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Do geopolitical events transmit opportunity or threat to green markets? Decomposed measures of geopolitical risks

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ABSTRACT

The growth of clean energies and technologies requires a sound financial market, while equity and bond markets are exposed to geopolitical risks. We investigate the response of green equity and green bonds to newly develop decomposed measures of geopolitical risks, including geopolitical acts, threats, and narrow and broad measures. To this end, we apply two robust methods; namely, the cross-quantilogram and quantile and quantile (QQ) approaches, to estimate the conditional and unconditional volatility spillovers considering short, medium, and long term. Surprisingly our empirical investigation demonstrates that all measures of geopolitical risk (except geopolitical acts) transmit positive shocks to the green investments (both equity and bonds) from bearish to bullish market states. At the bullish state, green markets respond negatively to the highest quantiles of all measures of geopolitical risks under a long memory. However, the geopolitical acts negatively shock the green bonds and green equity at some extreme quantiles. Our empirical findings are beneficial by transmitting opportunities and preventing risks for investment decision-making in the green markets, considering geopolitical risks.

1. Introduction

To accelerate the green movement towards sustainable development requires a sound financial market as proponents argue that financial constraints are the prime obstacle in implementing sustainability in the energy markets, which could be compounded by seeping geopolitical risks. Stock and credit markets development are the prime indicators of the overall financial development in the case of developed and developing countries. However, the equity and bond markets including green bonds markets are highly volatile and exposed to climate and geopolitical risks (Antonakakis et al., 2017; Apergis et al., 2018; Cheng and Chiu, 2018; Das et al., 2019; Gu et al., 2021; Lee and Chen, 2020; Lee and Lee, 2020). Given this backdrop, we aim to estimate the response of green equity and green bonds to various geopolitical risks in a global context. Geopolitical risk can influence green markets through two different channels.

First, the geopolitical risk can influence the green markets through the indirect channel, which is mainly the hydrocarbon prices. Many recent empirical studies observe an inverse relationship between changes in oil prices and changes in green equity and green bonds (e.g., Henriques and Sadorsky, 2008; Dutta et al., 2020; Lee et al., 2021; Yang et al., 2021). A large pool of studies documents that the crude price is significantly exposed to geopolitical risks (Demirer et al., 2018; Bouoiyour et al., 2019; Liu et al., 2019; Bouras et al., 2019; Das et al., 2019; Hedström et al., 2020). According to Plakandaras et al. (2019) and Reboredo et al. (2017), geopolitical risk also affects the crude oil market through the supply and demand channels. However, the literature also argues that the renewable or cleaner energies can substitute for dirty or carbon content energies; hence, rising oil prices should increase green investments through the substitution effect (Gong et al., 2020; Rasoulinezhad et al., 2020).

Second, higher geopolitical risks adversely lead to lower asset prices

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and returns. Many recent studies observe a negative effect of the geopolitical risks on asset prices including the green markets (Caldara and Iacoviello, 2018; Balcilar et al., 2018; Rigobon and Sack, 2005; Karolyi, 2006; Enamul Hoque et al., 2019; Smales, 2021). Frequent geopolitical shocks such as terrorist attacks, escalating military conflicts, or tensions of wars are associated with significant economic downturns due to their declining effects on trade and global economic welfare (Glick and Taylor, 2010). Eventually, mounting geopolitical turmoil can cause consumers to postpone consumption and firms to postpone investments, which feeds uncertainty to the overall economy (Bloom, 2009; Nikkinen and Vähämaa, 2010). Thus, such prolonged geopolitical shocks and sluggish economic growth could lead to a plunge in the equity returns.

Given these two different channels in the linkage between geopolitical risks and green market performance, we are thus motivated to investigate whether green markets respond negatively or positively to geopolitical risks.

Although, a few studies were conducted to investigate the geopolitical risks and green market performance nexus (e.g., Lee et al., 2021; Sweidan, 2021; Yang et al., 2021). We extend the existing studies in several ways. For instance, Yang et al. (2021) assessed the impact of geopolitical risks on green markets using the general GPR index. Yang et al. (2021) could have revealed the response of the renewable energy stocks returns of major Chinese companies to geopolitical risk, but the responses' directions had remained a puzzle. Besides, Lee et al. (2021) investigated the unidirectional and bi-directional causality between geopolitical risks and the green bonds without specifying whether green bonds positively or negatively respond to geopolitical risk. Besides, Sweidan (2021) investigated the response of renewable deployment to geopolitical risk. However, our concerns remained unsolved regarding the directions of the response, that is, do green equity and green bonds respond positively or negatively towards geopolitical risks? Moreover, the prior literature has overlooked the memory length in terms of a volatility spillover from geopolitical risk to green markets. We also assume that different measures of geopolitical risks may have different implications explaining the natural green markets.

Recently, Caldara and Iacoviello (2018) developed a broad measure of the global geopolitical uncertainty that detects both the direct and indirect risks of geopolitical events by counting the occurrence of words related to geopolitical tensions in leading international newspapers.[2] This news-based Geopolitical Risk (GPR) index not only concentrates on terror attacks but also considers other forms of geopolitical tensions such as war risks, military threats, terrorist acts, and political tensions. Accordingly, the novel index of GPR includes sub-indices which follow different estimation methodologies, considering the distinct categories of geopolitical events. Namely, the Geopolitical Threats Index focuses on the military or nuclear tensions, while the Geopolitical Acts Index focuses on the phrases related to the realization or the escalation of adverse events. We also use the broad and narrow versions of the indices/subindices. The narrow version uses smaller words and does not exclude non-relevant phrases from the benchmark geopolitical risk index, whereas the broad index considers a wide range of articles associated with rising geopolitical tensions. Given these differences, we presume that the impact of the geopolitical indices on the green markets may follow an asymmetric nature.

For this purpose, this study proposes a new insight into the literature by analyzing the green equity and green bonds markets' responses to various GPR indices. Moreover, Lee et al. (2021) focused on the relationship between geopolitical risks and the green bond index in the U.S. economy. We believe the market's response to geopolitical events varies across economies, depending upon its degrees. In several countries (e.g., India), prices of national assets demonstrate high stability to external factors, thereby underscoring that investors focus their attention on internal investment circumstances. In contrast, financial markets in other countries (e.g., Russia and China) are more responsive to geopolitical shocks. (Balcilar et al., 2018; Das et al., 2019). Hence, we examine the response of global green investment and green bond markets to the newly developed geopolitical risks indices focusing on the global context.

