**Asymmetric Effects of US Geopolitical Risk and uncertainties on Green Bond Returns**

# Abstract

In our study, we discuss the specific role that green bond returns play as a result of multiple uncertainties and risks. We examine the asymmetric effects of US economic policy uncertainty (USEPU), geopolitical threats (GPRT), geopolitical acts (GPRA), and WTI oil on green bond returns. Our study analyzes the monthly data of USEPU, GPRT, GPRA, WTI, and green bond from September 2012 to August 2022. By applying the Nonlinear Autoregressive Distributed Lags (NARDL) model, our empirical evidence shows that in the short run, the return on green bonds is negatively affected by an increase in USEPU, GPRA but positively affected by an increase in GPRT and WTI. In the long run, the return on green bonds is negatively affected by an increase in USEPU, GPRA, and GPRT but positively affected WTI. Our results can be used by policymakers for a policy design that will mitigate green bond market volatility caused by external uncertainties and risks. Furthermore, we conclude that there are uncertainties should be considered when investing in green bonds and managing investment portfolios. In light of the climate crisis, it is important to look at these findings in the context of green bonds as a way to entice green investments.

**Keywords**: Economic policy uncertainty; Geopolitical threats; Geopolitical acts; WTI; Green Bond; NARDL

**JEL Codes**: Q41, Q58, G12

# Highlights

* We are the first to investigate the asymmetric effects of USEPU, GPRT, GPRA, and WTI oil on green bond returns.
* Employs the NARDL model and nonlinear Ganger causality.
* In the short run, the return of green bonds is negatively affected by USEPU and GPRA but positively by GPRT and WTI.
* In the long run, the return on green bonds is negatively affected by USEPU, GPRT, and GPRA but positively affected by WTI.

# 1. Introduction

Green economies have been widely proposed as a way to reduce global climate change and are attracting great attention. Green projects require appropriate financial instruments to be able to be financed in the transition to a green economy (Zhang et al., 2023). As a result, green bonds are considered to be the most recognized source of funding for climate friendly projects (Caramichael and Rapp, 2022; Monasterolo and Raberto, 2018). The global green bond market has been growing exponentially (Kuchtyak and Bruce, 2022). A rapidly growing market for green bonds has seen issuance hit $556 billion in 2021 and is expected to reach £1.35 trillion by 2022 (Kuchtyak and Bruce, 2022). A compound annual growth rate (CAGR) of approximately 50% can be seen for the overall market compared with only $31 billion in 2014. There are several countries fueling this growth, including the United States (US), Germany, France, China, and the Netherlands, but the US is taking the lead among all (GlobalData, 2022). Market value of green bond in the US hit $67.648 billion in 2021, recording a CAGR of 98.3% during 2017–21, and a 29.9% increase over 2020. Furthermore, it is estimated that approximately 12% of the global green bond market is accounted for by the US green bond market.

We are the first to investigate the impacts of multiple uncertainties (i.e., US economic policy uncertainty, geopolitical threats, geopolitical acts, and WTI oil prices) on green bond returns in both short- and long-run scenarios in the US market. There have been some studies that have examined the performance of different green bond markets, but they have reported mixed empirical results (Caramichael and Rapp, 2022) or examined one particular external risk and its impact on green bonds. Existing research (e.g., Pham and Nguyen, 2022; Piñeiro-Chousa et al., 2021; Lee et al., 2021) has examined how uncertainty indexes affect green bond returns. For example, Pham and Nguyen (2022) analyzed the relationship between stock market uncertainty (VIX), oil price uncertainty (OVX) and green bonds using a time-varying and state-dependent approach. As a result of high uncertainty periods (e.g., the COVID-19 crisis), the degree of connectedness between uncertainties and green bonds increases. In contrast, Piñeiro-Chousa et al. (2021) used VIX to measure stock market volatility and provided empirical evidence that the VIX has minimal or no effects on green bond returns. A quantile Granger causality test performed by Lee et al. (2021) shows that geopolitical risk (GPR) is unidirectionally related to green bond prices in the lower quantiles. Their results suggest that the GPR is a significant factor in the returns of green bonds. Nevertheless, as a result of their varying sample periods, green bond market segments, and empirical methodologies, it is difficult to compare the findings between existing studies.

Additionally, prior studies have investigated the relationship between green bonds and uncertainty in a particular region or compared different political economies to determine the best investment path for sustainable growth. As an example, Lee et al. (2022) use a SVAR framework to analyze the relationship between geopolitical uncertainty, oil shocks, and green bond performance in China. They report that oil price shocks and China's green bond returns are negatively associated, whereas GPR and green bond returns are positively correlated. Also, it is reported by Kang et al. (2014), Marques et al. (2018), and Reboredo et al. (2020) that stock and oil markets’ uncertainty contributes significantly to net price volatility shocks in both the European and US green bond markets. As shown by Tian et al., (2022), the green bond markets in the US, Europe, and China display heterogeneous behavior due to climate policy uncertainties, GPR, equity market volatility, and oil volatility. However, there is no conclusive evidence that a green bond market is robust when it issues bonds. Our study aims to select the most appropriate empirical technique to assess the impacts of specific external uncertainties and risks on green bonds.

The green bond market has continued to flourish as the world’s first green bond was issued by the European Investment Bank in 2007. The majority of green bond issuances are denominated in euros or US dollars (Kuchtyak and Bruce, 2022). In spite of the numerous green bonds issued across the world, the US has been the most active issuer, making it the country with the most cumulative issuers. Thus, the US green bond markets need to be examined for their anti-risk capabilities, which will allow us to explore the effects of various uncertainties and provide market stakeholders (e.g., policymakers, investors, and issuers) with hedging and investment diversification options.

Our study analyzes the monthly data of USEPU, GPRT, GPRA, WTI, and green bonds from September 2012 to August 2022. By applying the Nonlinear Autoregressive Distributed Lags (NARDL) model, we find asymmetric impacts of USEPU, GPRT, GPRA, and WTI on green bond returns. We summarize the main contributions of our paper into three points. First, this study is the first attempt to examine the short- and long-run asymmetric effects of green bond return responding to the fluctuations in uncertainties by using the NARDL model. Investors may react differently from the positive change in UESPU, GPRA, GPRT, and WTI to the negative changes in UESPU, GPRA, GPRT, and WTI. The nonlinear model can capture investors’ positive and negative reactions to the green bond prices due to the positive and negative changes in the USEPU, GPRA, GPRT, and WTI. The linear econometric methods, such as the ARDL model, cannot capture because of linear assumptions. This study is also unique because it explored the characteristics of green bonds in a different time-horizon and other events, such as the COVID-19 pandemic and COP26, using data from September 2012 and August 2022 and, thus, providing conclusive findings. Neglecting that will undermine the goal of maximizing return and minimizing risk for investors. Second, we contribute to the literature by examining the primary market pricing of green bonds using a well-defined empirical method, while taking into account the short- and long-run impacts of multiple uncertainties (i.e., uncertainty regarding US economic policy, geopolitical threats, geopolitical acts, and WTI oil prices) simultaneously. Investment returns for green bonds will likely be influenced by geopolitical and climate policy uncertainties since green bonds were developed to address concerns about future climate change. Third, it is the first-time multiple uncertainties are studied in the US market and their heterogeneous effects are examined. More precisely, we apply portfolio theory to explain the connection between uncertainties and green bond volatility. We provide empirical evidence for hedging uncertainties by comparing the short- and long-run responses of green bond returns to uncertainties. Fund managers and retail investors can take advantage of our results to control and optimize their investment portfolio strategies involving green bonds. Furthermore, our results offer policymakers important insights to formulate policies aimed at stabilizing the green bond market.

