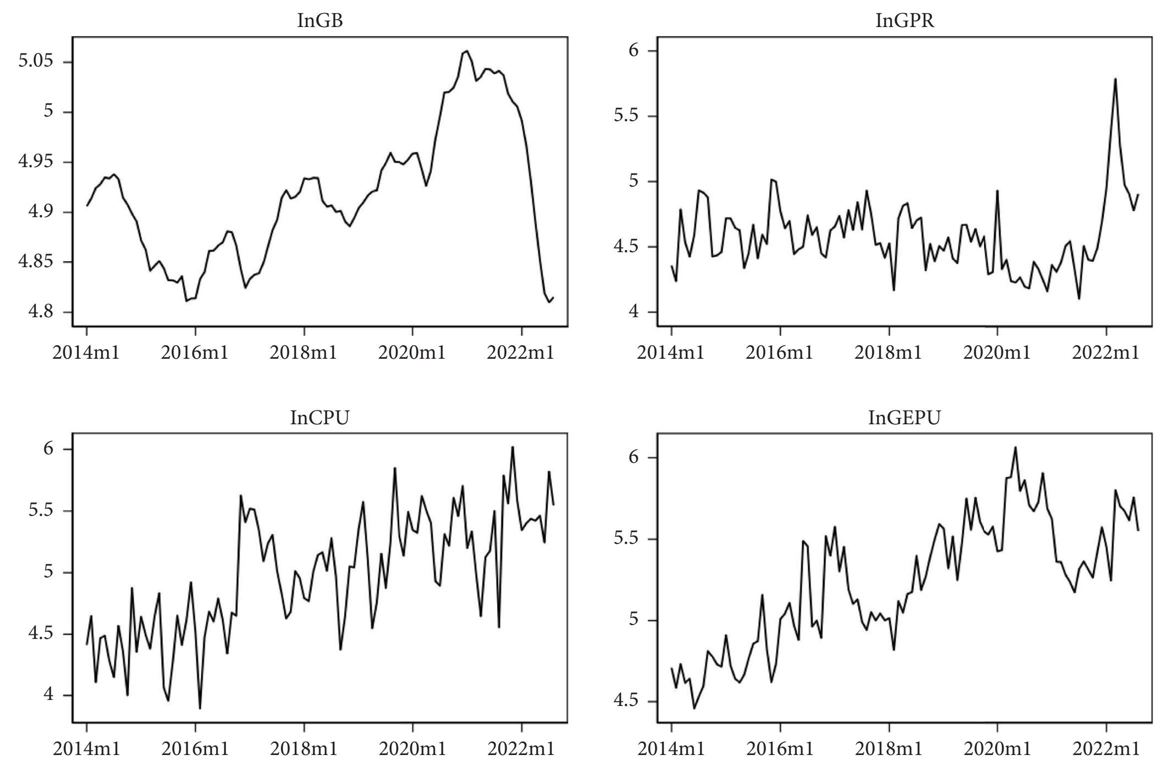

Figure 1: Plots of log-transform of variables for the study (January 2016–August 2022).

Table 2: Unit root test estimation.

Variables	$I(0)$		$I(1)$	
	PP	ADF	PP	ADF
lnGB	−1.6303	−1.8827	−3.9913***	−4.0408***
lnCPU	−4.3486***	−4.5008***	−16.5563***	−6.0516***
lnGPR	−3.4999**	−3.6278***	−12.9350***	−11.3973***
lnGEPU	−3.1040**	−2.4996	−15.9108***	−11.9539***

Notes. ** and *** indicate 5% and 1% levels of significance. lnGB represents green bond returns, lnCPU indicates climate policy uncertainty, lnGPR represents geopolitical risk, and lnGEPU indicates global economic policy uncertainty.

returns in the short run. These findings imply that there is a dynamic asymmetric sentiment among green bond investors, indicating that their reactions differ when faced with a decrease or increase in CPU in the short run. Evidently, the results demonstrate that investors in the US green bond market tend to sell their holdings when there is an increase in climate policy uncertainty or negative news regarding climate policy changes, leading to a decrease in green bond returns and returns and vice versa. In other words, this suggests that investors can utilize information about the market to make returns prediction and investment decisions accordingly [18, 76].

