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Do climate policy uncertainty and geopolitical risk transmit opportunity or threat to the green market? Evidence from non-linear ARDL

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ABSTRACT

This paper examines the asymmetric impacts of climate policy uncertainty (CPU), and geopolitical risk (GPR) on US green bond (GB) returns. By using the non-linear ARDL model and monthly data for GB, CPU and GPR from January 2016 to August 2022, our empirical findings show that in the short run, GB returns are negatively affected by both positive and negative shocks to GPR. In the long term, GB returns are positively impacted by negative shocks in GPR and negatively affected by positive shocks in GPR. CPU on the other hand shows an insignificant symmetric effect. These results have vital implications for policymakers and fund managers. Policymakers should consider implementing policies that reduce uncertainties and ensure stability in the green bond market. For fund managers, there is the need to adopt dynamic approaches to portfolio management, considering the evolving nature of geopolitical risks and their impact on green bond performance.

1. Introduction

The introduction of green bonds in 2007 by the European Investment Bank gained popularity as a promising way to finance green initiatives (Flammer, 2021; Gyamerah et al., 2022; Pham & Cepni, 2022). Green bonds are financial instruments specifically designed to fund projects that have positive environmental or climate impacts. After their introduction, the green bonds market has experienced significant expansion, starting with a market value of approximately \$11 billion in 2013 (Reboredo, 2020), subsequently, valued at \$37.0 billion in 2014 (Tu et al., 2020), culminating in an excess of \$670.0 billion by 2022 and a total issuance of \$2.247 trillion as of February 2023. In addition to their position in financial markets, these bonds serve as a crucial means to tackle the pressing global concern of climate change. For instance, the aim of carbon neutrality has driven the development of a wide range of financial instruments specialized for green economic endeavors. Consequently, investors currently have the chance to diversify their investment portfolios and incorporate sustainability into their strategies by utilizing green finance. In this context, considerable risk factors originate from uncertainties such as climate policy uncertainty and geopolitical risks. These concerns are differentiated by the unpredictability surrounding prospective legislative initiatives and regulatory frameworks.

The challenges posed by geopolitical risks and climate policy uncertainty on the green market are intense. For example, geopolitical

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risks create instability in financial markets by disrupting supply procedures, and increasing cost which can impact the green market negatively (Konvalova & Abuzov, 2023). In addition, the growth of green technology is also hindered by geopolitical uncertainty (Nygaard, 2023). Uncertainty in climate policy on the other hand, makes it challenging for businesses to set long-term investment goals (Lavigne & Tankov, 2023). In the presence of uncertainties surrounding climate policies, firms may be hesitant to invest in green technologies leading to a slowdown in the improvement of green market and transitioning to a low-carbon economy (Adediran et al., 2023).

As a result, several researchers have investigated the hedging capabilities of green bond instruments against risks and uncertainties (Bouri et al., 2022; Y. Tang et al., 2023; Tian et al., 2022; Ul Haq et al., 2021; Wei et al., 2022; Xia et al., 2023; Yu et al., 2023). However, very few research papers addressed the simultaneous effect of multiple uncertainties on green bond markets (e.g., Lee et al., 2022; Tang et al., 2023; Tian et al., 2022). Furthermore, existing literature suggests that the response patterns of investors exhibit inconsistency when uncertainties fluctuate both downwards and upwards within a comparable range. This inconsistency results in asymmetric influences on asset prices or economic activity, as highlighted by Aye (2021) and Long et al. (2021).

To fill these gaps, this paper proposes two objectives: (i) To explore the short- and long-term asymmetric response of green bonds to uncertainties using the Nonlinear Autoregressive Distributed Lag (NARDL) model. In recent years, the application of non-linear models has become increasingly prevalent in the analysis of financial markets, particularly for capturing the asymmetric effects of uncertainties. The non-linear ARDL model is specifically chosen for this study because it allows us to examine the different reactions of investors to both positive and negative shocks in climate policy uncertainty (CPU) and geopolitical risk (GPR). This is crucial for investors in the green bond market who aim to maximize returns while minimizing risks. Linear models often fail to capture these subtleties, which potentially overlook critical aspects of the market behavior. For instance, linear models might treat positive and negative shocks symmetrically, ignoring the fact that investor reactions can be significantly different depending on the direction of the shock. (ii) To investigate the joint effect of climate policy uncertainty and geopolitical risk, using the newly developed climate policy uncertainty index by Gavriilidis (2021).