The remainder of this paper is arranged as follows. In Section 2, we discuss the existing literature on the relationship between US economic policy uncertainty (USEPU), geopolitical acts (GPRA), geopolitical threats (GPRT), WTI oil prices, and green bond returns. In Section 3, we describe our regression method and how we constructed the model. Detailed information about the data can be found in Section 4. In Sections 5 and 6, we present result discussions and policy implication, respectively. In Section 7, we provide conclusions, limitations, and recommendations for future studies.

# 2. Literature review

It is suggested that investing in green bonds improves environmental performance while providing high investment returns (Flammer, 2019; Maltais and Nykvist, 2020). In fact, green bonds enable investors to diversify their portfolios and allow them to achieve financial gains while preserving the environment (Huynh et al., 2020). Ever since its introduction in 2007, green bond markets have expanded dramatically (Febi et al., 2018; Reboredo & Ugolini, 2020; Tang & Zhang, 2020). Indeed, green bonds are found to perform better than conventional bonds (Kanamura, 2020). As a result, green bonds are expected to become a significant sustainable investing asset (Maltais & Nykvist, 2020). There is no doubt that green bond prices are affected to a great extent by macroeconomic indicators, for instance, geopolitical risk and economic policy uncertainty (Broadstock & Cheng, 2019).

The link between green bonds and firm value in the context of political uncertainty and geopolitical risk can be explained by portfolio theory. Portfolio theory suggests that investors should construct a diversified portfolio that maximize their returns with acceptable levels of risks. We argue that incorporating social and environmental considerations into firm strategies and operations reduces company risk would promote value creation in the long term and lower the investment risks (Masini and Menichetti, 2013). In the context of economic policy uncertainty, firms are encouraged to diversify to mitigate the negative effects of EPU, GPR, and oil price volatility. Therefore, the company's value will be enhanced, and potential investors will be able to better predict the returns on their investments. Furthermore, Bona-Sanchez et al. (2017) argue that sustainability helps inventors analyze financial information in an uncertain context which is in line with portfolio theory. Investors who are risk averse can minimize uncertainty risks by investing in securities (e.g., green bonds) that reduce risk and maximize returns. As a result, diversification is an important aspect of this investment strategy. Indeed, Chopra and Mehta (2023) found that green bonds acted as a strong hedge for eleven US stock sectors during the COVID-19 crisis. They suggest that investors hedge their equity portfolios with green bonds regardless of the economic consciousness of the companies in their portfolio.

## 2.1 Economic policy uncertainty, oil prices, and green bond returns

Economic policy uncertainty relates to financial system risk due to unclear strategies of government spending, taxation, monetary, and other regulations (Baker et al., 2016). Due to international trade conflicts and financial globalization, economic policy uncertainty has increased immensely (Al-Thaqeb & Algharabali, 2019). Furthermore, the COVID-19 crisis has exacerbated the economic policy uncertainty around the world, making it a more devastating catastrophe than the world economic downturn and the Eurozone crisis (Baker et al., 2020). From portfolio theory perspective, investors always seek to diversify their investment portfolio to reduce the risk (Masini and Menichetti, 2013). Economic political uncertainty presents a serious issue for investors and policymakers and is expected to curtail the volume of investment (Bernanke, 1983).

Existing literature examines the correlation between financial asset performances, such as cryptocurrency, international stocks, and conventional stocks, against economic political uncertainty (Yen & Cheng, 2021; Zhang et al., 2023). Furthermore, some studies investigated the influencing factors of green bonds' performance, in particular, the relationship between sustainable bonds and traditional bonds (Nguyen et al., 2021), sustainable bonds and black bonds (Broadstock & Cheng, 2019) and green bonds prices, and spillovers (Reboredo, 2018). It is, however, important to note that there is little evidence of the impact of EPU on green bond prices, thus, the emerging green market requires more empirical evidence. In this study, we respond to Broadstock and Cheng’s (2019) recommendation that research should be directed towards the relationship between environmentally friendly securities and macroeconomic indicators.

According to Afonso et al. (2020), the financial market perceives unfavorable monetary and fiscal strategy announcements as an indicator of government bond failure. Further analysis by Žigman and Cota (2011) suggests that investors do not value the government deficit ratios. The debt-to-GDP ratio has received significant attention, particularly during the worldwide economic crisis (Capelle-Blancard et al., 2019; Silvapulle et al., 2016) and there was evidence of its negative impact on the Eurobond market. Furthermore, Baumeister and Benati (2010) indicate that when assets are purchased by central banks in a deteriorating economic situation, it results in a decrease in long-term bond yield. It has been shown in previous literature that government bond yields and negative economic forecasts are negatively correlated. In particular, De Grauwe et al. (2017) conclude that fundamental indicators affect sovereign bonds.

Pham and Nguyen (2022), using the Markov Switching Dynamic Regression (MSDR), find that the linkage between sustainable bonds and economic policy ambiguity is not consistent over time; their analysis suggests that unclear policies related to the economy influence these financial instruments in particular when governments did not disclose clear and certain economic policies. Wei et al. (2022) investigate the quantile influence of Economic Policy Uncertainty on green bond performance using wavelet analysis and show that EPU has an asymmetric causal relationship with green bonds. Ren et al. (2022) reveal that carbon prices mostly positively affect green bonds. Therefore, we assume that green bonds, which are issued with the purpose of funding projects aimed at maintaining environmental sustainability, can reduce the volatility induced by economic uncertainty when they are added to an investment portfolio (Chopra and Mehta, 2023). Thus, green bonds become an important criterion for portfolio managers to consider when hedging their investments.

Although the performance of green bonds with respect to other financial instruments has been studied from many perspectives in previous research, the link between green bonds and economic political uncertainties has not been ascertained. As we have established uncertainty measurements (e.g., VIX and OVX) and their impact on financial markets has been demonstrated, determining their influence on green bonds is critical considering the expansion of green bonds. Furthermore, the possible hedge and safe haven characteristics of green bonds would have significant implications for portfolio diversification (Chopra and Mehta, 2023). This information may pique market interest in green bonds resulting in more sustainable economic growth.

## 2.2 GPR, oil prices, and green bond returns

Geopolitical risks occur when doubts about the stability of the government and its institutions adversely influence the sustainability goals of a country’s economy. This risk consists of a system of interrelated pressure factors that have a significant effect on nations’ long-term development (Castells‐Quintana et al., 2019). Therefore, in order to achieve sustainable development goals, countries need to control a knotty system of variables related to the economy, the environment, and society development regulations (Castells‐Quintana et al., 2019; Hopwood et al., 2005).

### 2.2.1 GPU and equity market

A well-established research body addresses the impact of geopolitical uncertainty risk on capital market fluctuations (Balcilar et al., 2018; Fernandez, 2008). It is well-recognized that political uncertainties have a considerable impact on investment decisions. In turn, influence the returns of the financial instruments in question (Apergis et al., 2017; Caldara & Iacoviello, 2022). The repercussions of geopolitical risk on financial markets are particularly severe in nations with higher geopolitical turmoil. Balcilar et al. (2018) and Mensi et al (2016) study the effect of GPR on the BRICS financial market using a geopolitical risk index which incorporates terrorism acts and different types of political conflicts and discover that GPR determines fluctuation more than returns. Bouri et al. (2019) examine the relationship between geopolitical uncertainties and both the return and volatility patterns of Islamic equities. Their results suggest these risks are likely to influence equity market volatility rather than bond returns and volatility. In this paper, we turn our attention to green bonds. Green bonds generate fixed income like all traditional bonds. In addition, their component and risk-to-return features are similar to those of a traditional bond. The main distinction is the green use of revenues.