Thus, this study contributes to the literature in the following ways. Firstly, our study is the first attempt to scrutinise the responses of green stock and bond markets to the different components of the GPR indices, including acts, threats, and broad and narrow versions of the indices. Secondly, we also apply the Cross-Quantilogram (CQ) approach (Han et al., 2016) to estimate the conditions and unconditional volatility spillovers in the short, medium, and long memories. The features of CQ provide an opportunity to capture the dynamics of the relationship between two-time series, allowing for structural changes and accounting for the non-linear character of the relationship. Besides, CQ allows one to consider short, medium and long memories to measure the response of one time series to another under different quantiles. Third, our empirical investigation highlights that green investments respond positively to all measures of geopolitical risk (except geopolitical acts) from the bearish to the bullish market states. At the bullish state, the green markets react negatively to the highest quantiles of all measures of geopolitical risks under a long memory. Besides, the geopolitical acts transmit risk to the green bonds and the green equity at some extreme quantiles.

We validate our findings by using the Quantile-on-Quantile (Q-Q) approach through considering double conditional volatility spillovers from one series to another, thereby accounting for several local linearities instead of the global linearity restriction. However, unlike the CQ approach, the Q-Q is non-parametric method that overlooks the long-time lag properties in the estimation. Finally, using both approaches, our empirical findings provide new insights discerning that different measures of geopolitical events transmit both opportunities and risk to green equity and bonds under different market conditions.

The remainder of this study is structured as follows. Section 2 provides a literature review. Section 3 presents data and methodology. Section 4 highlights results and discussion. Finally, Section 5 concludes the study.

2. Literature review

The first strand of the literature is related to the impacts of geopolitical risk on traditional asset prices and returns. The prior literature consistently concluded that geopolitical risks crucially affect financial market performance (Balcilar et al., 2018; Blomberg et al., 2004; Fernandez, 2008; Zhou et al., 2020a, Zhou et al., 2020b) and decisions made by economic agents concerning investments, which subsequently affect the performance of the underlying financial assets (Apergis et al., 2018; Bouri et al., 2019; Caldara and Iacoviello, 2018). Geopolitical risks are considered one of the key determinants of financial decisions by economic agents at both the national and international levels (Dogan et al., 2021). According to the Wells Fargo/Gallup Survey, investors rank geopolitical risks as a key determinant of investment and portfolio allocation decisions. High levels of geopolitical tension adversely impact economic activities, stock returns, and cause capital outflows from developing to developed economies (Caldara and Iacoviello, 2018). On the one hand, political instability can exert a noteworthy effect on the equity markets through changes in the cross-correlation of assets, portfolio allocation, and diversification decisions (Elsayed and Helmi, 2021; Omar et al., 2017). On the other hand, civil unrest, armed conflicts, and violent episodes including terrorist attacks trigger high levels of risk and uncertainty, which in turn has a devastating impact and traceable mark on the stocks and financial markets (see e.g., Choudhry, 2010; Elsayed and Yarovaya, 2019; Guidolin and La Ferrara, 2010; Kollias et al., 2013).

Measuring geopolitical risk has been challenging until recently, and

[2] For more information, please see Caldara and Iacoviello (2018).

Table 1
Variables' construction, definitions and data sources.

Variables	Definitions	Sources
Green Equity (LGE)	We construct the green Equity Index by using the closing prices of equities of the following companies across the world including LONGi Green Energy Technology; Vestas Wind Systems; Hanwha Solutions; NHPC Limited; Ameresco; Renewable Energy Group; Jinko Solar; Solaria Energía; Green Plains; Gevo; Albioma; Suzlon; Aemetis; REX American Resources; ReneSola; and Sunworks. "We use the weighted average based on the market capitalisation of companies"	Orbis database Yahoo Finance
Green Bond (LGB)	We utilise the S&P Dow Jones Green Bond Index (LGB) as a measure of green bonds. This index composed of globally issued bonds that are labelled "green" by the Climate Bonds Initiative (CBI) and are used to finance environmentally friendly projects. The index starts on the 30th of March 2014 and ends on the 9th of November 2021 in our data	S&P Global
Geopolitical Risks (LGPR)	The geopolitical risk index is based on a tally of newspaper articles related to six categories of geopolitical events and tensions in 11 leading newspapers for each month. Caldara and Iacoviello (2018) distinguish between the direct detrimental impact of geopolitical events and the impact of purely geopolitical risks	Caldara and Iacoviello (2018)
Geopolitical Threats Index (GPR Threats)	They propose two indicators of potential risk, namely the Geopolitical Threats Index (GPT), which focuses on words related to military tensions or nuclear tensions (War Threats, Peace Threats, Military Buildup, Nuclear Threats, Terrorist Threats)	Caldara and Iacoviello (2018)
Geopolitical Acts Index (GPRACT)	Geopolitical Acts Index (GPA) focuses on phrases related to the realization or escalation of adverse events (beginning of a war, the escalation of a war, and Terrorist Acts)	Caldara and Iacoviello (2018)
Geopolitical Risks broad (GPRBROAD)	Geopolitical Risks broad Index uses the Boolean operator 'AND' for all search categories instead of searching two terms within two words from each other	Caldara and Iacoviello (2018)
Geopolitical Risks narrow (GPRNARROW)	The narrow version uses a smaller set of essential words and does not exclude phrases from the benchmark index that are not related to geopolitical events (e.g., movie, museum, book, "real estate")	Caldara and Iacoviello (2018)

earlier studies had flaws in the data used. Caldara and Iacoviello (2018) created the Geopolitical Risk Index (GPR) based on a calculation of newspaper articles reporting on geopolitical tensions. The geopolitical Risk Index has been widely applied in recent studies, confirming equity price declines in response to cumulative geopolitical risk (Antonakakis et al., 2013; Apergis and Apergis, 2016; Aslam and Kang, 2015, Arin et al., 2008; Hoque & Zaidi, 2020, Zhou et al., 2020a, Zhou et al., 2020b; Cai and Wu, 2021; Smales, 2021). Nevertheless, there is no consensus in the existing literature about the impact of geopolitical on standard equity markets. Balcilar et al. (2018) investigate the influence of geopolitical risk on the BRICS equity market and find that geopolitical risk does not affect the BRICS equity returns; however, it causes price volatility. Bouri et al. (2019) argue that the geopolitical risk index influences the equity market volatility and can predict the Islamic bond yields and volatility. In general, geopolitical risks can alter investors' expectations of market conditions and affect the incentives to invest.

