Chapter 10

Frequency Domain Causal Effects of Geopolitical Risk and Economic Uncertainty on Green Bond Market Around the Invasion of Ukraine

Remzi Gök[1]

Abstract

We analyze causal effects of geopolitical risks and economic uncertainty indices on the green bond market, utilizing two causality tests, around the military conflict in Ukraine. Consistent with the existing literature, the results of Toda and Yamamoto (1995) and Breitung and Candelon (2006) in the static framework show no causal flows from geopolitical risks throughout the period, either before the war or during the war. Further, we find no evidence for both temporary and permanent causal impacts from the geopolitical risks on green bonds. However, we see that changes in economic policy uncertainty Granger-causes fluctuations in green bonds in both full and during the invasion of Ukraine. The results also reveal that the causality is temporary and permanent over the full period; temporary before the war; but turns out to be permanent and stronger during the war, indicating that uncertainty index can exert causal impacts on green bond indices regardless of market conditions and strengthens its power across extreme market conditions. Further, we resort to a time-varying approach of Breitung and Candelon (2006) causality test based on a rolling window of 50 and 60 daily observations. We find that the causal flows from both indicators appear significant and those causation impacts are not constant but time-varying. Economic policy uncertainty is stronger than geopolitics risks in forecasting the movements in green bonds given a higher rejection of the null hypothesis for the former variable. The causality is mostly permanent rather than temporary and the causation impacts from both variables are stronger during the war.

1 Corresponding author, Dr., Department of Business Administration, Dicle University, Diyarbakır, Turkey, e-mail: remzi.gok@dicle.edu.tr; http://orcid.org/0000-0002-9216-5210.

https://doi.org/10.58830/ozgur.pub67.c175

1. Introduction

We seek to assess the causal impact of two leading factors on a relatively new fixed income financial instrument, green bonds around the ongoing invasion of Ukraine by Russia. Although these sustainability-focused bonds, also known as climate bonds, have similar characteristics to conventional bonds in terms of pricing and rating, they differ in that their proceeds must be used to finance environmentally friendly projects to create a climate -resilient economy (Reboredo, 2018)[2]. As a prominent financial instrument for reallocating the required financial resources to finance projects focused on environmental sustainability, they have received increasing attention from policymakers and investors since their first issuance by the European Investment Bank (Broadstock and Cheng, 2019; Piñeiro-Chousa et al., 2021; Lin and Su, 2022). Although it was not seen as an attractive financial product for both investors and issuers at first, the global capitalization of green bond markets has begun to be widely accepted after the Paris Climate Agreement (2015), which held to fight the climate change problem and deliver a low-carbon economy. While the value of market for green bonds in 2013 was around $11 billion (Reboredo, 2018), it has seen a substantial acceleration, from $11.0 and $37.0 billion in 2013 and 2014 (Anh Tu et al., 2020) to a value exceeding $670.0 billion in 2022 and the cumulative green bond issuance reaches $2.247 trillion as of February 2023[3].

Given the tremendous growth in green bond market in past decade and its essential role in mitigating the adverse effects of climate change and accelerating decarbonization in the economy (Haq et al., 2021), a host of papers focus on how green bond instruments provide a protection against risks and uncertainty in financial markets (e.g., Lee et al., 2021; Lee et al., 2022; Long et al., 2022) as well as geopolitical and pandemic-related risks (Piñeiro-Chousa et al., 2021; Tian et al., 2022). Among of these studies, Piñeiro-Chousa et al. (2021) find a significantly positive impact from the investor sentiment extracted from social networks on the green bond market. Kanamura (2020) study the existence of greenness in green bond and compare the performance of green and conventional bond. The author finds that green bonds perform better than conventional bonds, in where this superiority is decaying over time, and reveals evidence of the greenness in the S&P green bond given its positive correlation with oil prices, indicating the existence of an environmental asset for the green bond. Azhgaliyeva et

2 They are essentially issued to finance energy efficiency projects, renewable energy projects, low-carbon transport, sustainable water projects, and waste and pollution projects.

3 Total issuance aligned with CBI definitions in January and February 2023 is around $65.9 billion according to https://www.climatebonds.net/market-intelligence

al. (2022) obtain a similar result, where they measure the effects of crude oil shocks and sovereign green bond issuance on corporate green bond issuance, showing that flow supply and flow demand shocks exhibit a positive impact on and are important determinants of the probability of issuance of green bond instruments. Hammoudeh et al. (2020) confirm the predictive powers of the US 10-year Treasury bond index, the CO2 emission allowances price, and the clean energy index on green bonds between 2014 and 2020. Rehman et al. (2023) claim that the predictive power of oil shocks weaken during the COVID19 period. Dutta et al. (2020) find that the vulnerability of green assets to oil market volatility is higher than that of price fluctuations. Anh Tu et al. (2020) highlight the importance of financial and infrastructural factors in expanding the green bond market in Vietnam. Chopra and Mehta (2023) establish that green bonds offer both safe-haven and hedge properties against stock market equities during both full and pandemic. Nguyen et al. (2021) suggest a higher diversification benefit for short-term investors in constructing portfolio comprising green bonds as well as stocks, commodities, clean energy, and conventional bonds given a low or negative correlation existence between green bond and other assets.