Socio-political research suggests that ethnic strife undermines the political-legal system, particularly when members of political society are divided into different ethnic affiliations (Suarez et al., 2018). This conflict creates tension between political leaders and makes reaching a consensus on sustainability projects difficult to achieve (Doyle & Stiglitz, 2014; Koziuk et al., 2020). Recent research looks at the role of GPR in the green economy (Forouli et al., 2020), covering the effectiveness of institutions, domestic conflicts, army power, religion, social, and economic factors (Cernev & Fenner, 2020). Furthermore, Mauerhofer (2019) suggests that order and law order are intertwined with the implementation of sustainability policies that affect sustainable investment. Using a GPR index that accounts for government instability, socioeconomic factors, investment characteristics, domestic and foreign wars, corruption, the interference of the army and religion in politics and regulations, and democratic accountability, Hunjra et al. (2022) found that high political risk negatively affects sustainable development due to the disinterest of investors in buying in the long term. Additionally, Bouri et al. (2019); Caldara and Iacoviello (2022) found that investment decisions are largely affected by extraordinary geopolitical events. We add to this research body by looking at green bonds as a financial instrument. Tian et al. (2022) examine the asymmetric effects of green bonds on multiple uncertainties in the long term and short term by the nonlinear ARDL (NARDL) approach and reveal that uncertainty has an asymmetric effect on Chinese green bonds. Tian et al. (2022) also find that in the long run, Europe’s sustainable bonds markets have a considerable asymmetrical effect and share this effect with the United States market. Yang & Yang (2021) demonstrated that geopolitical risk enhances stock market accuracy forecasts. provides more accurate stock market predictions.

### 2.2.2 Oil price and financial market

Although oil prices and equity market dynamics have been investigated widely by previous literature (Arouri & Nguyen, 2010; Xia et al., 2019), results regarding this link are not conclusive. Antonakakis et al. (2017) documented a negative impact of oil prices on stock markets. Kang et al. (2014) and Tang et al. (2010) found that increments in oil demand had a negative impact on bond return when they investigated the impact of oil price volatility on the US bond market. Studies (Dutta et al., 2020; Forouli et al., 2020; Hunjra et al., 2022) examined the association between oil prices and sustainable investment performance and identified a volatility transfer between oil and sustainable stock markets. Results corroborate the causal relationship between oil and clean energy markets (Reboredo et al., 2017). Since conventional energy and renewable energy are substitutes (Ferrer et al., 2018), it is commonly assumed that sustainable investment is influenced heavily by the price of energy (Troster et al., 2018). Dutta et al. (2020) point out that when crude oil markets undergo significant negative volatility, investors will be less interested in green products. Conversely, when oil market prices increase, investors will be more interested in this type of product, hence the price of green bonds will be expected to increase (Bondia et al., 2016). It is also found that crude oil prices promote the non-renewable energy market, while climate policy uncertainty lowers crude oil prices (Shang et al., 2022).

### 2.2.3 Oil price and GPR

Recent research examines the influence of GPR on oil prices (Caldara & Iacoviello, 2022; Cunado et al., 2020; Demirer et al., 2018). Considering the effect of geopolitical risk on the economic-financial markets, which are the major reasons for oil price fluctuations (Antonakakis et al., 2017; Apergis et al., 2017; Cheng & Chiu, 2018), variations in the oil market are expected to be influenced by geopolitical issues related to the general geo-politic scene through the demand mechanism (Plakandaras et al., 2019). Furthermore, extant research indicates that GPR has a negative impact on oil prices. Using structural VAR models, (Caldara & Iacoviello, 2022) confirmed the negative relationship between GPR and oil price. Demirer et al. (2018) suggest that catastrophe threats predict oil prices. Their results reveal that the relationship between risk and return is nonlinear, resulting in the misspecification of linear Granger-Causality tests. They found that the aforementioned risks had a significant impact on oil returns at lower quantiles when they used a non-parametric quantile-based technique. Furthermore, Cunado et al. (2020) demonstrate that geopolitical uncertainties have a negative influence on oil demand, which leads to oil price decrements.

Previous studies investigated the moderating effect of oil prices on the linkage between GPR and financial market prices. Particularly, research found that the effect of geopolitical uncertainties on stock market prices is mostly determined by forecasts of future supply and demand for oil (Demirer et al., 2019; Liu et al., 2019; Peng et al., 2018). Lee et al. (2021) found that green bonds and oil prices have a mutual relationship, where any change in one price results in a change in the other’s price. Furthermore, their results highlight that the observed effect of the oil price is lesser in the upper quantile. Their study also suggests that geopolitical risk affects green bond prices. This could be explained by the fact that the risk sensitivity to geopolitical issues causes modifications in global uncertainty, which contributes to stock market volatility (Mensi et al., 2016).

The potential impact of geopolitical uncertainty on green bonds may be studied independently through three pathways. First, the high geopolitical risk increases oil prices, encourages the adoption of green sources, and strengthens the motivation to invest in sustainable projects (Marques et al., 2018). Second, greater geopolitical risk motivates governments to advocate a faster switch to renewable energy, hence improving green sustainable investments return (Yang & Yang, 2021). Third, growing geopolitical risk raises markets' uncertainties, which have a negative impact on the economic and financial settings, in turn, reducing stock market  performance.

# 3. Methods

We consider the NARDL model of Shin et al. (2014). The NARDL illustrates the magnitude of asymmetric responses of return in the response variable (green bond returns (GB)) as a result of changes (increases and decreases) in the independent variables (climate policy uncertainty (CPU), geopolitical risk (GPR), and WTI oil prices (WTI)) in the short- and long-run. The choice of the model is based on the nonlinearity and asymmetry characteristics of the data. Besides, the NARDL model offers an advantage over other linear econometric methods because it can account for both short- and long-run asymmetries by modeling asymmetric cointegration (Mensi et al., 2016; Demir et al., 2021). Also, the problem of multicollinearity is avoided by selecting the appropriate lag order for the included variables (Shin et al., 2014). This method can catch the asymmetric short-run and long-run impact of each independent variable, on the dependent variable. (Li et al., 2022). Besides, NARDL can analyze the presence of any asymmetry of non-stationary variables in a single equation. Most price series are usually non-stationary; therefore, NARDL is found to be suitable for exploring and establishing the relationship between green bond prices and WTI oil prices (Chattopadhyay & Mitra, 2015). The technique has been applied to a variety of assets and markets (see, Bouri et al., 2018; Demir et al., 2021; Sahu et al., 2022; Sarker et al., 2022; Tian et al., 2022)

Generally, the NARDL model is presented as follows in Equation (1):

 (1)

where, is an error term, andare the asymmetric long-run parameters, and is a vector of independent variables decomposed as in Equation (2):

 (2)

where, is an initial value, and are partial sum processes corresponding to positive and negative changes in , as shown for EPU in Equations (3) and (4).