The second strand of the literature stresses the impacts of the oil market on the green market performance. Frequent geopolitical shocks affect economic conditions and financial markets, which constitute a significant source of sharp fluctuations in crude oil prices (Liu et al., 2019). As an immediate reaction to geopolitical shocks, investors can expect an increased likelihood of supply disruptions or abrupt changes in supply and demand shortly. Numerous studies have examined the indirect impact of oil prices on equity prices or returns through the supply and demand channels (Plakandaras et al., 2019; Reboredo et al., 2017). From a theoretical perspective, incremental geopolitical risk in oil-producing countries will reduce oil supply; eventually, there will be an increase in oil prices (Antonakakis et al., 2017; Cunado et al., 2020; Demirer et al., 2019). Rising oil prices, in turn, should stimulate green investments, as they require a diversification of energy sources, especially for an oil-importing economy, since the renewable or cleaner energies can substitute for dirty or carbon content energies (Gong et al., 2020; Gozgor and Paramati, 2022). Rasoulinezhad et al. (2020) reiterate previous results, arguing that geopolitical risks positively affect the energy transition by boosting investment in green markets. In other words, when the significant effect of the incremental geopolitical risk is on the supply side of oil, then energy prices should increase.

Empirical studies on the interdependence between geopolitical risks and green markets are scarce. Moreover, the prior studies can be extended by several folds. For instance, a specific measure of geopolitical risks (e.g., threats, acts, narrow, and broad) should be incorporated in the empirical setup to avoid an aggregated bias. Besides, the geopolitical risks and green investments can follow a fat-tailed relationship in different memories. Moreover, the geopolitical risk is a global measure, thus, the green market indicator should be global rather than a single country's context. Our study fills these gaps by employing various global geopolitical categories (especially acts, threats, narrow and broad) for several reasons. First, the geopolitical actions can intensify geopolitical threats; for example, a terrorist attack can increase the risk of threatening future attacks. Second, analyzing the differential impacts of geopolitical threats and actions on green markets can provide new insight into whether green investments are more resilient or not to those exogenous shocks. Finally, this study aspires to provide a better predictive model to facilitate portfolio managers to hedge against geopolitical risk-induced market plunge.

3. Data and methodology

3.1. Data and sources

Table 1 explains the data, variables' definitions, and sources of data. We consider daily data (five days in a week) from 31 July 2014 to 11 September 2021.

3.2. Cross-quantilogram

To estimate a bivariate causal relation between two pairs of the respective variables, we apply the cross-quantilogram (CQ) approach developed by Han et al. (2016). The CQ was used due to its several distinctive features. First, the method is robust to estimating the bivariate volatility spillover between two markets in the presence of an abnormal distribution and extreme observations (Cho and Han, 2021). Secondly, the CQ method can calculate the magnitude of the shock from one market to another under different quantiles. Third, the CQ technique relaxes the assumption of moment conditions. Hence, the method is suitable for fat-tailed distributions. Finally, the method allows for taking long lags in order to assess the strength relationship between two variables in terms of durations and directions simultaneously.

Eq. (1) below represents the cross-quantilogram between two strict stationary time series $\{(y_t, x_t) : t \in \mathbb{Z}\}$ comprising $y_t = (y_{1t}, y_{2t})^\intercal \in \mathbb{R}^2$ and

Table 2
Descriptive statistics.

	LGE	LGB	GPR	GPR BROAD	GPR NARROW	GPR THREAT	GRP ACT
Mean	5.3500	4.9154	4.8614	4.6911	4.90857	4.9481	4.0888
Median	5.2432	4.9090	4.8164	4.6626	4.85728	4.8880	4.0800
Maximum	6.8643	5.0688	5.9417	5.6812	5.99623	6.0408	5.6074
Minimum	4.3427	4.8022	4.0335	4.1862	4.04509	4.0514	2.5214
Std. dev.	0.6095	0.0672	0.3440	0.2770	0.36242	0.3635	0.5113
Skewness	0.9060	0.5619	0.4216	0.6124	0.39477	0.4160	−0.1500
Kurtosis	3.1372	2.5010	2.7153	3.2654	2.61626	2.5798	3.3865
Jarque-Bera	254.6827	116.6134	61.0958	121.1349	59.4353	67.002	18.4704
Probability	0.0000	0.0000	0.0000	0.0000	0.000000	0.0000	0.0000
Observations	1851	1851	1851	1851	1851	1851	1851

Notes: LGE refers to the green Equity Index, LGB denotes the S&P Dow Jones Green Bond Index, GPR captures the geopolitical risk index. GPR BROAD refers the broad measure of the geopolitical risk index. GPR NARROW indicates the narrow form of the geopolitical risk index. Lastly, GPR THREAT and GRP ACT refer geopolitical risks indices threat and acts respectively.

$x_t = (x_{1t}, x_{2t}) \in \mathbb{R}^{d1} \times \mathbb{R}^{d2}$, where $x_{it} = [x_{it}^1 \dots x_{it}^{di}]^\intercal \in \mathbb{R}^{di}$with $d_i \in \mathbb{N}$. The conditional distribution between two series follows the function $F_{yi|xi}(.|x_{it})$ indicating the green investments given the geopolitical risks, corresponding to $q_{i,t}(\tau_i) = \inf\{v : F_{yi|xi}(v|x_{it}) \geq \tau_i\}$ for $\tau_i \in (0,1)$, *for* $i = 1, 2$. The framework considers $\mathscr{T}$ as a Cartesian product of two closed intervals in (0,1), that is, $\mathscr{T} \equiv \mathscr{T}_1 \times \mathscr{T}_2$, where $\mathscr{T}_i = \left[\underline{\tau} i, \overline{\tau}_i\right]$ *for some* $0 < \underline{\tau} i < \overline{\tau}_i < 1$. The CQ framework incorporates serial dependence between two shocks $\{y_{1t} \leq q_1, t(\tau_1)\}$ and $\{y_{2,t-k} \leq q_2, t-k(\tau_2)\}$ for a particular pair of $(\tau_1, \tau_2)^\intercal \in \mathscr{T}$ for lag order k. Cross-quantilogram can be estimated by following Eq. (1).

$$\rho_\tau(k) = \frac{E[\psi_{\tau_1}(y_{1t} \leq q_{1t}(\tau_1))\psi_{\tau_2}(y_{2t-k} \leq q_{2t-k}(\tau_2))]}{\sqrt{E\left[\psi_{\tau_1}^2(y_{1t} \leq q_{1t}(\tau_1))\right]}\sqrt{E\left[\psi_{\tau_2}^2(y_{2t-k} \leq q_{2t-k}(\tau_2))\right]}} \quad (1)$$

where $y_{i,t}$ represents stationary time series, i is equal to 1, 2, 3, 4 or 5 and represents the green equity index, green bond index and geopolitical risk indicators. Besides, t is time ($t = 1, 2, \dots, T$). The functions $F_i(\cdot)$ and $f_i(\cdot)$ capture the distribution and density functions of y_{it}, $i = 1,2$, respectively. Note that $q_{it}(\tau_i) = \inf\{v : F_i(v) \geq \tau_i\}$ is the corresponding quantile function for $\tau_i \in (0,1)$ and $\psi_a(u) = 1[u < 0] - a$ is the quantile-hit process.