We contribute and extend the existing literature on the causal linkage from geopolitical risks and economic policy uncertainty to the speedy expanding green bond market in the following points. We employ two causal tests, which are robust to integration and/or cointegration properties of the time series and eliminate the need for pre-testing the underlying series (Ciner, 2011) in the static and time-varying frameworks. By doing this, we confirm the time-varying causal impacts of two risk indicators on the green bond market and show how the causality fluctuates over time. Further, the frequency causality proposed by Breitung and Candelon (2006) makes it available to measure the causal impacts at different frequencies, short- and long-term, and thus provide significant enlightenment on heterogonous investors and policymakers with different investment horizons and objectives. Last but not least, we assess the relationship around the ongoing war in Ukraine, which has created severely adverse impacts on the financial markets, and obtain more comprehensive insight into extremely high tensions.

We analyze the causal linkage in the full, before, and during the war in Ukraine. Our results show that only the economic uncertainty index has the ability to forecast the changes in green bond markets while underpinning a safe-haven role for the green bond market against geopolitical risks in the three periods. However, the time-varying causality test results imply that this relationship is not constant but heterogeneous over time and the causal impacts of risk indicators on the green bond market intensify during the war.

The remainder of this paper is organized as follows. Section 2 provides a brief literature overview of the (causal) impacts of economic policy uncertainty and geopolitical risks on green bond market. Section 3 describes the methodology and dataset. We discuss the empirical results in Section 4 while Section 5 concludes the paper with policy implications.

2. Literature Review

Numerous papers (e.g., Lee et al., 2021; Lee et al., 2022; Long et al., 2022; Piñeiro-Chousa et al., 2021; Tian et al., 2022) study the impact of financial or uncertainty/risk factors on the green bond market by applying various techniques other than causality tests. For example, Long et al. (2022) examine the relationship between uncertainty and green bonds in the U.S., Europe, and China using a quantitative connectedness approach based on VAR and find that stock market uncertainty (VIX) and oil market uncertainty (OVX) exhibit a larger influence on green bonds, particularly in emerging markets. Tian et al. (2022) use a nonlinear ARDL model to examine how climate policy uncertainty (CPU), infectious disease stock market volatility (IDEMV), the CBOE Crude Oil Volatility Index (OVX), and geopolitical risk (GPR) affect green bond prices in the United States, Europe, and China. They find that the impact of uncertainty on green bond markets varies by country. In the short term, only the Chinese green bond market is asymmetrically affected. However, in the long run, the European green bond market exhibits more extensive asymmetric effects similar to those in the United States. Lee et al. (2022) examine the relationships between oil shocks, geopolitical uncertainties, and green bond returns for the period from January 2010 to May 2021 and their findings reveal that positive changes in geopolitical risk positively affect green bond returns. Lin and Su (2022) study the relationship between macro risks, uncertainty indicators, and green bond markets in the U.S. and China using a cross-quantilogram method and quantile causality test, and find that uncertainty indicators have a significant impact on green bond market returns and volatilities in both countries.

Another strand of the literature (Haq et al., 2021; Mokni et al., 2022; Pham and Nguyen, 2022; Dong et al., 2022; among many others) investigates the safe-haven characteristics of green bonds against other assets and risk/uncertainty indices. Of these studies, Haq et al. (2021) investigate the relationship between economic policy uncertainty, clean energy stocks, global rare earth elements, and green bonds using the DCC-MGARCH model and reveals that while clean energy stocks and rare earth elements serve as safe havens and diversifiers with green bonds, green bonds act as a hedge instead of a safe haven against economic policy uncertainty. Pham and Nguyen (2022) examine the impact of stock volatility (VIX), oil volatility (OVX), and economic policy uncertainty (EPU) indices on green bond returns for the period from October 2014 to November 2020 and conclude that green bonds can be used as a hedge against uncertainty during periods of low uncertainty. Mokni et al (2022) study whether green bonds (GBs) are effective in protecting against oil price shocks and uncertainty, compared to gold, European government bills, and US T-bills, using GARCH and quantile regression models. They reveal that GBs serve as hedging and safe haven tools against oil price shocks and uncertainty. In a recent paper, Dong et al. (2022) investigate the effects of geopolitical (GPR), economic policy (EPU), and climate policy uncertainty (CPU) on the long-term correlations between conventional/energy stocks and conventional/green bonds. They find that both conventional and green bonds exhibit safe-haven characteristics when geopolitical risk is high. However, due to economic and political uncertainty and climate policy risks, green bonds outperform conventional bonds as a safe haven instrument.