The NARDL error correction model can be defined as follows from Equations (5) to (8):

 (5)

 (6)

 (7)

 (8)

In Equations (5), (6), (7), and (8), the terms GB represent green bond returns prices, EPU represents the uncertainty associated with US economic policy, GPRT represents the geopolitical threats, GPRA represents the geopolitical acts, WTI represents the West Texas Intermediate crude oil prices, and SP500 represent the Standard & Poor's 500 stock market composite index. We use the S&P 500 index to capture global financial and macroeconomic trends as well as demand for clean energy prices. SP500 is a suitable indicator based on recent evidence (e.g., Bertheau, 2020; Demir et al., 2021; Kumar et al., 2021).

We would conclude that the effect will be asymmetric in the short run if for all . Similarly, if we would conclude that the effect will be asymmetric in the long run. Cointegration is checked using the NARDL bounds test approach.

For the nonlinear ARDL framework, the BDM test statistic (tBDM) (Banerjee et al., 1998; Demir et al., 2021) and PSS F statistic (FPSS) test (Eissa and Al Refai, 2019; Pesaran et al., 2001) are used to check for cointegration. In this study, we test the null hypothesis that there is no cointegration. The hypothesis of FPSS can be written as follows:

We would conclude that cointegration exists if the test statistic exceeds the upper-bound values. In contrast, if the test statistic falls between the upper and lower bounds or is less than the lower bound, cointegration is not observed.

# 4. Data

In this study, we collected monthly data on US economic policy uncertainty (USEPU), green bond prices (GB), geopolitical threats (GPRT), geopolitical acts (GPRA), and WTI oil prices between September 2012 and August 2022. The data of the GPR and US EPU was obtained from [www.policyuncertainty.com](http://www.policyuncertainty.com) while the data of S&P 500, WTI oil prices and green bond prices were obtained from DataStream. We calculate the rate of change *(R)* for each variable on a monthly basis using the , where ‘*s*’ is a time series data at time ‘*t*’.

There are descriptive statistics provided in Table 1 for all of the data. Based on Table 1, green bond returns have negative skewness and high kurtosis. The positive skewness of US economic policy uncertainty and geopolitical acts means that investors may expect frequent small changes and few large changes in USEPU and GRPA. The skewness of green bond, GPRT, WTI, and SP500 are moderately skewed. The standard deviation of the USEPU, GPRA, GPRT, and WTI is high as these variables have high volatility as often influenced by market factors and policy news. Jarque-Bera (JB) test statistics indicate non-Gaussian distributions for the given data series, which are significant at the 1% and 5% levels.

Table 1 Descriptive statistics.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | GB | USEPU | GPRT | GPRA | WTI | SP500 |
| Mean | 0.0957 | 0.0185 | 0.3768 | 0.8286 | 0.0130 | 0.8615 |
| Maximum | 4.3235 | 135.7570 | 197.1660 | 257.1891 | 63.3268 | 11.9420 |
| Minimum | 0.0159 | 0.0011 | 0.0645 | 0.0083 | 0.0092 | 0.0831 |
| Std. Dev. | 1.7661 | 56.4863 | 71.2773 | 79.1927 | 13.0575 | 4.0545 |
| Skewness | -0.8375 | 0.0429 | -0.1076 | 0.5947 | -0.9736 | -0.6046 |
| Kurtosis | 4.7587 | 2.5737 | 3.6890 | 3.7549 | 16.2792 | 4.3129 |
| Jarque-Bera | 29.6206\*\* | 0.8802\*\*\* | 2.2264\*\*\* | 9.6659\*\* | 918.73\*\* | 16.2165\*\*\* |

Notes: \*\*\* and \*\* indicate 1% and 5% significance levels. GB is the green bond returns, USEPU is the US economic policy uncertainty, GPRT indicates geopolitical threats, GPRA is the geopolitical acts, and WTI is the West Texas Intermediate oil returns.

Figure 1 Plots of logarithmic change of the time series data (2012M08-2022M08)



Figure 1 shows the logarithmic changes in the data series over the period of the study. Our findings show that green bonds, EPU, and WTI have experienced extreme volatility during the COVID-19 pandemic. Due to the geopolitical conflicts between Russia and Ukraine in 2022 (Będowska-Sójka et al., 2022), the GPRT and the GPRA have been on the rise.

We perform a nonlinearity test on the time series using the BDS tests (Brock et al., 1996). A dimension m from 2–6 and distance (e) of 0.7 was selected to perform the test. Table 2 shows that the BDS test statistics at significant at 1% and 5% levels, indicating that the series is nonlinear.

Table 2 BDS test statistics.

|  |  |
| --- | --- |
|  | BDS Test Statistics |
| Dimension  | GB | USEPU | GPRT | GPRA | WTI |
| 2 | -0.002428 |  0.0319\*\*\* |  0.0204\*\*\* |  0.0252\*\*\* |  0.0278\*\*\* |
| 3 |  0.005264 |  0.0500\*\*\* |  0.0330\*\*\* |  0.0564\*\*\* |  0.0458\*\*\* |
| 4 | -0.007235 |  0.0543\*\*\* |  0.0366\*\*\* |  0.0730\*\*\* |  0.0587\*\*\* |
| 5 |  0.004654 |  0.0559\*\*\* |  0.0327\*\*\* |  0.0778\*\*\* |  0.0666\*\*\* |
| 6 | -0.012283 |  0.0566\*\*\* |  0.0218\*\* |  0.0793\*\*\* |  0.0695\*\*\* |

 Notes: \*\*\* and \*\* indicate 1% and 5% significance levels. GB is the green bond returns, USEPU is the US economic policy uncertainty, GPRT indicates geopolitical threats, GPRA is the geopolitical acts, and WTI is the West Texas Intermediate oil returns.

The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) (see Table 3) unit root tests reveal that the green bond returns are first-difference stationary, i.e., I(1) at a 1% significance level. The results also show that the USEPU, GPRT, and GPRA are stationary at levels, i.e., I(0). As a result, the data series are suitable for applying the nonlinear ARDL method, which requires that the data series to be stationary at levels or at the first difference but should not be stationary at the second difference (Shin et al., 2014).

Table 3 Results of the unit root test

|  |  |  |
| --- | --- | --- |
|  | ADF | PP |
|  | I(0) | I(1) | I(0) | I(1) |
| GBR | -2.3808 | -2.9628 \*\*\* | -1.5121 | -10.0343\*\*\* |
| USEPU | -3.2461\*\* | -16.9772\*\*\* | -4.9695\*\*\* | -23.7571\*\*\* |
| GPRT | -4.3418\*\*\* | -6.5094\*\*\* | -7.2992\*\*\* | -40.9655\*\*\* |
| GPRA | -7.3711\*\*\* | -8.3988\*\*\* | -7.4664\*\*\* | -52.0007\*\*\* |
| WTI | -1.7819 | -9.0610\*\*\* | -1.6717 | -8.9447\*\*\* |
| SP500 | -1.0815 | -12.9121\*\*\* | -1.17621 | -13.1781\*\*\* |

Notes: \*\*\* and \*\* indicate 1% and 5% significance levels. GB is the green bond returns, USEPU is the US economic policy uncertainty, GPRT indicates geopolitical threats, GPRA is the geopolitical acts, and WTI is the West Texas Intermediate oil returns.

Additionally, we checked whether the data series are cointegrated. It is evident from the results of the tBDM and FPSS test that green bond returns and other explanatory variables are cointegrated.