This study contributes to the existing research on the simultaneous asymmetric impact of uncertainties on the green bond market in the following ways: (i) Using the non-linear ARDL model, this research investigates the impacts of uncertain fluctuations on green bond returns, addressing the limitations of conventional linear econometric models like the ARDL model. By employing this approach, the study provides a more precise understanding of the dynamics within the green bond market. (ii) It offers an understanding of the joint effect of climate policy uncertainty and geopolitical risk, particularly focusing on climate policy uncertainty as climate change is a central part of the green market.

The remainder of the paper is divided into the following sections: The review of the related literature is presented in Section 2, the materials and methods used for the study are presented in Section 3, the empirical findings of the study are presented in Section 4, Section 5 presents the discussion of the study, and the conclusion and policy recommendation of the study are presented in Section 6 of this document.

2. Literature review

Green bonds as financial institutions do not only contribute to sustainability but also offer attractive returns on investment (Flammer, 2021; Maltais & Nykvist, 2020). They provide portfolio diversification benefits which allows investors to align their financial objectives with environmental considerations (T. L. D. Huynh et al., 2020). Moreover, according to Reboredo and Ugolini (2020) and Tang and Zhang (2020), green bonds have outperformed conventional bonds, recognizing the ability of sustainable investments in delivering much competitive returns. The pricing of green bonds is however challenging and does not depend solely on environmental factors. Macroeconomic factors like geopolitical risks also play a major role in determining green bond returns. Broadstock and Cheng (2019) emphasized on the need to effectively manage these macroeconomic risks to ensure profitability and stability in the green market as comprehensively managing the complex interactions of environment and societal development regulation variables to provide coherent policies and regulations that balance environment protection and societal well-being is important for countries focused on achieving sustainable development goals (Castells-Quintana et al., 2019; Wu et al., 2022).

2.1. Impact of climate policy uncertainty (CPU) on green bonds

Among the macroeconomic risks, climate risk has garnered the attention of researchers. Several studies have extensively examined the correlation between climate risk and financial markets from different angles. For example, while Seltzer et al. (2022) explored the impact of climate risks in the pricing and evaluation of corporate bonds, Huynh and Xia (2021), explored the yield of corporate bonds associated with positive climate news index. According to Huynh and Xia (2021), the yields of corporate bonds are relatively lower in the presence of positive climate news. Furthermore, Barnett et al. (2020) argued that discount rates of investor change due to climate policy uncertainty. Bouri et al. (2022) contended that climate policy uncertainty has a more intense positive effect on performance of green energy equities as compared to brown energy equities. In addition, Barro (2015) discovered that the effectiveness of CPU is positively correlated to the optimal level of environmental investment and vice versa.

Exploring the impact of climate policy uncertainty on the green market is an emerging area of research. However, recent papers have shed some light on this nexus and highlighted its importance. Using the time-dependent Granger test, Ren et al. (2023) analyze the bidirectional causal relationship between CPU and green markets. The results revealed that extreme climatic occurrences or significant policy changes increase the causality between CPU and its associated markets. Similarly, Yu et al. (2023) investigated the time-dependent impacts of CPU on the instability of the green bond market. According to their findings, the green market's under- and

overreactions can be attributed to the dynamic influence of CPU on the market. Using the NARDL model, Tian et al. (2022) investigated the asymmetric impact of CPU on the returns of green bonds in China, the US and Europe. Based on their empirical findings, all three regions showed a negative association between increase in CPU and green bond returns, with China responding asymmetrically. Furthermore, Husain et al. (2022) used the cross-quantilogram approach to study how sensitive green markets were to CPU in the US economy. Their results indicated a positive asymmetric association between green finance and CPU in the presence of high uncertainty, especially in the long-term.