When estimating how $\rho_\tau(k)$ varies with the lag length k, we are able to identify how the cross-quantile dependence between the variables varies across different time horizons, thereby quantifying the magnitude and duration of dependence. We consider the lag lengths $k = 1, 5, 22$ and 66 in our study which indicate daily, weekly, monthly, and quarterly lags, respectively.

Afterwards, we test the statistical significance of $\rho_\tau(k)$ by employing the Ljung-Box type test, where the test statistic is calculated according to Eq. (2) as follows:

$$Q_\tau^*(p) = T(T+2)\sum_{k=1}^{p}\widehat{\rho}_\tau^2(k) \Big/ (T-k) \quad (2)$$

where $\widehat{\rho}_\tau(k)$ represents the cross-quantilogram calculated as follows:

$$\widehat{\rho}_\tau(\mathrm{k}) = \frac{\sum_{t-k+1}^{T}\psi_{\tau_1}(y_{1t} - \widehat{q}_{1t}(\tau_1))\psi_{\tau_2}(y_{2t-k} - \widehat{q}_{2t-k}(\tau_2))}{\sqrt{\sum_{t-k+1}^{T}\psi_{\tau_1}^2\left(y_{1t} - \widehat{q}_{1t}(\tau_1)\right.}\sqrt{\sum_{t-k+1}^{T}\psi_{\tau_2}^2(y_{2t-k} - \widehat{q}_{2t-k}(\tau_2))}} \quad (3)$$

where $\widehat{\rho}_\tau(k)$ indicates the estimated partial cross-quantilogram.

By applying the stationary bootstrap, we approximate the null distribution of the cross-quantilogram in Eq. (2) and the Q-statistic in Eq. (3).

We subsequently calculate the partial-cross-quantilogram (PCQ) between variables to account for the uncertainties' effect. Let $z_t = [\psi_{\tau 3}(y_{3t} - q_{3t}(\tau_3)), \dots, \psi_{\tau l}(y_{lt} - q_{lt}(\tau_l))]$ be an $(l-2) \times 1$ vector for $l \geq 3$ of the control variables. The correlation matrix of the quantile hit process and its inverse matrix are defined as:

$$R_{\overline{\tau}} = E\left[h_t(\overline{\tau})h_t(\overline{\tau})^T\right]; P_{\overline{\tau}} = R_{\overline{\tau}}^{-1} \quad (4)$$

where $h_t(\overline{\tau}) = \psi_{\tau_1}(y_{1t} - q_{1t}(\tau_1)), \dots, \psi_{\tau_l}(y_{lt} - q_{lt}(\tau_l))$ be an $l \times 1$ vector of the quantile hit process. For $i, j \in [1, \dots, l]$, let $r_{\underline{\tau} ij}$ and $p_{\underline{\tau} ij}$ be the i[th] element of the $R_{\overline{\tau}}$ (correlation matrix of the quantile hit) and $P_{\overline{\tau}}$ (coefficnet under each quantile). matrices (*in* Equation (19)) Note that the cross-quantilogram is $r_{\overline{\tau}12}/\sqrt{r_{\overline{\tau}11}r_{\overline{\tau}22}}$. Then the partial cross-quantilogram is represented as follows:

$$\rho_{\overline{\tau}|z} = -\frac{p_{\overline{\tau}12}}{\sqrt{p_{\overline{\tau}11}p_{\overline{\tau}22}}} \quad (5)$$

$\rho_{\overline{\tau}|z}$ can be regarded as the cross-quantilogram between y_{1t} and y_{2t} conditional on the control variable z.

3.3. Quantile-on-quantile

In order to check the robustness of our findings from the TVP-VAR Dynamic Connectedness and the Cross-Quantilogram, we apply the quantiles-on-quantile (QQ) technique due to double quantile distributions. First, the QQ approach is developed by synthesizing the standard quantile regression and the local linear regression under non-parametric properties, which were introduced by Sim and Zhou (2015) to overcome the drawbacks of the standard quantile regression (Bouoiyour et al., 2019). Second, this method provides the slope coefficients of the quantiles of the regressor on different quantiles of the dependent variable (DV). It also reveals the estimated impact of each quantile of the regressor on the quantiles of DV, using the OLS, which allows for stratifying the regressor as a quantile distribution. Hence, the method solves the reverse causality, or the interdependency issue. In addition, the QQ technique suits our data since it has high fluctuations and high frequency. DE_t represents the green investments, while IE_i signifies the geopolitical risks. DE_t signifies the dependent variable, while IE_i indicates the independent variable.

Therefore, we introduce our empirical model as follows:

$$DE_t = \alpha^{\mho} DE_{t-1} + \beta^{\mho}(IE_t) + \varepsilon_t^{\mho} \quad (6)$$

The slope $\beta^{\mho}(.)$ which captures the response of green investments to geopolitical risk. Additionally, $\mu_t^{\mho}$ indicates the error term with a zero $\mho-$ quartile. Taking the first-order Taylor expansion of $\beta^{\mho}(.)$, around IE^τ, we transform Eq. (6) into the first order Taylor expansion follows:

$$\beta^{\mho}(DE_t) \approx \beta^{\mho}(DE^\tau) + \alpha^{\mho} DE_{t-1} + \beta^{\mho'}(DE^\tau)(DE_t - DE^\tau) \quad (7)$$

The double indexing of $\beta^{\mho}(DE^\tau)$ and $\beta^{\mho'}(DE^\tau)$ in $\mho$ and τ means that both $\beta^{\mho}(DE^\tau)$ and $\beta^{\mho'}(DE^\tau)$ are functions of both $\mho$ and τ. Eq. (7) can be represented as:

$$\beta^{\mho}(DE_t) \approx \beta_0(\mho, \tau) + \alpha^{\mho}\mathrm{DE}_{t-1} + \beta_1(\mho, \tau)(\mathrm{DE}_t - \mathrm{DE}^\tau) \quad (8)$$

Substituting Eq. (8) into the initial QQ equation will give us:

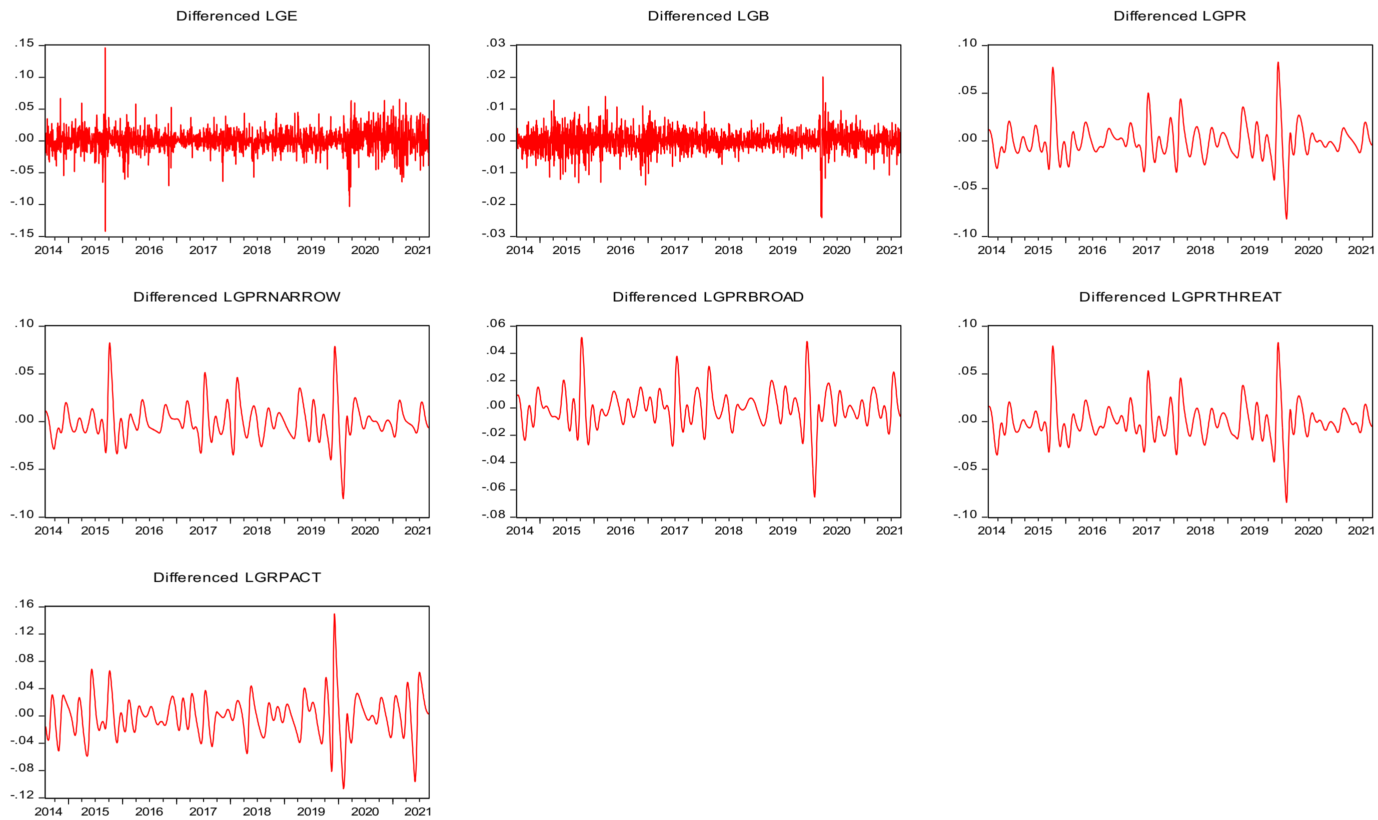

Fig. 1. Trend of Green Investment and Geopolitical Risk. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

$$DE_t = \beta_0(\mho, \tau) + \alpha^{\mho}\, \mathrm{DE}_{t-1} + \beta_1(\mho, \tau)(\mathrm{DE}_t - \mathrm{IE}^{\tau}) + \mu_t^{\mho} \quad (9)$$

We substitute the green investments as dependent and geopolitical risks as independent variables in order to confirm the interconnectedness between these two variables.

4. Results and discussion

4.1. Descriptive statistics

We start the analysis with the descriptive statistics to comprehend the nature of our data. Table 2 reports the descriptive statistics. The Jarque-Bera test strongly rejects the hypothesis of normality of our variables. Besides, Fig. 1 indicates that all series encounter a considerable fluctuation over time. Moreover, our all-return series follow an integrated order zero [I (0)]. Thus, Table 1 and Fig. 1 strongly endorse the application of the quantile-based method to capture the local linearity rather than the global linearity assumption.

4.2. Geopolitical risks to green equity transmission

Fig. 2 exhibits the volatility risk transmission from different measures of geopolitical risks to the green equity index under the Cross-Quantilogram. The vertical axis represents the GPR quantiles on each heat map, while the horizontal axis represents Green Equity. The method allows us to estimate the spillover effect considering the short, medium and long memories. We find an insignificant linkage volatility spillover between the two measures in the short and medium memories; hence, we exclude this finding from the main results. We use the Ljung-Box test to determine the statistical significance of predictive directionality. According to our estimates, the Cross-Quantilogram for the sample periods is more statistically significant in the long run.

Finally, we use a lag length of 64 since this relationship has a long memory. The results show that GPR, GPR Threats, and GPR Narrow positively affect Green Equity when GPR is in the (0.15–0.6) low and medium quantiles, and Green Equity is in the (0.25–0.4) low quantiles. However, the impact of GPR on GE turns negative at the middle quantiles (0.45–0.7) of the risk measures and at the higher quantiles (0.8–0.9) of GE. On the contrary, GE negatively responds to GPR Acts at most of the quantiles of both variables (0.10–0.95). GRP Broad transmits positive shocks to GE at the 0.15–0.7; and the 0.95 quantiles of GPR broad and at middle quantiles of GE (0.3–0.4; 0.6).

As can be seen, GPR transmits positive shocks on green equity markets when GPR is in 0.15–0.5 quantile and GE is in 0.25–0.4 quantile. An explicit negative linkage is evident when GPR is in middle (0.45–0.75) and GE is in upper (0.8–0.95) quantiles. The same pattern is observed for GPR Threats, GPR Narrow, with the exception of GPR Acts. Even though GPR Acts generally affect GE negatively, a positive effect is observable when both variables are in extreme quantiles. As for GPR Broad, positive signals for GE are observable in lower (0.15–0.35) and middle (0.5–0.7) quantiles of GPR Broad, as well as when GPR Broad is in 0.95 quantile and GE in middle (0.45–0.6) quantiles.