Table 4 Bounds test for cointegration.

|  |  |  |
| --- | --- | --- |
|  |  |  |
| USEPU | 8.2471\*\*\* | -5.0422\*\*\* |
| GPRT | 7.9480\*\*\* | -4.9801\*\* |
| GPRA | 5.0340\*\*\* | -6.3023\*\*\* |
| WTI | 8.2793\*\*\* | -4.5804\*\* |
| SP500 | 6.8103\*\* | -6.2039\*\*\* |

Notes. \*\*\* and \*\* indicate 1% and 5% significance levels. The lower and upper bounds of FPSS critical values are 1.99 and 2.94, 2.27, and 3.28, 2.88 and 3.99, respectively, for 10%, 5%, and 1%. The lower and upper bounds of tBDM test critical values are -2.57 and -4.04, -2.6 and -4.38, and -3.43 and -4.99, respectively, for 10%, 5% and 1%.

As a result of the cointegration analysis, we are able to estimate short- and long-run coefficients, as shown in Tables 4, 5, 6, and 7. We used the Akaike information criterion (AIC) to select the optimal order of lags, which enables the NARDL model to remove multicollinearity (Shin et al., 2014).

# 5. Results and discussion

## 5.1 Asymmetric effects of US economic policy uncertainty on green bond returns

According to Table 5, US economic policy uncertainty has asymmetric effects on green bond returns both short- and long-term. An increase in USEPU negatively impacts green bond returns by 0.22% in the current period and by 0.17% in the lagged period. In contrast, a decrease in the USEPU is positively correlated with green bond returns by 0.06%. The findings indicate dynamically asymmetric behavior or sentiment among green bond investors. Our findings are consistent with those of Tian et al. (2022), who find that climate policy uncertainty and geopolitical risks have asymmetric effects on green bond markets in the US, Europe, and China. This finding implies that green bond investors react differently in tandem with an increase and decrease in economic policy uncertainty. Thus, the relationship between green bond returns and economic policy uncertainty is nonlinear (Wei et al., 2022). In complement to Pham & Nguyen (2022), who reveal a weak relationship between green bond returns and uncertainty, our results demonstrate a robust relationship between green bond returns and US economic policy uncertainty. This finding signifies the dynamic asymmetric behavior or sentiment of the green bond investors and provides important insights about investors’ asymmetric responses to green bond returns, given an increase and decrease in US economic policy uncertainty. Investors sell off their green bond holdings when uncertainty increases or when they receive negative news about policy changes. As a result, prices decline, which lowers the returns on green bonds. Our results also indicate that the opposite may also occur, but the magnitude of uncertainty increases is greater than that of uncertainty decreases (Tian et al., 2022). It is also evident from the results that geopolitical threats and acts have a negative impact on the return on green bonds. The reason for this can be explained by the instability of the market or shocks resulting from geopolitical tensions (Apergis et al., 2018; Kang et al., 2014; Yang and Yang, 2021). The recent geopolitical threats and acts, such as the Russian invasion of Ukraine, have caused shocks to the global financial markets, especially the energy markets (Będowska-Sójka et al., 2022; Wang et al., 2022). Investors disinvested their holdings immediately after the geopolitical threats and acts took effect. Market indices plunged as they could not predict the ramifications of the geopolitical threats and acts. Moreover, WTI oil prices affect green bond returns negatively in the short term as a result of their adverse effects on short-term oil prices. Furthermore, it should be noted that, along with the negative return of the green bond, the green bond also results in a decrease in the bond return in the subsequent period.

Additionally, the long-term effects are asymmetric, which implies that green bond investors behave differently in the long run when there is an increase or decrease in USEPU. Using the results of our study, we are able to demonstrate that USEPU negatively impacts green bond returns by 0.11% when US economic policy uncertainty increases. In other words, it means that investors in green bonds, using market information, can predict prices and accordingly make investment decisions (Lee et al., 2021; 2022; Ren et al., 2022). For example, selling green bonds if USEPU rises or investing in green bonds if USEPU decreases. In contrast to Lee et al. (2022), we find that Geopolitical threats (GPRT) and WTI show long-run positive effects of green bond returns, while GPRA shows long-run adverse effects of green bond returns. This could be due to the fact that we use SP500 US data, whereas Lee et al. (2022) use Chinese data. Data results might be different given the two different political environments.

The term “ECM” is negative and significant, which means that the previous year’s errors are adjusted at the speed of 0.93% in the current year. The short- and long-run asymmetries (WSR and WLR) coefficients are significant at the 5% level. The heteroscedasticity and serial correlation results show that the models’ residuals are homoscedastic and not serially correlated. In addition, the normality and Ramsey reset test results indicate that the models’ residuals have a normal distribution and are stable, indicating that the models’ estimates are valid and reliable.

Table 5 Asymmetric effects of USEPU on Green bond (GB) returns.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Short-run estimates |  | Long-term estimates  |
| Variables | Coefficients. | Std. Error | Variables | Coefficients. | Std. Error |
| Short-run estimates | Long-term estimates |  |
| ∆USEPU+ | -0.2249\*\*\* | 0.0305 | UESPU+  | -0.1120\*\*\* | 0.0076 |
| ∆USEPU+ (-1) | -0.1760\*\* | 0.0745 | USEPU− (-1) | 0.0339\*\* | 0.0013 |
| ∆USEPU− | 0.0682\*\*\* | 0.0122 | GPRT− | -0.1081 | 0.0171 |
| ∆GPRT | 0.1102\*\* | 0.0450 | GRPA− (-1) | -0.0375\*\* | 0.0024 |
| ∆GPRT (-1) | 0.0700\* | 0.0452 | GPRT | -0.1432\*\*\* | 0.0527 |
| ∆GPRA | 0.0221\*\*\* | 0.0682 | GPRT (-1) | 0.1432\*\*\* | 0.0527 |
| ∆GPRA (-1) | -0.0731\*\* | 0.0091 | GPRA | 0.1102\*\* | 0.0639 |
| ∆GPRA (-2) | -0.1297\*\* | 0.0038 | WTI (-1) | 0.0349\*\* | 0.0109 |
| ∆WTI (-1) | -0.1375\*\* | 0.0080 | SP500 | 0.1445\*\*\* | 0.0775 |
| ∆WTI (-2) | -0.0618\*\* | 0.0893 | SP500(-1) | 0.1689\* | 0.0594 |
| ∆SP500 | 0.0440\*\*\* | 0.0630 |  |  |  |
| ∆GB (-1) | -0.1363\*\*\* | 0.0248 |  |  |  |
| Constant  | 0.1998\*\* |  |  |  |  |
| Asymmetries  |  |  |  |  |  |
| WSR | 2.7826 | [0.0000] |  |  |  |
| WLR | 1.9059 | [0.0187] |  |  |  |
| Diagnostics tests |  |  |  |
| R2 | 0.6860 |  |  |  |  |
| ECM (-1) | -0.9310\*\*\* | 0.0000 |  |  |  |
| χ2HETR | 1.1986 | [0.1087] |  |  |  |
| χ2SC | 0.0146 | [0.9030] |  |  |  |
| χ2NOR | 2.3385 | [0.3105] |  |  |  |
| Ramsey | 3.5698 | [0.0616] |  |  |  |

Notes: “+” and “-” are positive and negative cumulative sums. Superscripts “a”, “b”, and “c” specify the 1%, 5%, and 10% significance levels, respectively. χ2HETR, χ2SC, χ2NOR, and Ramsey are heteroskedasticity, LM tests for serial correlation, normality, and Ramsey RESET tests, respectively. WSR and WLR relate to the short- and long-run Wald tests. P-values are indicated in parentheses.