Table 3: Estimates and diagnostics of the NARDL.

Variable	Long-run estimates		Short-run estimates	
	Coefficient	Std. error	Coefficient	Std. error
Constant			0.8159***	0.1013
$\ln GB_{t-1}$			0.3904***	0.0701
$\ln CPU_t^+$	−0.0675**	0.0272		
$\ln CPU_{t-1}^+$			−0.0143***	0.0044
$\ln CPU_t^-$	−0.0575*	0.0314	−0.0106**	0.0048
$\ln CPU_{t-1}^-$			0.0142***	0.0053
$\ln GPR_t^+$	−0.2671***	0.0384		
$\ln GPR_{t-1}^+$			0.0210*	0.0091
$\ln GPR_t^-$	−0.1509***	0.0340		
$\ln GPR_{t-1}^-$			0.0297***	0.0082
$\ln GPR_{t-2}^-$			0.0258***	0.0077
$\ln GEPU_t^+$	0.0862**	0.0388		
$\ln GEPU_t^-$	−0.0956**	0.0338		
$\ln GEPU_{t-1}^-$			0.0283***	0.0096
$\ln GEPU_{t-2}^-$			0.0292***	0.0096
$\ln GEPU_{t-3}^-$			0.0313***	0.0092
ECT_{t-1}			−0.1684***	0.0212
Cointegration				
F_{PSS}	8.1892***			
t_{BDM}	−5.6788***			
Asymmetries				
$W_{LR,CPU}$	[0.4683]			
$W_{LR,GPR}$	[9.3893]***			
$W_{LR,GEPU}$	[18.4554]***			
$W_{SR,CPU}$	[3.1968]*			
$W_{SR,GPR}$	[3.9994]*			
$W_{SR,GEPU}$	[15.0183]***			
Diagnostic test				
R^2	0.7834			
χ^2_{HETR}	[0.5281]{0.9271}			
χ^2_{SC}	[1.3597]{0.2485}			
χ^2_{NOR}	[0.5486]{0.7601}			
Ramsey	[0.0953]{0.7587}			

Note. *, **, and ***represent 10%, 5%, and 1% levels of significance, respectively. The upper bounds for the F_{PSS} critical values provided by Narayan [76] for Case III ($k=6$, $n=75$) are 4.966, 3.9, and 3.397, respectively, for 1%, 5%, and 10%; and the upper bounds for the t_{BDM} critical values provided by Pesaran et al. [74] for Case III ($k=6$) are −4.99, −4.66, −4.38, and −4.04, respectively, for 1%, 2.5%, 5%, and 10%. W_{SR} and W_{LR} represent the Wald test for short- and long-run asymmetry, respectively. χ^2_{HETR}, χ^2_{SC}, and χ^2_{NOR} denote Breusch–Pagan–Godfrey conditional heteroscedasticity test, Breusch–Godfrey serial correlation LM test, and Jarque–Bera normality test, respectively; and Ramsey represents the Ramsey RESET misspecification test. Values in [] are F-values or χ^2 values and in {} are P values.