Regarding the causal flows from/between risk and uncertainty indices to green bonds during the crisis periods such as the invasion of Ukraine, the literature is scarce. For example, Lee et al. (2021) adopts a quantile causality approach to investigate the causal relation among oil price, geopolitical risks, and green bond index in the United States between 2013 and 2019. Their results disclose that geopolitical risks Granger-cause oil prices at the extreme quantiles and provide evidence of two-way causality between oil and green bond index for the lower quantiles, that is, when they are bearish. Further, we find strong evidence for geopolitical risks Granger-causing green bond changes over various quantiles of the distribution. They suggest both considering fluctuations in oil price market and reconciling geopolitical risks to maintain stability of the green bond market. In their recent paper, Wang et al. (2022) try to empirically examine the dynamic connections among clean energy, carbon, and green bonds through a battery of models over March 2012 and March 2021. The results of the DCC-MIDAS model show that green bond prices are less volatile than others given its nature as an emerging financing market. Further, this market has drastically risen during the COVID19 pandemic period. The results of the causality-on-quantile test, however, document significant causality impacts of EPU and OVX indices on the cross-correlations over different conditional distributions of three markets. EPU emerges as a dominant causal factor on the pairs of clean energy–carbon and carbon–green bond over all entire distributions and on the pair of energy–green bond at upper extreme quantiles. They conclude that clean energy and green bond markets are not immune from EPU shocks at the extremely high quantiles. Another paper of Wei et al. (2022) study the causal relationship between economic policy uncertainty (EPU) and Dow Jones green bond index from 2014 to 2021 by combining wavelets and quantile based approaches. The quantile coherency results reveal a weak and around the zero in the short term but a strong and positive correlation in both medium and long term. They also obtain a similar pattern for the quantile causality test results, which show that EPU has the ability to predict future movements in green bond in the long-term. Those significant causal flows from EPU to green bond gradually rise, as the time scale increases. Their wavelet-based quantile regression results reveal that the impact of EPU on the uncertainty index at the low and high quantiles vary dramatically during the pandemic, indicating that green bonds could serve as an effective tool when the market is bearish. More recently, Dogan et al. (2023) examine the predictability of crude oil market dynamics on four major indices—the Bloomberg commodity index, geopolitical index, green bond index, and the US economic policy uncertainty index—for a sample period spanning from August 2014 to February 2021. They find that the economic policy index Granger-cause all three markets at varying magnitudes. Green bond is relatively resilient to volatility in EPU and geopolitical risks at lower quantiles and has a strong safe haven property in bearish, normal, and bullish market conditions against EPU and geopolitical risks. Moreover, green bond acts a safe haven against shocks in oil market. By utilizing two nonlinear approaches, Tang et al. (2023) investigate the asymmetric effects of economic policy uncertainty, geopolitical risks, and oil prices on the green bond market from September 2012 to August 2022. Evidence shows an asymmetric and negative impact from US economic policy uncertainty and geopolitical acts on green bonds in both short and long-term, indicating that investors in green bond market react differently concurrently with an increase and decrease in economic policy uncertainty and geopolitical conflicts. A positive impact emerges between geopolitical threats (GPRT) and green bond returns while their findings reveal a unidirectional nonlinear causality from EPU and GPRA and no causal flows from GPRT. Zhang et al. (2023), utilizing a causality test in both static and time-varying framework on daily green bond and geopolitical risk for the sample covering March 2012 to February 2022, finds no causal effects from the geopolitical risk to return and volatility series of green bond, clean energy, and renewable energy. However, their findings show that the causality relationship from geopolitical risk to green bond market is not constant but time-varying as well as event dependent and that risk indicator poses a more persistent causal impact on the volatility of green bond than return.

3. Methodology and Data

We respectively discuss details of the selected methodology and describe the dataset in the following sections.

3.1. Methodology

We prefer using the frequency causality test introduced by Breitung and Candelon (2006), which its framework is based on the two noteworthy papers of Geweke (1982) and Hosoya (1991). This approach is based on the following two linear restrictions

$$\sum_{k=1}^{p} \delta_{12,k} \, cos(k\omega) = 0 \tag{1}$$

$$\sum_{k=1}^{p} \delta_{12,k} \, sin(k\omega) = 0 \tag{2}$$

If $\omega = 0$ and $\omega = \pi$, then $sin(k\omega) = 0$, which requires restriction defined in Equation 2 be dropped. To make simpler the notation, we let $\alpha_j = \delta_{11,j}$ and $\beta_j = \delta_{12,j}$, so that the VAR equation for X_t can be given by the following expression

$$X_t = a_1 X_{t-1} + \cdots + a_p X_{t-p} + \beta_1 Y_{t-1} + \cdots + \beta_p Y_{t-p} + \epsilon_{1t} \tag{3}$$

With given by

$$R(\omega) = \begin{bmatrix} cos\,(\omega) & cos\,(2\omega) & \cdots & cos\,(p\omega) \\ sin\,(\omega) & sin\,(2\omega) & \cdots & sin\,(p\omega) \end{bmatrix} \tag{4}$$

and $\beta = [\beta_1, \dots, \beta_p]^{'}$, then the hypothesis "y does not cause x at frequency", that is, $M_{y\rightarrow x}(\omega) = 0$ is equal to the following linear restriction

$$H_0 : R(\omega)\beta = 0 \tag{5}$$

The ordinary *F* statistic for the testing of the null hypothesis described in Equation (5) is approximately distributed as for $\omega \in (0, \pi)$.

In their pioneering paper, Toda and Yamamoto (1995) suggest using a VAR(p+1) model instead of VAR(p) model when Wald test of restrictions of the augmented VAR model involve nonstationary, $I(1)$, variables and has a standard asymptotic distribution. Further, Breitung and Candelon (2006) argue that this approach can be used to establish standard inference for the frequency domain causality test.