## 5.2 Asymmetric effects of geopolitical threats on green bond returns

Table 6 illustrates the asymmetric effects of geopolitical threats on green bond returns. We find that geopolitical threats (GPRT) have a positive influence on green bond returns. For example, a 1% increase in GPRT will increase green bond returns by 0.20%, whereas a 1% decrease in GPRT will decrease green bond returns by 0.11%. This finding provides important insights into investors’ asymmetric responses to green bond returns, given an increase and decrease in geopolitical threats. Additionally, a negative effect of USEPU can be observed on the returns of green bonds (-0.16%). Likewise, GPRA has a negative impact on green bond returns. As a result of the WTI and lagged returns of the green bond (GB(-1)), green bond returns are positively affected, whereas the SP500 has a positive impact on green bond returns as well.

The long-term asymmetric effects are significant, suggesting a 1% increase in GPRT is associated with a 0.33% decrease in green bond returns, while a 1% decrease in GPRT increases green bond returns by 0.26%, supporting the findings of (Lee et al., 2022) who claim that geopolitical threats positively influence green bond returns in China. The reasons may be that when geopolitical threats are exchanged between oil, gas, or other energy-rich countries, the effects shortly occur in energy and financial markets, where investors often shift to green investments that may benefit from geopolitical risk exposure. However, the spillover effects (volatility) from traditional financial assets due to geopolitical threats may adversely affect green bond returns (Naeem et al., 2022) in the long run. The results indicate that USEPU has adverse effects on green bond returns, i.e., a 1% change in USEPU decreases green bond returns by 0.18%. GPRA negatively affects green bond returns, too (0.23%). WTI and SP500 have a positive long-term effect on green bond returns.

The error correction term (ECM) shows that the previous year’s errors are adjusted at the speed of 0.96% in the current year. The diagnostic test statistics show that the models’ residuals are homoscedastic, not serially correlated, normally distributed, and stable.

Table 6 Asymmetric effects of geopolitical threats (GPRT) on green bond returns.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Panel A: Short-run estimates |  | Panel B: Long-term estimates  |
| Variables | Coefficients. | Std. Error | Variables | Coefficients. | Std. Error |
| ∆GPRT+ | 0.2081\*\*\* | 0.0112 | GPRT+  | -0.3361\*\*\* | 0.0298 |
| ∆GRPT+ (-1) | 0.1644\*\*\* | 0.0701 | GPRT− | 0.2617\*\*\* | 0.0189 |
| ∆GPRT−(-2) | -0.1174\*\*\*  | 0.0216 | USEPU | -0.1894\*\*\* | 0.0100 |
| ∆GPRT−(-3) | -0.0912\*\* | 0.0319 | USEPU(-1) | -0.1652\*\* | 0.0271 |
| ∆USEPU | -0.1697\*\*\* | 0.0381 | GPRA | -0.2399\*\*\* | 0.0527 |
| ∆GPRA | -0.0775\*\* | 0.0594 | GPRA(-1) | -0.1953\*\* | 0.0639 |
| ∆WTI (-1) | 0.0434\*\*\* | 0.0126 | WTI(-1) | 0.1348\*\*\* | 0.0126 |
| ∆WTI (-2) | 0.0711\*\* | 0.0210 | SP500(-1) | 0.2426\*\*\* | 0.0804 |
| ∆GB (-1) | -0.1762\* | 0.0958 |  |  |  |
| ∆SP500(-1) | -0.0562\*\*\* | 0.0031 |  |  |  |
| ∆SP500(-2) | 0.0913\*\* | 0.0355 |  |  |  |
| Constant  | -0.51465\*\*\* | 0.0551 |  |  |  |
| Asymmetries  |  |  |  |  |  |
| WSR | 2.1750 | [0.0921] |  |  |  |
| WLR | 1.2886 | [0.0582] |  |  |  |
| Diagnostics tests |  |  |  |
| R2 | 0.6871 |  |  |  |  |
| ECM (-1) | -0.9680\*\*\* | 0.0926 |  |  |  |
| χ2HETR | 1.7759 | [0.9343] |  |  |  |
| χ2SC | 0.7548 | [0.6856] |  |  |  |
| χ2NOR | 3.3109 | [0.2119] |  |  |  |
| Ramsey | 2.0151 | [0.4365] |  |  |  |

Notes: “+” and “-” are positive and negative cumulative sums. Superscripts “a”, “b”, and “c” specify the 1%, 5%, and 10% significance levels, respectively. χ2HETR, χ2SC, χ2NOR, and Ramsey are heteroskedasticity, LM tests for serial correlation, normality, and Ramsey RESET tests, respectively. WSR and WLR relate to the short- and long-run Wald tests. P-values are indicated in parentheses.

## 5.3 Asymmetric effects of geopolitical acts on green bond returns

Based on Table 7, we can see that increases and decreases in geopolitical acts (GPRA) have asymmetrical effects on the returns on green bonds. According to the results, an increase in GPRA negatively impacts green bond returns; that is, changes in GPRA by 1% reduce green bond returns by 0.25%. However, decreases in GPRA are associated with positive effects on green bond returns. Specifically, a 10% change in the GPRA will result in an increase of 0.16% in the green bond returns. Investors’ asymmetric reactions to geopolitical acts are well aligned with market volatility and returns in the short run. These asymmetries can be explained by investors' perceptions of potential risks arising from geopolitical acts and market reactions (Eissa and Al Refai, 2019; Tian et al., 2022). For example, the Russian invasion of Ukraine on 24th February 2022 triggered volatility across global markets. Gas and oil prices spiked to all-time highs after 2008. Foods, commodity, and energy markets remained highly disrupted following the series of sanctions from the US, EU, the UK, Canada, Japan, and Australia and deep concerns over Russian energy supply bans. The volatility spillover of geopolitical acts shortly affects all market indices, causing green bond prices to fall. For example, the Nasdaq and S&P 500 fell in March 2022 following the uncertainty about the conflicts in Ukraine and expectations that the Federal Reserve would hike interest rates. USEPU, GPRT, and past returns of the green bond (∆GB (-1)) have further been found to affect the green bond returns negatively. The SP500, however, has a positive effect on green bond returns.

Green bond returns are not asymmetrically affected by GPRA over the long run. The results demonstrate that geopolitical factors similarly affect the returns on green bonds during times of increase and decrease in geopolitical acts. The responses of investors are similar regardless of whether geopolitical events increase or decrease. It is generally accepted that geopolitical acts, such as wars, invasions, and forceful possession, have long-term effects on the economy and the financial markets (Apergis et al., 2018; Balcilar et al., 2019; Będowska-Sójka et al., 2022; Lee et al., 2021; 2022). Despite a decrease in geopolitical activity, investors' expectations do not change. Therefore, even a decrease in geopolitical acts cannot increase investor confidence. Our results also demonstrate that USEPU adversely affects green bond returns in the long run, whereas SP500 positively affects them in Table 7.

The error correction term (ECM) indicates that the previous year’s errors are adjusted at the speed of 0.84% in the current year. The short-run asymmetries (WSR) hold at the 5% significance level, while the long-run coefficients (WLR) are symmetric, meaning for a given change in the GPRA, the positive or negative changes have similar effects. The diagnostic test statistics show that the NARDL models are free from heteroskedasticity and serial correlation.