4.3. Geopolitical risks transmission to green bonds

Fig. 3-Panel A displays the response of green bond investment to the general measure of the GPR index. The green bonds respond positively to the general measure of GPR at the 0.10 to 0.40 quantiles of green bonds investment and the 0.10–0.85 quantiles of GRP. However, the green bonds react negatively towards GRP at the bullish state (0.80–0.90) of these bonds and the medium to the upper-medium quantiles (0.55–0.80) of GRP. Fig. 3-Panel B shows the response of the green bonds to the geopolitical act. In general, green bonds respond negatively towards an increasing geopolitical act at the 0.05–0.85 quantiles of the GRP act and at the 0.25–0.85 quantiles of a green bond

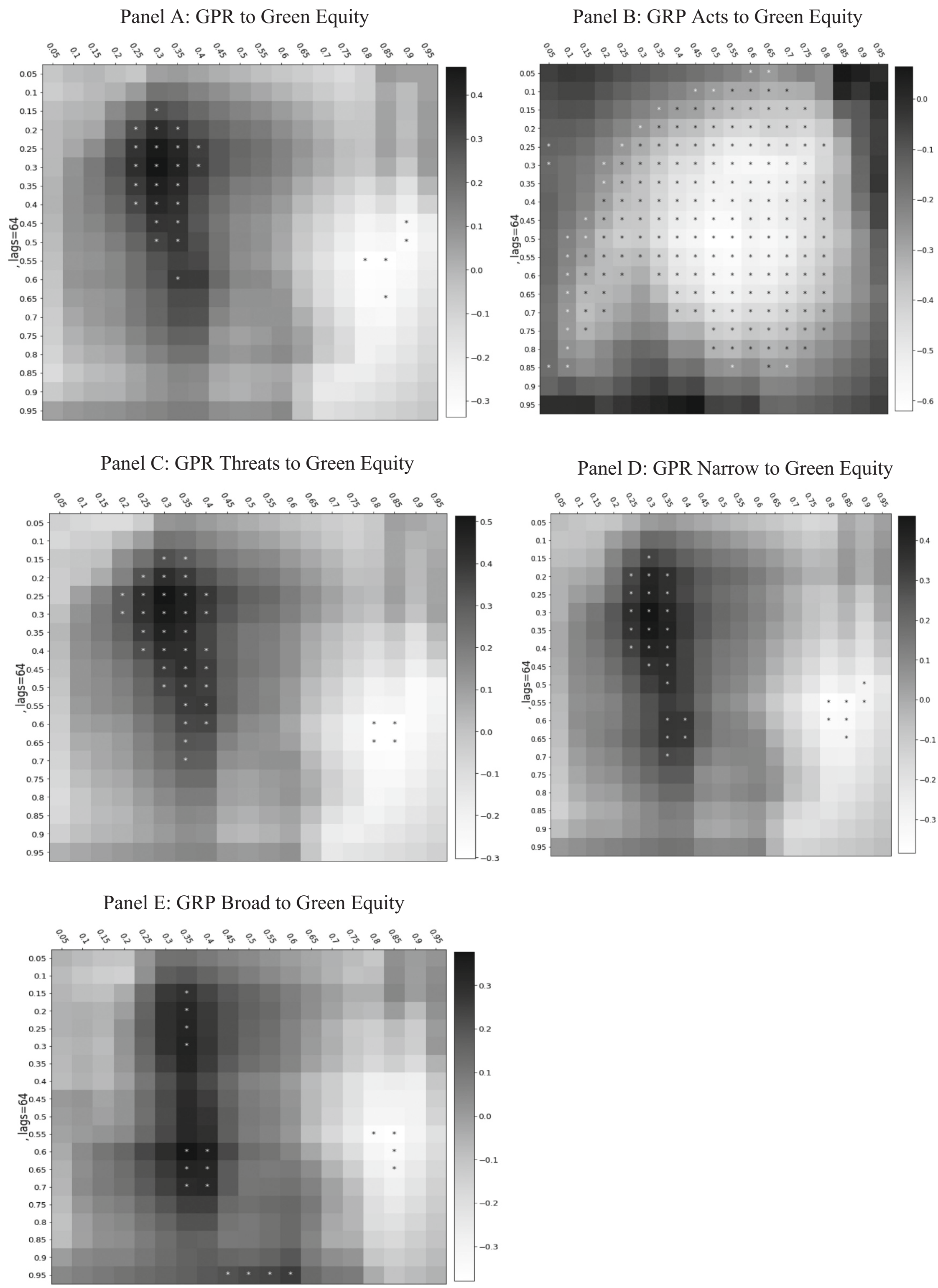

Fig. 2. Geopolitical Risk transmission to Green Equity in long memory. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Notes: 0.95 is the most bullish state for both geopolitical risk and green investment and vice versa for 0.1. White stars show positive spillover, while black stars show negative spillover.

investment. Fig. 3-Panel C highlights that the green bonds respond to the GPR broad measure asymmetrically. For instance, the green bonds are positively associated with the GPR broad at only the 0.3–0.4 quantiles of the GPR broad and the 05.-0.90 quantiles of the green bonds. However, the green bond investment is negatively associated with the GPR broad at the higher quantiles (0.80–0.95) of the GPR broad and the medium to the higher quantiles (0.40–0.80) of the green bond investment. Lastly, Fig. 3-Panels D and E show that the green bonds respond positively to