3.2. Data

Our dataset includes daily observations of SP500 Green Bond Index (SPGB), Geopolitical Risk Index (GPRD, Caldara and Iacoviello, 2022), and US Economic Policy Uncertainty Index (EPU, Baker et al., 2016) and are obtained from various web sites of https://www.spglobal.com, https://www.matteoiacoviello.com/gpr.htm, and https://policyuncertainty.com/, respectively. It spans from April 20, 2021 to December 30, 2022 for a total of T=430 observations for variable and is divided into two subperiods (i) before the war and (i) during the war. Figure 1 depicts trajectory of levels (left column) and returns (right column) of the underlying series and indicates that they encounter a substantial fluctuation over time, coinciding with the outbreak of the war in Ukraine in February 24, 2021. Both SPBG and GPRD series exhibit a considerable pattern during the sample period. For example, SPBG index is characterized by a steady downward trend over the sample period while we see an upward trend in GPRD until the start of the war and then it declines considerably with the occurrence of the war. All return series show solid evidence of volatility clustering during (SPGB) and before (GPRD and EPU) the war.

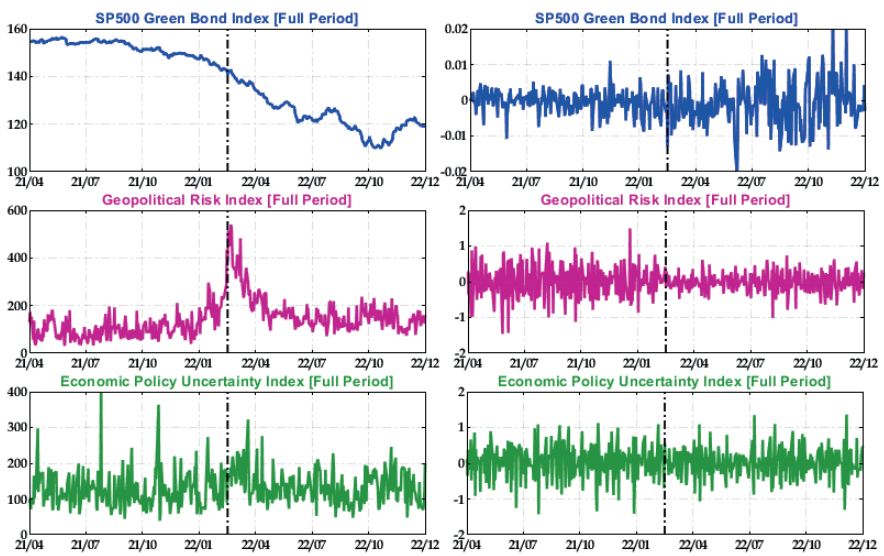

Figure 1: Time variations in prices (left column) and returns (right column)

We provide summary statistics of each variable for logarithmic changes, calculated as first difference of two consecutive index prices, for three periods in Table 1. It appears that all returns series are approximately zero; albeit a negative mean emerges for SPBG in all periods and a positive mean appear for GPRD (in full and before the war period) and EPU (in all periods). As indicated by standard deviations, EPU is most volatile than other two variables in three periods, followed by GPRD and SPBG. The skewness value of SPBG and EPU switches sign from period to period, while GPRD have an insignificantly left-skewed distribution in three periods. Further, all series show the characteristics of leptokurtosis and a heavy-tail than normal. The JB test statistics of SPBG (in three periods) and GPRD (only in full period) are significant at the different conventional levels of significance, rejecting the null hypothesis of data normality. However, GPRD and EPU changes have a significant nonnormal distribution before and during the war period. Both risk indices exhibit a negative correlation with the green bond markets in all periods, indicating that they serve as both a hedge and a safe haven during normal and crisis periods.

Table 1: Descriptive Statistics for Returns

	Mean	SD	Min	Max	Skewness	Kurtosis	JB (1980)	Correlation
Panel A: Full Period (2021/04/20 to 2022/12/30)								
RSPGB	-0.00060	0.00510	-0.02070	0.02270	0.141	2.089***	79.411***	
RGPRD	0.00050	0.39880	-1.45580	1.49210	-0.084	0.837***	13.015***	-0.074
REPU	0.00190	0.45990	-1.42610	1.36000	-0.036	0.329	2.027	-0.082*
Panel B: Before the War (2021/04/20 to 2022/02/23)								
RSPGB	-0.00040	0.00300	-0.01080	0.01110	-0.397**	1.259***	19.756***	
RGPRD	0.00570	0.48900	-1.45580	1.49210	-0.067	0.026	0.168	-0.011
REPU	0.00000	0.49280	-1.42610	1.12740	-0.177	0.088	1.181	-0.091
Panel C: During the War (2022/02/23 to 2022/12/30)								
RSPGB	-0.00080	0.00650	-0.02070	0.02270	0.267	0.649*	6.296**	
RGPRD	-0.00410	0.28350	-1.01640	0.73780	-0.24	0.482	4.12	-0.161**
REPU	0.00110	0.42520	-1.30490	1.36000	0.196	0.592*	4.495	-0.079

Note: ***, **, and * denote rejection of the null hypothesis at a 1%, 5%, and 10% significance levels, respectively.