Table 7 Asymmetric effects of geopolitical acts (GPRA) on green bond returns.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Short-run estimates |  |  Long-term estimates  |
| Variables | Coefficients. | Std. Error | Variables | Coefficients. | Std. Error |
| ∆GPRA+ | -0.2583\*\*\* | 0.0148 | GPRA+  | -0.2361\*\*\* | 0.0372 |
| ∆GPRA+ (-1) | -0.1850\*\*\* | 0.0711 | GPRA+(-1) | -0.1918\*\* | 0.0128 |
| ∆GPRA− | 0.1602\*\* | 0.0149 | GPRA− | -0.1072\*\* | 0.1171 |
| USEPU | -0.7281\*\*\* | 0.0253 | USEPU | -0.0875\*\*\* | 0.0424 |
| USEPU(-2) | -0.3729\*\*\* | 0.0197 | GPRT(-1) | 0.2832\*\*\* | 0.0529 |
| ∆GPRT | 0.1044\*\*\* | 0.0199 | GPRT(-2) | 0.1953\*\* | 0.0510 |
| ∆GPRT (-1) | 0.1981\*\*\* | 0.0252 | SP500 | 0.0945\*\* | 0.0675 |
| ∆GB (-1) | -0.8454\*\*\* | 0.0610 | SP500(-1) | 0.1189\*\*\* | 0.0494 |
| ∆SP500 | 0.0240\*\* | 0.0945 |  |  |  |
| ∆SP500(-1) | 0.0778\*\* | 0.0349 |  |  |  |
| Constant  | 0.4921 | 0.2567 |  |  |  |
| Asymmetries  |  |  |  |  |  |
| WSR | 1.7826 | [0.0510] |  |  |  |
| WLR | 2.3259 | [0.0497] |  |  |  |
| Diagnostics tests |  |  |  |
| R2 | 0.6839 |  |  |  |  |
| ECM (-1) | -0.8454\*\*\* | 0.0883 |  |  |  |
| χ2HETR | 0.0234 | [0.8783] |  |  |  |
| χ2SC | 0.0641 | [0.9685] |  |  |  |
| χ2NOR | 1.2980 | [0.8048] |  |  |  |
| Ramsey | 1.7726 | [0.0791] |  |  |  |

Notes: “+” and “-” are positive and negative cumulative sums. Superscripts “a”, “b”, and “c” specify the 1%, 5%, and 10% significance levels, respectively. χ2HETR, χ2SC, χ2NOR, and Ramsey are heteroskedasticity, LM tests for serial correlation, normality, and Ramsey RESET tests, respectively. WSR and WLR relate to the short- and long-run Wald tests. P-values are indicated in parentheses.

## 5.4 Asymmetric effects of WTI oil prices on green bond returns.

Asymmetric effects of WTI oil price changes on green bond returns are shown in Table 8. An increase in WTI positively affects green bond returns by 0.20% in the current period and by 0.16% in the lagged period in the short run, which supports previous findings (Su et al, 2022). Conversely, a reduction in the WTI adversely affects green bond returns by 0.06%. Our finding signifies that green bond investors’ dynamic reactions or sentiments are asymmetric. It is found that when investors perceive that the WTI is rising, they may increase their investments in green bonds. In turn, this leads to an increase in the price of green bonds, ultimately leading to an increase in returns on green bonds. There is the possibility that the opposite may also occur, as evidenced by our results and other studies (e.g., Lee et al., 2021). This result supports the goal of the COP26 zero-emission transition by lowering the use of fossil fuels (Dogan et al., 2022; Ren et al., 2022). Representatives of governments, businesses, and other organizations with an influence over the future of the automotive industry and road transport are rapidly accelerating the transition to zero-emission vehicles to achieve the goals of the Paris Agreement by 2035 in leading markets. However, the magnitude of WTI increases is more significant than that of WTI decreases. The results also show that USEPU and geographic acts (GPRA) negatively affect green bond returns. This can be explained by the policy uncertainty or shocks that arise from government policy change or geographical conflicts. For example, global financial and commodity markets (Apergis et al., 2018; Wang et al., 2022), especially those in the energy sector, have been negatively affected by recent geopolitical threats and acts, e.g., the Russian invasion of Ukraine. In response to these threats, investors disinvested their holdings to reduce the risk of their portfolios being exposed to these risks. The effects immediately led to a decline in market indices as investors were not able to anticipate the ramifications of the events. Furthermore, we find a negative effect of geopolitical risks on asset prices and returns. Several studies have demonstrated that geopolitical risks negatively impact asset prices, including green markets (see Balcilar et al., 2018; Smales, 2021; Caldara & Iacoviello, 2022).

Geopolitical threats (GPRT) have positive short-run effects on green bond returns. This finding is consistent with previous studies, i.e. (Sohag et al., 2022); Geopolitical threats. Moreover, the short-term effects of SP500 and green bond returns are adverse, meaning SP500 changes negatively affect the green bond returns. The negative return of the green bond itself also decreases the bond returns in the subsequent period.

When WTI increases or decreases, the long-term effects on green bond investors are asymmetric, suggesting that investors behave differently in the long run (Wei et al., 2022). According to the results, rising WTI positively impacts green bond returns by 0.29%. This finding is similar to the previous studies (e.g., Rasoulinezhad et al., 2020; Gong et al., 2020). It can be explained that an increase in oil prices can be expected to result in rises in the prices of commodities, energy markets, and energy stocks as well (Eissa and Al Refai, 2019; Sahu et al., 2022). Moreover, As oil prices rise, green investments should also increase due to substitution effects. Thus, the positive spillover effects can lead to an increase in green bond prices. The substitution effect can be capitalized to transit to zero-emission vehicles (ZEVs)─a goal of COP26─ by reducing the dependence on fossil energy (Dogan et al., 2022). This transition will immensely help to achieve zero greenhouse gas emissions as road transport accounts for over 10% of global greenhouse gas emissions, and the total emissions are rising faster than any other sector. However, a decrease in WTI also lowers green bond returns by 0.11%. It means green bond investors can predict the price of green bonds based on market information and adjust their investment decisions accordingly, such as replacing green bonds in response to WTI oil prices and vice versa. Also, GPRT has a positive influence, and GPRA has adverse long-run effects on green bond returns. Also, SP500 positively affects green bond returns.

The short- and long-run asymmetries (WSR and WLR) hold at the 5% level. The diagnostic test statistics show that the application of the NADRL models is well suited as the results show no heteroskedasticity, serial correlation, or normal distribution problems.

Table 8 Asymmetric effects of WTI on green Bond’s returns.

|  |  |  |  |
| --- | --- | --- | --- |
|  |  Short-run estimates |  | Long-term estimates  |
| Variables | Coefficients. | Std. Error | Variables | Coefficients. | Std. Error |
| ∆WTI+ | 0.2064\*\*\* | 0.0305 | WTI+  | 0.2961\*\* | 0.0376 |
| ∆WTI+  | 0.1644\*\*\* | 0.0645 | WTI− | -0.1172\*\* | 0.0159 |
| ∆WTI−(-1) | -0.0695\*\* | 0.0157 | WTI− (-1) | 0.2017\*\*\* | 0.0524 |
| ∆WTI−(-2) | -0.8291\*\*\* | 0.0164 | USEPU | -0.2402\*\*\* | 0.0527 |
| ∆USEPU | -0.2290\*\*\* | 0.0025 | GPRT  | 0.3530\*\*\* | 0.0199 |
| ∆USEPU(-1) | -0.1025\*\* | 0.0452 | GPRA | -0.3460\*\*\* | 0.0177 |
| ∆GPRT | 0.2101\*\* | 0.0682 | SP500 | 0.1589\* | 0.0975 |
| ∆GPRA (-1) | -0.0413\*\* | 0.0211 | SP500(-1) | 0.2046\*\*\* | 0.0793 |
| ∆GB | -0.0440\*\*\* | 0.0080 |  |  |  |
| ∆GB (-1) | -0.1214\* | 0.0940 |  |  |  |
| ∆ SP500 (-1) | -0.1075\*\* | 0.0230 |  |  |  |
| Constant  | -0.4890 | 0.2799 |  |  |  |
| Asymmetries  |  |  |  |  |  |
| WSR | 1.7826 | [0.0964] |  |  |  |
| WLR | 2.9801 | [0.8057] |  |  |  |
| Diagnostics tests |  |  |  |
| R2 | 0.4009 |  |  |  |  |
| ECM (-1) | -0.8385\*\*\* | 0.0876 |  |  |  |
| χ2HETR | 0.9275 | [0.8682] |  |  |  |
| χ2SC | 0.7546 | [0.8804] |  |  |  |
| χ2NOR | 3.5124 | [0.1728] |  |  |  |
| Ramsey | 3.0944 | [0.8160] |  |  |  |