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 (Balcilar et al., 2018; Fernandez, 2008). Geopolitical risks are well known to have a considerable impact on investment choices (Gozgor et al., 2022), subsequently affecting financial instruments' returns (Caldara & Iacoviell, 2022). Different empirical studies, including Mensi et al. (2016), Balcilar et al. (2018), Choi (2022), Lee, Lee, and Xiao (2021a) have revealed a negative association between geopolitical shocks and asset prices. For instance, Balcilar et al. (2018) and Mensi et al. (2016) investigated how the BRICS stock markets' return and volatility dynamics are affected by geopolitical uncertainty index that incorporated measures of political conflicts and terrorism. Their findings demonstrated that geopolitical shocks significantly contribute to volatility in the BRICS stock markets rather than directly affecting returns. On the other hand, Lee, Lee, and Li (2021b) evaluated the impact of GPR on corporate financing using data from the Chinese stock market. From their findings, GPR appears to be detrimental to corporate finance activities. According to Choi (2022), there is a substantial correlation between GPR and volatility in North-East Asian stock markets. Our research rather focuses on green bonds, which, like traditional bonds, generate fixed income and have risk-to-return characteristics features (Balcilar et al., 2018; Fernandez, 2008). However, the defining feature of green bonds is the allocating of profits for ecologically friendly purposes.

The influence of geopolitical threats in the context of the green economy has been examined in recent studies (Forouli et al., 2020). The effectiveness of institutions, internal conflicts, the role of religion, the impact of economic and social issues, and the influence of military power are only a few of the topics covered by these studies (Cernev & Fenner, 2020). Mauerhofer (2019) advances the idea that sustainable investment is impacted by the efficient execution of sustainability rules, which are closely linked to upholding law and order. High political risk, which includes elements such as conflict, government instability, corruption, and involvement from the army and religion, is said to have a detrimental effect on sustainable development by discouraging long-term investors (Hunjra et al., 2022). Similar conclusions were made by Bouri et al. (2019), and Caldara and Iacoviell (2022) who found that geopolitical risks have a significant influence on investment decisions. In a pioneering study, Tian et al. (2022) explored the asymmetrical impacts of geopolitical risks on the Chinese, European, and the United States green bond market over the long and short terms. Their results shown geopolitical risks had an asymmetric effect on Chinese green bond market with a notable difference observed in the long run between Europe and the United States market. These findings are consistent with the conclusion of Lee, Lee, and Li (2021b) who indicated that the explanatory power of geopolitical risk differs depending on the state of the market. Using the non-linear ARDL approach, Tang et al. (2023) explored the impact of two types of geopolitical risks—geopolitical threats (GPRT) and geopolitical acts (GPRA)—on the returns of green bonds. They found that while an increase in GPRT has a favorable impact on returns, an increase in GPRA has a negative short-term impact on green bond returns. But over time, GPRT and GPRA have a detrimental effect on green bonds. On the other hand, Sohag et al. (2022) discovered that GPRT transmits positive shock to green bonds by employing quantile regression techniques. Moreover, Dong et al. (2023) found that green bonds act as a safe haven when GPR levels are high.

3. Data and methodology

3.1. Methodology

To examine the asymmetric response of green bond returns (GB) to changes in climate policy uncertainty (CPU) and geopolitical risks (GPR) in both short- and long-term, we employed the non-linear Autoregressive Distributed Lag (ARDL) model proposed by Shin et al. (2014). This model is selected for its advantage to capture nonlinearity in the data both in the short and long-term through asymmetric co-integration (Demir et al., 2021; Mensi et al., 2016). Additionally, it accommodates a wide range of data characteristics since it handles variables stationary at I(0), I(1) or both. It also effectively addresses the issue of weak endogeneity of nonstationary explanatory variables and eliminates residual serial autocorrelation through the selection of an appropriate lag structure (Shin et al., 2014).

3.2. The nonlinear Autoregressive Distributed Lag (ARDL) model

The base form of the linear error correction model (ECM) without asymmetry is expressed as follows:

$$\Delta \ln GB_t = \mu + \beta_0 \ln GB_{t-1} + \beta_1 \ln CPU_{t-1} + \beta_2 \ln GPR_{t-1} + \sum_{i=0}^{p-1} \gamma_1 \Delta \ln GB_{t-i} + \sum_{i=0}^{q-1} \gamma_2 \Delta \ln CPU_{t-i} + \sum_{i=0}^{r-1} \gamma_3 \Delta \ln GPR_{t-i} + \varepsilon_t \quad (1)$$

Where Δ denotes that the first-order difference, GB represents green bond returns, CPU denotes the climate policy uncertainty, GPR indicates the geopolitical risks, p , q , r denotes the lag order for their corresponding variables, μ indicates the constant term and ε_t

represents the error correction term.