4. Empirical Results and Discussions

In this section, we calculate the causal flows from geopolitical risks and economic policy uncertainty indices on green bond dynamics over short- and long-term and during three different periods, utilizing both causality approaches of Toda and Yamamoto (1995) and Breitung and Candelon (2006). For robustness check, we re-estimate causal linkages in a time-varying framework using two different window lengths.

Prior to causality testing, we performed two conventional unit root tests on the level and changes of underlying series and present the results in Table 2. Results of two different unit root tests, Dickey and Fuller (1979) and Phillips and Perron (1988), show strong evidence of no rejection of the null hypothesis of unit root for SPGB prices for three cases. However, we can strongly reject the nonstationarity for GPRD and EPU prices for three cases at the 1% significance level. These results suggest that GPRD and EPU are integrated of order zero, $I(0)$, while SPGB is integrated into the first order, I(1) regardless of the sample periods. All variables become stationary in their first difference at the 1% significance level. Accordingly, the static and time-varying causality linkages are estimated from a lag augmented VAR model with the maximal order of integration (dmax) = 1 for each cases and three periods.

Table 2: Traditional unit root test results

	Level (intercept & trend)		**Return (none)**	
	ADF	**PP**	**ADF**	**PP**
Full Period: 2021/04/20 to 2022/12/30				
SPBG	-1.921	-1.939	-17.562***	-17.702***
GPRD	-16.66***	-17.358***	-12.361***	-73.756***
EPU	-4.115***	-12.598***	-15.949***	-64.669***
Before the War: 2021/04/20 to 2022/02/23				
SPBG	-1.77600	-1.564	-13.646***	-13.621***
GPRD	-12.299***	-12.25***	-11.012***	-76.482***
EPU	-5.102***	-10.884***	-13.995***	-38.58***
During the War: 2022/02/23 to 2022/12/30				
SPBG	-1.38900	-1.288	-12***	-12.141***
GPRD	-7.378***	-7.778***	-11.395***	-39.306***
EPU	-11.725***	-11.793***	-13.562***	-69.183***

Note: The SP500 green bond index, geopolitical risk index, and US economic uncertainty index are taken in natural logarithms. ***, **, and * denote rejection of the null hypothesis of nonstationarity in the ADF (Dickey and Fuller, 1979) and PP (Phillips and Perron, 1988) tests at a 1%, 5%, and 10% significance levels, respectively.

In order to assess the predictive power of GPRD and EPU indices on SPGB index, we implement the widely used causality test of Toda and Yamamoto (1995) and report the findings in Table 3. Evidence shows that we cannot reject the null hypothesis of no-causality from GPRD to SPBG during the full, post, and the war periods at any conventional levels since the estimated test statistics do not exceed the critical values of 3.709 (10%), 4.60 (5%), and 5.99 (1%). The results suggest that green bond dynamics is relatively resistant to geopolitical risk fluctuations, thereby providing hedging and safe haven propriety of green bond market against geopolitical risk in both normal and turbulent periods. However, there is significant evidence that EPU Granger-causes SPBG over the full sample period, indicating that the current movements in US economic policy uncertainty index could be useful in predicting future dynamics of green bond. After dividing the full sample into two subperiods, we see that there is no causal flow from innovations in policy uncertainty through the pre-war period. However, we find that policy uncertainty index has explanatory power for green bond prices during the Russian invasion of Ukraine. This result shows that green bond market lost its protection against economic policy uncertainty during the military conflict in Ukraine.

Table 3: Toda-Yamamoto Causality Test (1995) Results

	Full Period	**Before**	**During**
	2021/04/20 to 2022/12/30	**2021/04/20 to 2022/02/23**	**2022/02/23 to 2022/12/30**
GPR → SPGB	0.65 [4]	3.091 [3]	1.028 [3]
EPU → SPGB	10.382*** [2]	1.569 [1]	8.398*** [1]

Note:* *** *denotes rejection of the null hypothesis that "X does not Granger-cause Green Bond Index" at the 1% significance level. Values in bracket [] is the selected lag length determined by AIC. The maximal order of integration (dmax) is equal to 1 for each cases and periods. The results show the causality relationship for each VAR(k+dmax), where k is the optimal lag length.