Notes: “+” and “-” are positive and negative cumulative sums. Superscripts “a”, “b”, and “c” specify the 1%, 5%, and 10% significance levels, respectively. χ2HETR, χ2SC, χ2NOR, and Ramsey are heteroskedasticity, LM tests for serial correlation, normality, and Ramsey RESET tests, respectively. WSR and WLR relate to the short- and long-run Wald tests, respectively. P-values are indicated in parentheses.

## 5.5 Nonlinear Granger Causality

The causal relationship of green bond returns with economic policy uncertainty, geopolitical threats and acts, and WTI crude oil can provide investment information to investors and portfolio managers. Notably, in the wake of the COP-26 and COP-27 summits, the talk of climate change and its perceived effects have made green bonds a timely investment instrument. In light of that, we examined the causal relationship between green bond returns and USEPU, GPRT, GPRA, and WTI. In doing so, we used the nonlinear Granger causality test (Diks & Panchenko, 2006). A dimension (m) of 1 and 2 is used with a bandwidth of 0.7.

Table 9 Nonlinear Granger causality test.

|  |  |  |
| --- | --- | --- |
| Hypothesis  | m=1 | m=2 |
| USEPU→GB  | 0.389 | 0.507 |
|  | [0.032] | [0.019] |
| GB →USEPU | 1.036 | 1.284 |
|  | [0.383] | [0.627] |
| GPRT →GB | 0.581 | 0.677 |
|  | [0.209] | [0.228] |
| GB →GPRT | 1.694 | 1.738 |
|  | [0.461] | [0.509] |
| GPRA →GB | 0.881 | 1.002 |
|  | [0.020] | [0.069] |
| GB →GPRA | 1.489 | 1.508 |
|  | [0.198] | [0.281] |
| WTI →GB | 1.029 | 1.485 |
|  | [0.000] | [0.002] |
| GB →WTI | 0.984 | 1.437 |
|  | [0.092] | [0.130] |

Notes: T-statistics and p-values (in brackets) reported. \*\*\* < 0.001, \*\* < 0.05, \* < 0.1

 The results show that USEPU has a unidirectional causal effect on green bond returns. As a market force, the policy news swiftly affects the investors’ reactions. For example, United Nations Climate Change Conference (COP26 and COP27) has positively influenced green bond investors by committing to zero-emission by 2035 in the leading markets globally, as seen from the green bond market growth (Dogan et al., 2022). Our results also indicate that the US economic policy uncertainty affects green bond returns, whereas the green bond returns have no causal effects on US economic policy uncertainty. This finding is consistent with (Wei et al. (2022). Geopolitical threats have no causal relationship with green bond returns, whereas geopolitical acts have unidirectional causal effects on green bond returns. However, WTI has bidirectional Granger causality with green bond returns, supporting the finding of Dutta et al. (2020) and Shang et al. (2022). Crude oil is a leading source of fossil energy and is thus mainly used by the power-intensive industry. As closely linked with carbon emissions, WTI crude oil is opposite to green bond investment (Shahbaz et al., 2020). Thus, with increases and decreases in WTI prices, green bond prices may fluctuate and vice-versa. Nonlinear causality supports the bidirectional causal relationship. Most importantly, this result is aligned with the COP26 commitment to zero emission (Ren et al., 2022). Transition to zero-emission vehicles implies that fossil fuel will be gradually replaced by green energy, which will eventually increase green investment.

# 6. Policy implications

The green bond market is booming, although its share of the overall bond market remains small. In this paper, insights are provided into the extent to which policies implemented by various countries have been effective in an uncertain environment (Chopra and Mehta, 2023). There has been an increase in interest in green bond policies, including those related to green bond guidelines and standards, as well as those related to green bond grants. Increasing transparency through the implementation of policies is one of the key components of improving market efficiency. The purpose of these legislative initiatives is to increase the confidence of investors and issuers in green bond markets as well as increase the share of institutional investor-controlled capital flowing into green bonds. By increasing institutional investors' capital pool, it contributes to sustainable development.

 In light of the fact that green bond markets are effective at mitigating the effects of uncertainty, policymakers should provide more assistance to sectors that are new to issuing bonds. The reason for this is that they are subject to higher costs and risks. Among these sectors are renewable energy inventors and industries (Azhgaliyeva & Kapsalyamova, 2021). Both the EPU and the GPR have a significant impact on these sectors. Grants and tax incentives, as well as collaboration and regional and global policies, may be used by governments to encourage the issuance of green bonds. According to Azhgaliyeva and Kapsalyamova (2021), regional cooperation and green bond standardization are beneficial to fostering green bonds in the corporate sector of the European Union. In order to mitigate uncertainty risks, policymakers should focus on regional cooperation and green bond standardization.

# 7. Conclusions, limitations and recommendations

Our study extends previous scanty literature on the relationship between EPU, GPRT, GPRA, WTI oil price and green bonds. We conclude that fund managers and retail investors can utilize green bonds to mitigate economic policy uncertainty, geopolitical threats, and volatility in the WTI oil market. Investing in environmentally sustainable products (e.g., green bonds) should be widely promoted by institutional investors and fund managers due to the hedging benefits of green bonds.

 We have identified some limitations in our study. First, we only used a limited period of data to study the implications of contextual factors on green bonds and their impact on sustainable investment strategies. Additional research is required to comprehend the potential of modern financial instruments. Green bonds are critical to meeting the aims of the COP 26 Agreement because they can provide funding for sustainable projects. However, this kind of funding is currently facing significant difficulty as a result of the COVID-19 situation. This is exacerbated by inflation, and governments have responded with a variety of monetary and fiscal measures. In light of the COVID-19 scenario, it would be interesting to study how different components of economic policy uncertainty (e.g., fiscal policy and monetary policy) affect green bond markets and to consider how inflation and government responses through fiscal and monetary policy affect green bonds. Third, our study focuses on the US context only. Future research could focus on emerging economies (e.g., India and China) to examine the impact of such contextual factors on the green bond markets. Fourth, we only examined the relationship between EPU, GPRT, GPRA, WTI oil prices, and green bond returns with data from the American stock market. We posit that geopolitical risk will be more pronounced (Balcilar et al., 2018; Qin et al., 2020) in countries such as Russia and Ukraine due to the recent invasion. Therefore, we recommend performing comparative studies investigating the hedging effect of green bonds on carbon market risks.

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