The linear ECM is then reparametrized to form non-linear ECM by decomposing the independent variable into positive (x_t^+) and negative (x_t^-) partial. The decompositions for CPU are show in equations (2) and (3) below:

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

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

The reparametrized error model (non-linear ECM) is obtained as follows:

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

3.3. Modeling approach

As proposed by Shin et al. (2014), we first establish the stationarity status of the variables through unit root tests—Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. This is done as that non-linear ARDL model requires all variables to be integrated at levels I(0) or I(1). We then specify the non-linear ARDL model and determine the appropriate lag lengths using the Akaike Information Criterion (AIC). Subsequently, the t_{BDM} test proposed by Banerjee et al. (1998) with the null hypothesis of no-cointegration ($H_0 : \beta_0 = 0$) against the alternative of co-integration ($H_1 : \beta_0 < 0$) and F_{PSS} test suggested by Pesaran et al. (2001) with the null hypothesis of no cointegration ($H_0 : \alpha_1 = \beta_{j(j=0,1,2,3,4)} = 0$) against the alternative of cointegration ($H_1 : \beta_j \neq 0$) are used to determine the existence of a cointegration relationship between the dependent and the independent variables. The critical value for these two tests is provided by Pesaran et al. (2001) and Narayan (2005) respectively. If the upper-bounds values are exceeded by the test statistics, we would conclude that cointegrations exists. Following a cointegration relationship, the Wald test is employed to determine the short- and long-term asymmetric effects. By rejecting the null hypothesis of $\beta_1 = \beta_2$, and $\beta_3 = \beta_4$ for CPU and GPR respectively imply the existence of long-term asymmetric effects. Similarly, rejecting the null hypothesis of $\sum_{i=0}^{q-1} \rho_i^+ = \sum_{i=0}^{q-1} \rho_i^-$ and $\sum_{i=0}^{r-1} \sigma_i^+ = \sum_{i=0}^{r-1} \sigma_i^-$ for CPU and GPR respectively implies the existence of short-term asymmetric effects. Lastly, we performed diagnostic tests, specifically Ramsey RESET Misspecification test, Jarque–Bera normality test, Breusch-Godfrey Serial Correlation LM test and Breusch-Pagan-Godfrey conditional heteroskedasticity test to ensure the model provided a good fit to the data.

3.4. Data sources

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

The positive skewness revealed in green bond returns, and geopolitical risk in Table 1 shows that investors can expect frequent minor variations but fewer substantial shifts in GB and GPR. The negative skewness of climate policy uncertainty, on the other hand, suggests the inverse pattern. Because of their volatility, CPU and GPR have a large standard deviation, which can be impacted by policy news and market conditions. With the exception of GB and CPU, which have normal distributions, the Jarque-Bera (JB) test data

Table 1
Descriptive statistics.

	lnGB	lnCPU	lnGPR
Mean	4.9046	5.0132	4.5991
Median	4.9065	5.0718	4.5926
Maximum	5.0614	6.0193	5.7815
Minimum	4.7159	3.8944	4.1043
Std. Dev.	0.0752	0.4692	0.2592
Skewness	0.2052	-0.3141	1.0542
Kurtosis	2.533	2.303	6.0382
Jarque-Bera	1.8682	4.2562	66.1017 ^a

Notes.

^a Indicate 1% level of significance. lnGB represents green bond returns, lnCPU denotes climate policy uncertainty and lnGPR indicates geopolitical risk.

demonstrate that GPR has non-normal distributions, which is significant at the 1% level.

4. Empirical findings

4.1. Result of unit root tests

Prior to estimating the non-linear ARDL model, we examined the variables to check their stationary status over the study period. The outcome of the ADF and PP unit root tests in Table 2 shows that GB returns is stationary at first difference, I(1), at 1% significance level whereas CPU and GPR were stationary at level, I(0). The shows that non-linear ARDL model is appropriate for our dataset.

4.2. Estimation of the non-linear ARDL model

We estimated the coefficients for both long- and short-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 (Shin et al., 2014). Following Shin et al. (2014), we examined the presence of cointegration among the data series in Equation (4). The values of the F_{PSS} and t_{BDM} tests results (i.e., -7.3560 and -4.8557) exceed the critical values at a 1% significance level demonstrating the presence of cointegration between green bond returns and the explanatory variables. We then used the cumulative sum (CUSUM), and cumulative sum of square (CUSUMSQ) graph to access the stability of the model. As seen in Fig. 1, the estimated values exhibited stability within the confidence bounds.