Next, we turn our attention to Table 4, where we provide the frequency causality results over three periods and across two frequency bands, $\omega = 2.50$ and $\omega = 0.01$, denoting short and long-term causal linkages, respectively. In line with the findings in Table 3, there are no causal flows from geopolitical risks to green bond markets over short and long-term in three periods. That is, geopolitical risks exert neither a temporary nor a permanent causal impact on green bond market over different time periods. This result accords with that of Lee et al. (2021) and Tang et al. (2023), which reveal no linear causality between geopolitical risks and green bond market. We may interpret this evidence that geopolitical risk has lost its explanatory power for green bond market, which could be attributable to the nature of the selected underlying sample period and methodology, which is sensitive to the presence of structural breaks and instability of parameters in VAR models. However, they (2021) provide evidence of causality relationship at lower quantiles and conclude that only the lower geopolitical risk changes drive the returns of green bond index. Again supporting the findings in Table 3, we observe significant short and long run causal flows from EPU to SPBG over full sample period. Such result could be interpreted as evidence that there are both transmissions of temporary and permanent shocks derived from economic policy uncertainty on green bond dynamics. Our results confirm previous studies (Wang et al., 2022; Tang et al., 2023;), which find unidirectional causality from (US) EPU to green bond returns and argue that green bond market does not serve as a safe haven against policy uncertainty given that the policy news quickly influences the investors' reactions in green bond market. Additionally, Wei et al. (2022) provide evidence of no causal flows in the short but in the long-term and this partly reinforces our findings. We further find that EPU has indeed a unidirectional causality relationship with green bond returns in the short-term before the war, indicating that green bond market is vulnerable to economic policy uncertainty in the short-term, but resilient in the long-run. During the invasion of Ukraine, there is a long-run causality, implying that changes in policy uncertainty drive returns of green bonds and transmission of shocks is permanent, rather than temporary.

Table 4: Frequency Causality Test (Breitung and Candelon, 2006) Results

	Full Period 2021/04/20 to 2022/12/30		**Before the War 2021/04/20 to 2022/02/23**		**During the War 2022/02/23 to 2022/12/30**	
	ω = 2.50	**ω = 0.01**	**ω = 2.50**	**ω = 0.01**	**ω = 2.50**	**ω = 0.01**
GPR → SPGB	0.533	0.27	2.807	1.995	0.361	1.021
EPU → SPGB	9.362***	9.362***	4.856*	1.249	4.31	9.879***

Note: *** and * denotes rejection of the null hypothesis that "X does not Granger-cause Green Bond Index" at a 1% and 10% significance levels, respectively. The maximal order of integration (dmax) is equal to 1 for each cases and periods. See Table 3 for the selected lag length (k) for each VAR(k+dmax).

Until now, we have assessed causal linkages regarding the parameter stability assumption in all VAR models. However, as argued by Li et al. (2015), the causation impact, if any, may be unstable and unreliable in the existence of structural breaks. In order to overcome the parameter instability in VAR models and uncover causal linkages, if exist and hidden in subsamples, we rely on the time-varying framework for causality testing in different time periods. Following Phillips et al. (2015), two optimal window lengths (50 and 60) are determined, which are greater than optimal length based on the rule $r_0 = 0.01 + 1.8 / \sqrt{T}$, where T is equal to 430.

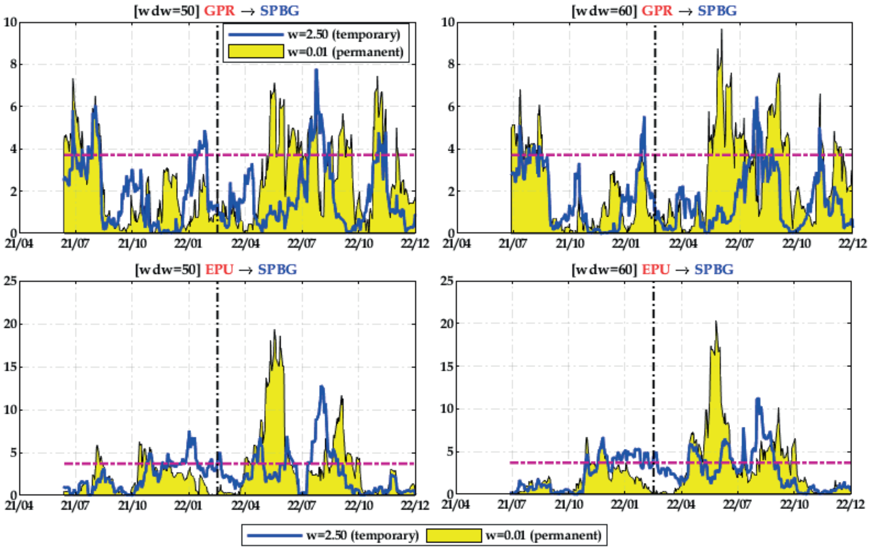

Figure 2: Time-Varying Frequency Causality from GPR and EPU to SPGB

Note: Yellow-shaded area (blue solid line) denotes rejection of the null hypothesis that "X does not Granger-cause Green Bond Index" when the test statistic exceed the critical value of 3.709, represented by a dashed violet red line, at the 10% significance level. The optimal lag length for two windows is determined by AIC. The start date of invasion of Ukraine is depicted by a vertical black dashed line (February 24, 2022).