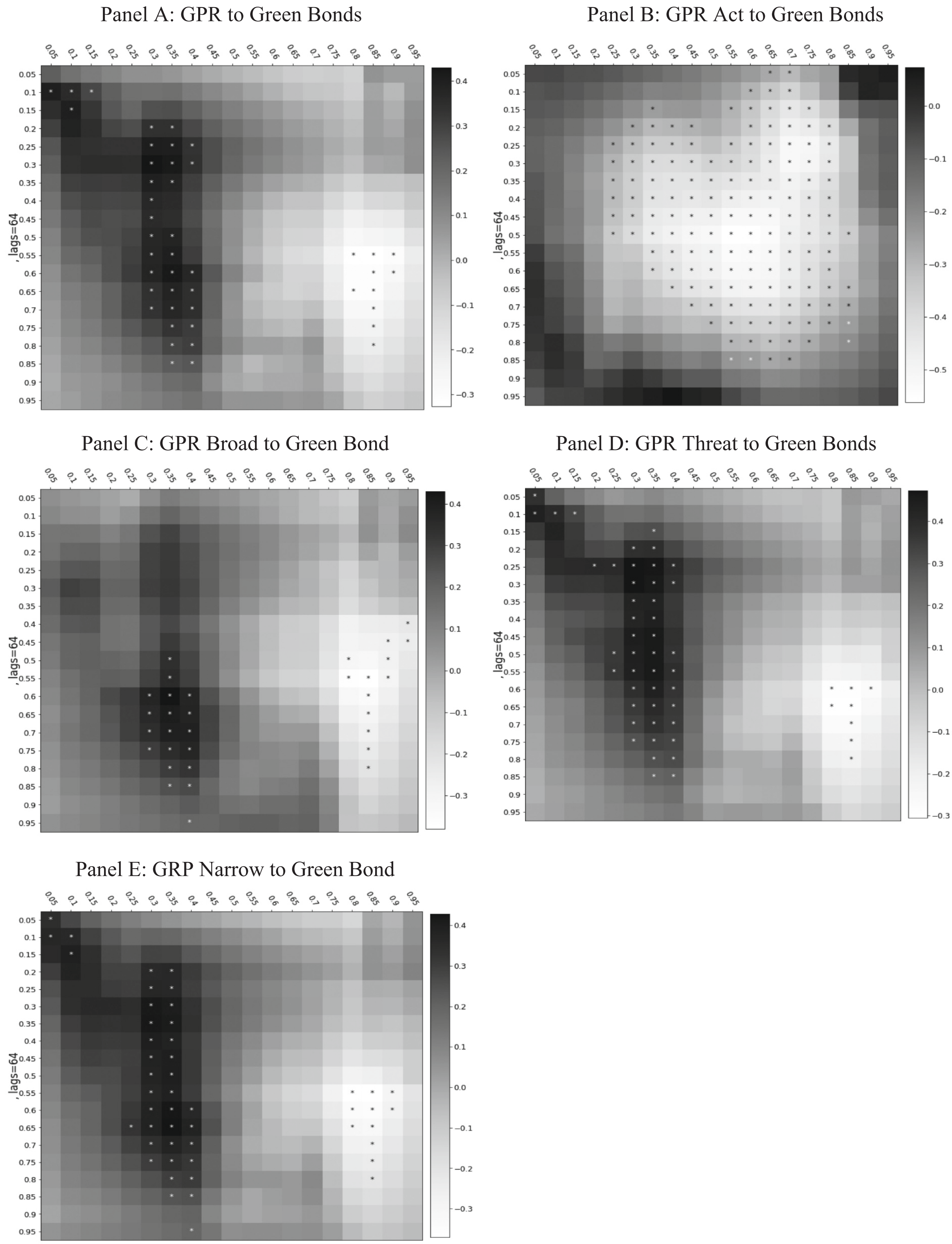

Fig. 3. Geopolitical risks transmission to Green Bonds in long memory. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the GPR threats and narrow measures at the lower-medium quantiles (0.05–0.40) of the green bonds and the lower to the upper quantiles of the GPR threats and narrow. However, the green bonds respond negatively towards the GPR threats and narrow measures at the higher quantiles (0.8–0.9) of the green bonds.

Our empirical findings can be explained by the substitution effect on the hydrocarbon price hikes induced by geopolitical risk. For instance, we observe a significant new investment in green energy in European countries during the Russian-Ukraine conflict. Besides, the green energy-related equities appear to be a promising asset since the