5. Discussion

Our findings reveal that a positive shock of 1% to geopolitical risks reduces GB returns by 0.1177% over the long term. A negative shock of the same magnitude, on the other hand, raises GB returns by 0.1423%. While both coefficients are reported as negative in the table, it is essential to understand that these coefficients represent different directions of shocks and their asymmetric effects on returns. This result is consistent with Lee et al. (2022) who demonstrated a positive influence of geopolitical risks on green bond returns in China. In the short run, the impact of a positive shock of 1% in geopolitical risks on GB returns is negative (i.e. -0.0275%). On the other hand, a negative shock of 1% in geopolitical risks decreases GB returns by 0.0182% in the one lagged period and 0.0304% in the two lagged period. This evidence is similar to the findings of Tian et al. (2022), who found that negative shocks in geopolitical risks in the short run have a significant negative impact on GB returns in the US. The long- and short-run asymmetries ($W_{LR,GPR}$; $W_{SR,GPR}$) hold at a 1% significance level. This implies that investors response differently when faced with a decrease or increase in geopolitical risks in both the short- and long-term. These asymmetries can be attributed to how investors perceive the risks associated with geopolitical events and the subsequent market reactions (Tian et al., 2022). 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. Finally, we observe a symmetric and insignificant impact of climate policy uncertainty on GB returns in contrast to Tian et al. (2022), who found that climate policy uncertainty has a significant symmetric impact on GB returns. This disparity could be attributed to Tian et al. (2022) controlling for green bond search trend indexes, interest rates in the United States and global economic activity index, whereas we did not. Furthermore, the error correction term (ECT_{t-1}) (-0.1464) implies that GB returns adjust towards the long-run equilibrium level by 14.6% per month in response to negative and positive shocks in CPU and GPR. Moreover, the diagnostics statistics provide evidence of the model's specification accuracy (Ramsey), normally distributed residuals (χ^2_{NOR}), freedom from the issue of serial correlation (χ^2_{SC}) and heteroskedasticity (χ^2_{HETR}) and model fitness (R^2).

6. Conclusion and policy implications

The growth of the green bond market and its ability to effectively address environmental challenges is hindered by uncertainties surrounding the green bond market. To address this issue, 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., geopolitical risks, and climate policy uncertainty) on US green bond returns from January 2016 to August 2022. Empirical results from the non-linear ARDL demonstrate evidence of asymmetry concerning the directions and magnitude of the impacts of geopolitical risks

Table 2
Unit root test estimation.

Variable	I(0)		I(1)	
	PP	ADF	PP	ADF
$\ln GB$	-1.6303	-1.8827	-3.9913***	-4.0408***
$\ln CPU$	-4.3486***	-4.5008***	-16.5563***	-12.4763***
$\ln GPR$	-3.5065**	-3.6336***	-12.9388***	-11.3934***

Notes: ** and *** indicate 5% and 1% level of significance. $\ln GB$ represents green bond returns, $\ln CPU$ indicates climate policy uncertainty, and $\ln GPR$ represents geopolitical risk.

Table 3
Estimates and diagnostics of the NARDL.

Variable	Long-run estimates		Short-run estimates	
	Coefficient	Std. Error	Coefficient	Std. Error
Constant			0.7311***	0.1463
$\ln GB_{t-1}$			0.5610***	0.0923
$\ln GB_{t-4}$			0.2603***	0.0949
$\ln CPU_t$	-0.0235	0.0204		
$\ln GPR_t^+$	-0.1177***	0.0351		
$\ln GPR_{t-2}^+$			-0.0275***	0.0089
$\ln GPR_t^-$	-0.1423***	0.0339		
$\ln GPR_{t-1}^-$			0.0182*	0.0096
$\ln GPR_{t-2}^-$			0.0304***	0.0090
ECT_{t-1}			-0.1464***	0.0301
Cointegration				
F_{PSS}	7.3560***			
t_{BDM}	-4.8557***			
Asymmetries				
$W_{LR,GPR}$	[10.0358]***			
$W_{SR,GPR}$	[22.2946]***			
Diagnostic test				
R^2	0.6899			
χ^2_{HETR}	[11.5933]{0.2372}			
χ^2_{SC}	[1.8978]{0.3872}			
χ^2_{NOR}	[1.4629]{0.4812}			
Ramsey	[1.9657]{0.1654}			