Figure 2 illustrates the rolling causality results over the full sample period in the short and long-term. A quick inspection for the findings in the left column, in which the length of window is 50 days, suggests heterogeneous causal impacts on the green bond markets, which strengthens over time and across two different time horizon. The findings detect temporary causal flows rather than permanent ones before the war period. Actually, the test detects both short and long-run causal episodes for GPRD during the start of sample period, that is, between June and August 2021. In early 2022, we observe a temporary causality from GPRD and EPU, reducing the safe-haven property of green bond market against both geopolitical and economic policy uncertainties. There is hardly any causal linkage in either short or long-run during the first days of invasion, which started in February 24, 2022, and this indicate a presence of relatively strong resilient to shocks derived from both risk indicators. A permanent causality impact from geopolitical emerges in May and remains until early August 2022, with several breaks. We observe a similar long-run causal pattern and a short-lived temporary causality from EPU during the same period. Between July and September, the role of transmission of shocks changes in favor of short-run causality for both risk indicators. We find that geopolitical risks causing green bonds is significant in the short and long-term around October and November in 2022, indicating that the variations in GPRD cause changes in bond market. However, there is no evidence that EPU Granger-causes SPGB either in the short or long-term, implying the strong resistant to economic policy uncertainty of green bond market. Looking at the right column, we see that our temporary and permanent causal results remain almost the same and are robust to a wider window of 60 days for both variables.

5. Conclusions and Policy Implications

In this paper, we investigate causal impacts of two risk indicators, geopolitical risk and economic uncertainty indices, on the green bond market around the military conflict in Ukraine. To do so, we implement two causality tests in the static and time-varying framework for three subperiods. Result of Toda and Yamamoto (1995) and Breitung and Candelon (2006) in the static framework show no causation impact from the geopolitical risks in the full period, either before the war or during the war, supporting the previous studies such as Lee et al. (2021) and Tang et al. (2023). Further, no evidence for both short and long-run causality from the geopolitical risks on green bond is found. However, we see that changes in economic policy uncertainty Granger-causes fluctuations in green bond in both full and during the invasion of Ukraine, reinforcing the findings of Wang et al. (2022) and Wei et al. (2022). The results also reveal that the causality is temporary and permanent over the full period; temporary before the war; but turns out to be permanent and stronger during the war, indicating that uncertainty index can exert causal impacts on green bond indices regardless of market conditions and strengthens its power during the turmoil period. Considering the fact those parameters in VAR models may be unstable on the existence of structural breaks, we resort to a time-varying approach of Breitung and Candelon (2006) causality test based on a rolling window of 50 and 60 daily observations. We obtain intriguing results and find that the causal flow from both indicators appears significant and those causation impacts are not constant but time-varying. Results also show that economic policy uncertainty is stronger than geopolitics risks in forecasting the movements in green bond given a higher rejection of the null hypothesis for the former variable. The causality is mostly permanent rather than temporary and market turmoil during the military conflict strengthens the causation impacts from both variables.

The results provide vital implications for policymakers and investors. On the one hand, the issuance of green bonds and environmentally friendly investments should be encouraged by providing grand and tax incentives to corporate sectors in order to achieve and maintain sustainable development goals (Tang et al., 2023) given their vital contributions against rising uncertainties and conflicts. On the other hand, given that our results shed light on strong causation effects of economic policy and geopolitical uncertainty on green markets, investors should take into account those factors if they are interested in investing in green bonds and thus managing or mitigating portfolio risks. Green bond investors may benefit by closely monitoring past and current changes in economic policy uncertainty and geopolitical risks as it improves price forecastability of green bond markets and thus provides safe haven against rising uncertainties. Further, the time-varying and particularly long-term causation impacts require an active portfolio management strategy when extreme events and adverse market conditions take place. Future studies may focus on how causation impact changes over various conditional distributions of bond returns and thus implement quantile-on-quantile causality or quantile coherency tests.

References

Anh Tu, C., Sarker, T., & Rasoulinezhad, E. (2020). Factors influencing the green bond market expansion: evidence from a multi-dimensional analysis. Journal of Risk and Financial Management, 13(6), 126.

Azhgaliyeva, D., Kapsalyamova, Z., & Mishra, R. (2022). Oil price shocks and green bonds: An empirical evidence. Energy Economics, 112, 106108.

Baker, S. R., Bloom, N., & Davis, S. J. (2016). Measuring economic policy uncertainty. The quarterly journal of economics, 131(4), 1593–1636.

Breitung, J., & Candelon, B. (2006). Testing for short-and long-run causality: A frequency-domain approach. Journal of econometrics, 132(2), 363–378.

Broadstock, D. C., & Cheng, L. T. (2019). Time-varying relation between black and green bond price benchmarks: Macroeconomic determinants for the first decade. Finance Research Letters, 29, 17–22.

Caldara, D. & Iacoviello, M. (2022). Measuring Geopolitical Risk. American Economic Review, 112(4), 1194–1225.

Chopra, M., & Mehta, C. (2023). Going green: Do green bonds act as a hedge and safe haven for stock sector risk?. Finance Research Letters, 51, 103357.

Ciner, C. (2011). Eurocurrency interest rate linkages: A frequency domain analysis. International Review of Economics & Finance, 20(4), 498–505.

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*, 74(366a), 427–431.

Dogan, B., Trabelsi, N., Tiwari, A. K., & Ghosh, S. (2023). Dynamic dependence and causality between crude oil, green bonds, commodities, geopolitical risks, and policy uncertainty. The Quarterly Review of Economics and Finance.

Dong, X., Xiong, Y., Nie, S., & Yoon, S. M. (2022). Can bonds hedge stock market risks? Green bonds vs conventional bonds. Finance Research Letters, 103367.