Also, a positive shock to geopolitical risks causes a significant increase in GB returns in the short term, but a significant decline in the long term. In contrast, a comparable negative shock to geopolitical risks causes GB returns to decrease significantly in the short-term but rise significantly in the long term. Specifically, a 1% positive shock to geopolitical risks increases GB returns by approximately 0.0210% in the short term. In contrast, a 1% negative shock to geopolitical risks significantly reduces GB returns by 0.0297% and 0.0257% in the present period and lagged period, respectively. This evidence is similar to Tian et al. [20], who found that negative shocks in geopolitical risks in the short run have a significant negative impact on GB returns in the US. In the long term, our findings suggest that positive changes in geopolitical risks reduce GB returns significantly by 0.2671%. Conversely, a 1% negative change in geopolitical risk leads to a significant increase in GB returns by 0.1509%. This supports the results of Lee et al. [18], who demonstrate a positive influence of geopolitical risks on green bond returns in China. The long- and short-run asymmetries ($W_{LR,GPR}$, $W_{SR,GPR}$) hold at 1% and 10% levels, respectively. These asymmetries can be attributed to how investors perceive the risks associated with geopolitical events and the subsequent market reactions [20]. For instance, the volatility spillover of geopolitical risks during the February 24, 2022, invasion of Ukraine by Russia affected all market indices, leading to a decline in green bond returns.

Furthermore, we incorporated global economic policy uncertainty as a determinant of GB returns. Our results show that in the long run, global economic policy uncertainty has a significant positive impact on GB returns. Specifically, a 1% positive (negative) shock to global economic policy uncertainty increases GB returns by 0.0862% (0.0956%). This finding is in contrast with Tang et al. [19] and Wang et al. [66] who claim EPU has a significant negative effect on GB returns in the long term. This disparity

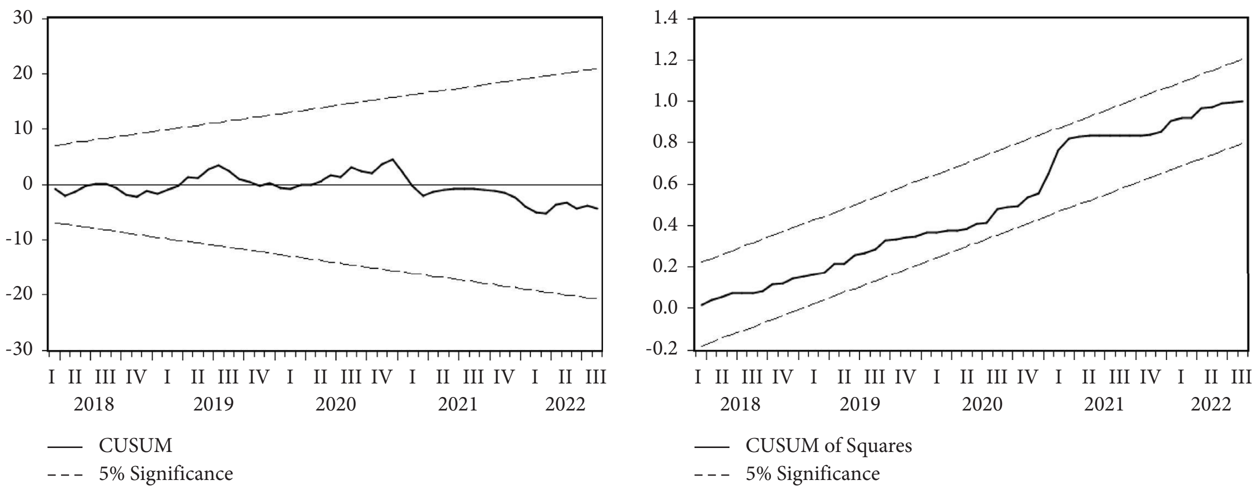

Figure 2: Result of CUMSUM and CUMSUM of squares.

in results might be attributed to the difference in green bond markets or the economic policy uncertainty data used. We used global EPU data, whereas Tang et al. [19] and Wang et al. [66] used US EPU and China EPU data, respectively. In the short run, however, only negative shocks to global economic policy uncertainty have a significant impact on GB returns. Specifically, a negative shock of 1% to global economic policy uncertainty reduces GB returns by 0.0283%, 0.0292%, and 0.0313% in the first-, second-, and third-lagged periods, respectively. The long- and short-run asymmetries ($W_{LR,GEPU}$, $W_{SR,GEPU}$) coefficients are significant at the 1% level. This result suggests that green bond investors' reactions differ when faced with a decrease or increase in GEPU. Thus, the relationship between EPU and green bond returns is asymmetric [16]. Furthermore, the error correction term (ECT_{t-1}) (−0.1684) implies that GB returns adjust towards the long-run equilibrium level by 16.8% per month in response to negative and positive shocks in CPU, GPR, and GEPU. Nonetheless, the diagnostics statistics provide evidence of the model's specification accuracy (Ramsey), model fitness (R^2), normally distributed residuals (χ^2_{NOR}), freedom from the issue of serial correlation (χ^2_{SC}), and heteroskedasticity (χ^2_{HETR}).