Notes: *, **, and *** represents 10%, 5%, and 1% level of significance. The upper bounds for the F_{PSS} critical values provided by Narayan (2005) for Case III (k = 3, n = 80) are 6.908, 5.320, and 4.605 respectively, for 1%, 5%, and 10%; and the upper bounds for the t_{BDM} critical values provided by Pesaran et al. (2001) for Case III (k = 3) are -4.37, -3.78, and -3.46 respectively, for 1%, 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} , χ^2_{NOR} denote Breusch-Pagan-Godfrey conditional heteroskedasticity 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 values in {} are p-values.¹¹

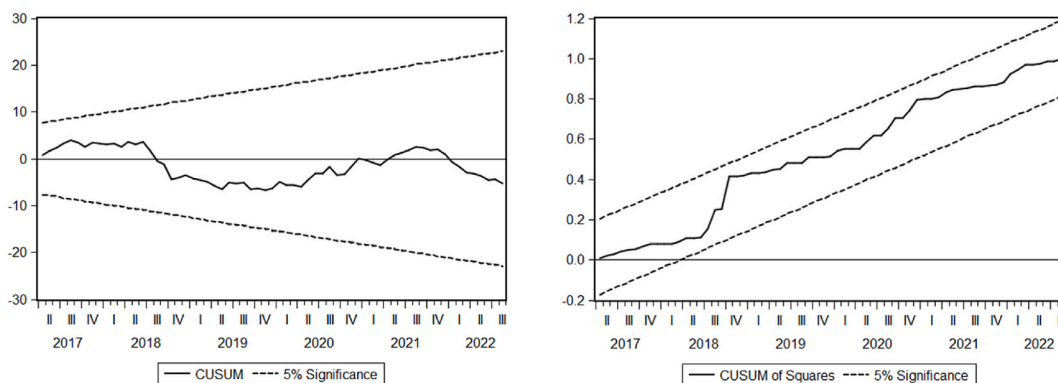


Fig. 1. Result of CUSUM and CUSUM of squares.

on green bond return. In the short term, we found that both positive and negative shock to geopolitical risks causes GB returns to decrease. In the long run, positive shocks to geopolitical risks reduce GB returns whereas negative shocks increase GB returns. Surprisingly Climate policy uncertainty exhibited an insignificant symmetric impact on the green bond returns.

The findings of this study carry important implications for policymakers and fund managers. For policymakers, given that negative shocks to GPR positively affect GB returns in the long run, policymakers should focus on mitigating geopolitical risks which could be done through fostering international cooperation in climate-related initiatives and promoting peace and stability. For fund managers, there is the need to adopt dynamic approaches to portfolio management, considering the evolving nature of geopolitical risks and their impact on green bond performance.

This study, while offering valuable insights into the U.S. green bond market, is subject to several limitations that warrant consideration. Firstly, the chosen time frame from January 2016 to August 2022 might not fully capture long-term trends or account for potential shifts in market dynamics over more extended periods. Secondly, the study’s exclusive focus on the U.S. green bond market restricts the generalizability of its findings to other geographical regions with different geopolitical and economic factors at

play. Additionally, the insignificant symmetric impact of climate policy uncertainty on green bond returns, as observed in this research, may be context-specific and dependent on the unique dynamics of the chosen time period. These limitations highlight the need for cautious interpretation and suggest avenues for future research to explore the temporal and geographical variations in the relationship between uncertainties and green bond market performance.

Ethics statement

N/A.

CRediT authorship contribution statement

Samuel Asante Gyamerah: Methodology, Investigation, Formal analysis, Conceptualization. **Henry Ofoe Agbi-Kaiser:** Writing – review & editing, Validation, Resources, Methodology, Investigation. **Luis Alberiko Gil-Alana:** Supervision, Formal analysis, Data curation.

Declaration of competing interest

There is no conflict of interest with the publication of the present manuscript.

Data availability

Data will be made available on request.

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¹ The CPU variable does not appear in the short-run estimates because it has no statistically significant effect on GB returns in the short run. As a result, none of its lags were selected during the switching regression process.

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