Dutta, A., Jana, R. K., & Das, D. (2020). Do green investments react to oil price shocks? Implications for sustainable development. Journal of Cleaner Production, 266, 121956.

Geweke, J. (1982). Measurement of linear dependence and feedback between multiple time series. Journal of the American statistical association, 77(378), 304–313.

Hammoudeh, S., A. N. Ajmi, & K. Mokni. (2020). Relationship between green bonds and financial and environmental variables: A novel time-varying causality. Energy Economics, 92, 104941. doi:10.1016/j.eneco.2020.104941.

Haq, I. U., Chupradit, S., & Huo, C. (2021). Do green bonds act as a hedge or a safe haven against economic policy uncertainty? Evidence from the USA and China. International Journal of Financial Studies, 9(3), 40.

Hosoya, Y. (1991). The decomposition and measurement of the interdependency between second-order stationary processes. Probability theory and related fields, 88(4), 429–444.

Jarque, C. & Bera, A. (1980). Efficient tests for normality homoscedasticity and serial independence of regression residuals. Econometric Letters, 6, 255–259.

Kanamura, T. (2020). Are green bonds environmentally friendly and good performing assets?. Energy Economics, 88, 104767.

Lee, C. C., Lee, C. C., & Li, Y. Y. (2021). Oil price shocks, geopolitical risks, and green bond market dynamics. The North American Journal of Economics and Finance, 55, 101309.

Lee, C.-C., Tang, H., & Li, D. (2022). The roles of oil shocks and geopolitical uncertainties on China's green bond returns. Economic Analysis and Policy, 74, 494–505.

Li, X., Balcilar, M., Gupta, R., & Chang, T. (2015). The causal relationship between economic policy uncertainty and stock returns in China and India: evidence from a bootstrap rolling window approach. Emerging Markets Finance and Trade, 52(3), 674–689.

Lin, B., & Su, T. (2022). Uncertainties and green bond markets: Evidence from tail dependence. International Journal of Finance & Economics.

Long, S., Tian, H., & Li, Z. (2022). Dynamic spillovers between uncertainties and green bond markets in the US, Europe, and China: Evidence from the quantile VAR framework. International Review of Financial Analysis, 84, 102416.

Mokni, K., Mensi, W., Hammoudeh, S., & Ajmi, A. N. (2022). Green bonds and oil price shocks and uncertainty: A safe haven analysis. International Economics, 172, 238-254.

Nguyen, T.T.H., Naeem, M.A., Balli, F., Balli, H.O., & Vo, X.V. (2021). Time-frequency comovement among green bonds, stocks, commodities, clean energy, and conventional bonds. Finance Research Letters, 40, 101739.

Pham, L., & Nguyen, C. P. (2022). How do stock, oil, and economic policy uncertainty influence the green bond market?. Finance Research Letters, 45, 102128.

Phillips, P. C., & Perron, P. (1988). Testing for a unit root in time series regression. Biometrika, 75(2), 335–346.

Phillips, P.C., Shi, S., & Yu, J., (2015). Testing for multiple bubbles: historical episodes of exuberance and collapse in the S&P 500. Int. Econ. Rev. 56(4), 1043–1078.

Piñeiro-Chousa, J., López-Cabarcos, M. Á., Caby, J., & Šević, A. (2021). The influence of investor sentiment on the green bond market. Technological Forecasting and Social Change, 162, 120351.

Reboredo, J. C. (2018). Green bond and financial markets: Co-movement, diversification and price spillover effects. Energy Economics, 74, 38–50.

Rehman, M. U., Raheem, I. D., Zeitun, R., Vo, X. V., & Ahmad, N. (2023). Do oil shocks affect the green bond market?. Energy Economics, 117, 106429.

Tang, Y., Chen, X. H., Sarker, P. K., & Baroudi, S. (2023). Asymmetric effects of geopolitical risks and uncertainties on green bond markets. Technological Forecasting and Social Change, 189, 122348.

The Paris Green Bonds Statement, 2015. http://www.climatebonds.net/files/files/COP21-Paris%20Green%20Bonds%20Statement-PGPS-9th%20Dec%202015.pdf

Tian, H., Long, S., & Li, Z. (2022). Asymmetric effects of climate policy uncertainty, infectious diseases-related uncertainty, crude oil volatility, and geopolitical risks on green bond prices. Finance Research Letters, 48, 103008.

Toda, H. Y., & Yamamoto, T. (1995). Statistical inference in vector autoregressions with possibly integrated processes. *Journal of Econometrics*, 66(1-2), 225–250.

Wang, X., Li, J., & Ren, X. (2022) Asymmetric causality of economic policy uncertainty and oil volatility index on time-varying nexus of the clean energy, carbon and green bond. International Review of Financial Analysis, 83, 102306.

Wei, P., Qi, Y., Ren, X., & Duan, K. (2022). Does economic policy uncertainty affect green bond markets? Evidence from wavelet-based quantile analysis. Emerging Markets Finance and Trade, 58(15), 4375–4388.

Zhang, D., Chen, X. H., Lau, C. K. M., & Cai, Y. (2023). The causal relationship between green finance and geopolitical risk: Implications for environmental management. Journal of Environmental Management, 327, 116949.