6. Conclusion and Policy Implications

Although the green bond market remains small in comparison to the overall bond market, its potential to drive sustainability and address pressing environmental challenges remains significant. However, uncertainties surrounding the green bond market can hinder its growth and ability to effectively address environmental challenges. Against this backdrop, many studies have provided insight into the effect of specific uncertainties on green bond markets. This study extends the literature by examining the asymmetric impact of multiple uncertainties (i.e., global economic policy uncertainty, geopolitical risks, and climate policy uncertainty) on US green bond returns from January 2016 to August 2022. Empirical results from the nonlinear ARDL demonstrate evidence of asymmetry concerning the directions and magnitude of the impacts of climate policy uncertainty, geopolitical risks, and global economic policy uncertainty. Furthermore, in the short run, we found that a positive climate policy uncertainty shock causes GB returns to fall. On the other hand, a similar magnitude of negative climate policy uncertainty shock causes GB returns to increase. Moreover, a positive shock to geopolitical risks increases GB returns, while a comparable negative shock to geopolitical risks reduces GB returns. Furthermore, only negative shocks to global economic policy uncertainty have an impact on GB returns in the short run. Specifically, a negative global economic policy uncertainty shock reduces GB returns in the US. In the long run, we found that the effect of climate policy uncertainty on GB returns is symmetric, so both negative and positive shocks in climate policy uncertainty have an impact of the same magnitude on GB returns. Moreover, positive shocks in geopolitical risks reduce GB returns, while negative shocks in geopolitical risks increase GB returns. Furthermore, both negative and positive shocks in global economic policy uncertainty have a positive impact on GB returns.

Hence, the findings of this study carry important implications for fund managers, investors, and policymakers. For policymakers, first, given that positive shocks to CPU negatively affect GB returns in the short run, policymakers can aim to reduce uncertainty in climate policy. This may involve providing clear, consistent, and long-term policies and regulations that support green industry. Encouraging investments in renewable energy and sustainable technologies can also contribute to reducing CPU. Second, as negative shocks to GPR positively affect GB returns in the short run and the long run, policymakers should focus on strategies to mitigate geopolitical risks. This could include diplomatic efforts to reduce international tensions, promote peace and stability, and foster international cooperation in climate-related initiatives. Third, policymakers should consider the impact of both positive and negative shocks in GEPU on GB returns. Encouraging a stable economic environment, consistent financial regulations, and policies that promote economic sustainability can help mitigate the negative effects of GEPU on the green market. For fund managers and investors, incorporating green bonds into their portfolios can provide a safeguard against the high levels of uncertainty stemming from global economic policies. However, it is crucial for them to also consider the potential negative impacts of climate policy uncertainty when making investment decisions within the green bond market.

Although the study provides valuable insights, it is crucial to recognize its limitations. The research primarily focuses on the green bond market in the United States, so the findings may not be completely applicable to other countries or regions. Furthermore, the study examines only a limited number of factors that contribute to the market, neglecting other potentially influential elements. To enhance our understanding of the dynamics of the green bond market, future research could broaden the analysis by considering additional variables like market liquidity or investor sentiment. This would provide a more comprehensive view. Moreover, investigating the impacts of climate policy uncertainty, geopolitical risks, and economic policy uncertainty on various aspects of the green market, such as issuance volumes or investor behavior, could yield further valuable insights.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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