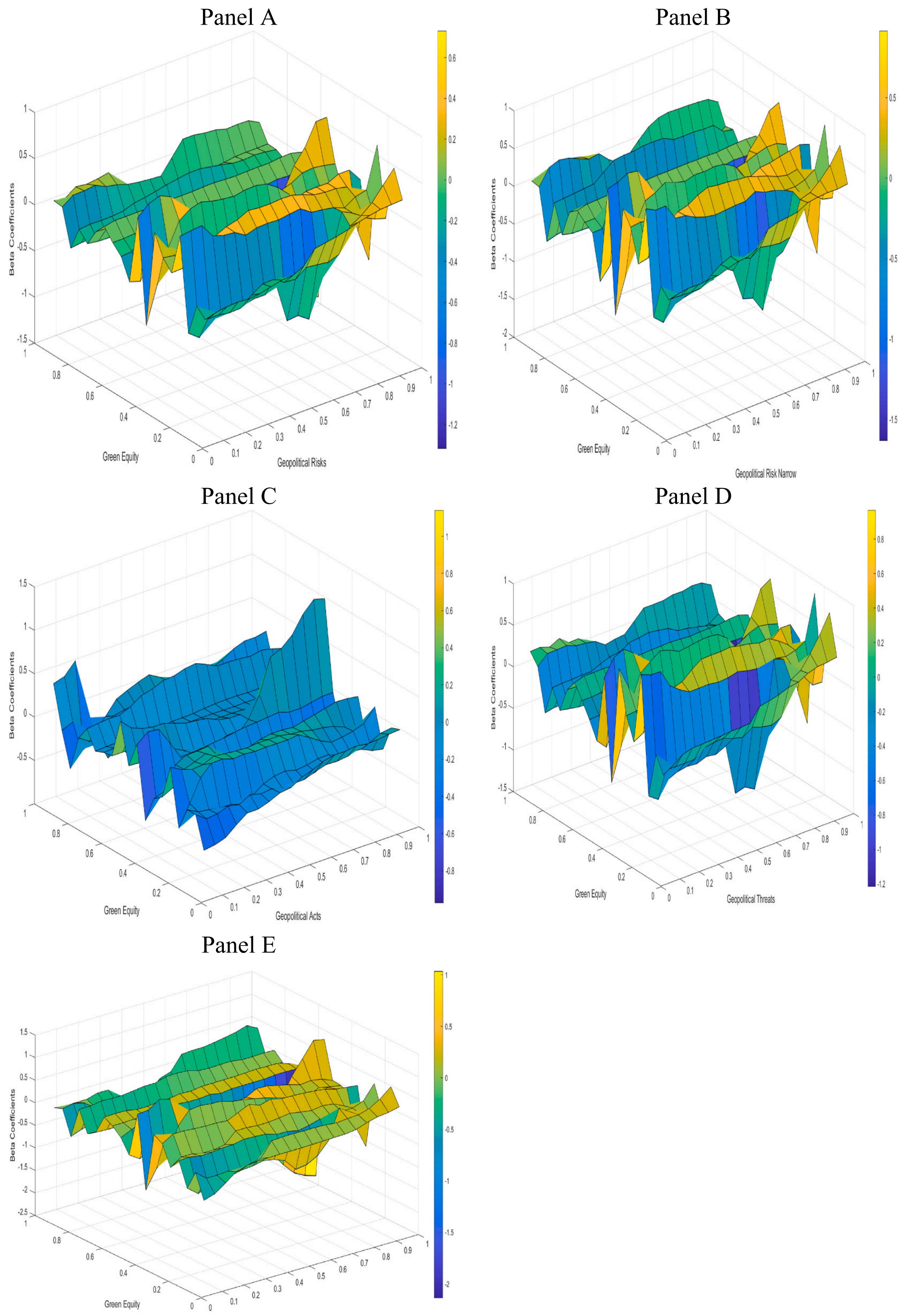

Fig. 4. From geopolitical risks to Green Equity transmission. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Notes: Fig. 4 reports estimated slope coefficients of the quantile-on-quantile regression for green equity and geopolitical risk measures.The slope coefficient is placed on the z axis against the quantiles of the green equity (θ) on the y axis and the quantiles of GPR(τ) on the x axis. The yellow and green colour implies positive and strong values of the coefficients while the light blue colour represents moderate positive values of slope coefficients. The dark blue colour represnts negligible negative values of the slope coefficients.

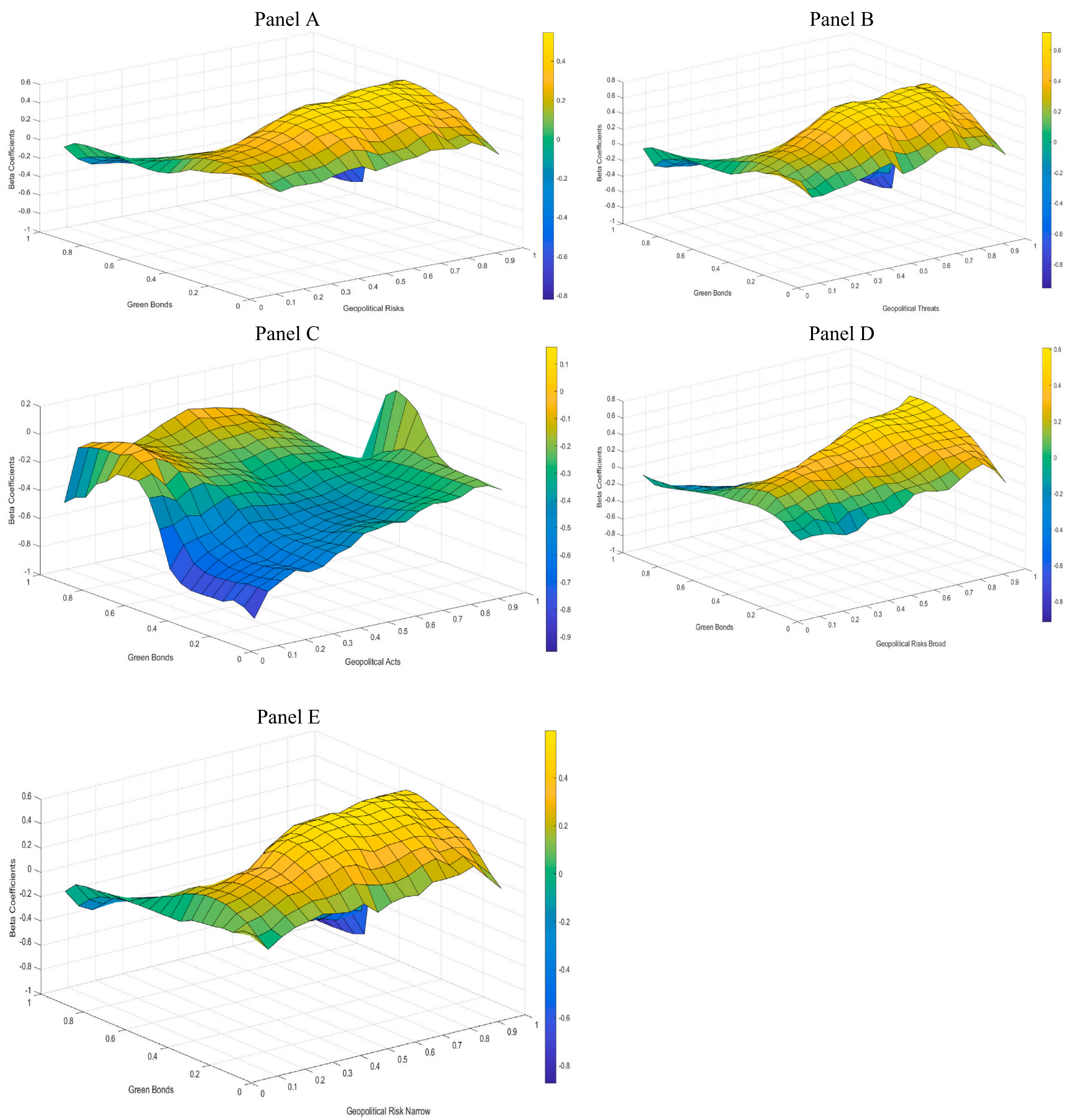

Fig. 5. From geopolitical risks to green bonds transmission. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Note: Fig. 5 reports estimated slope coefficients of the quantile-on-quantile regression for green bonds and geopolitical risk measures.The slope coefficient is placed on the z axis against the quantiles of the green bonds (θ) on the y axis and the quantiles of GPR(τ) on the x axis. The yellow and green colour indicate positive and strong values of the coefficients while the light blue colour represents moderate positive values of slope coefficients. The dark blue colour represnts negligible negative values of the slope coefficients.

fluctuations in energy prices impose constraints on the cost management decision of the firms. Our empirical results partially are in line with Lee et al. (2021) who observe a directional causal linkage between green bonds and geopolitical risk in the case of the U.S. economy. Thus, our study provides more insights in terms of the direction of spillovers from geopolitical risks to green bonds under different market conditions.

4.4. Robustness check under the quantile-on-quantile approach

Fig. 4 shows the response of the green equity investment to different measures of GPR under the Quantile-on-Quantile approach. Fig. 4-Panel A shows that the green equity investment responds positively to the general measure of GPR at the 0.30–0.95 quantiles of GPR and the

0.40–0.90 quantiles of the green equity. Panels B, D, and E of Fig. 4 show that the green equity responds positively to the GPR other measures including the narrow, threat and broad measures, roughly in the medium-to-upper quantiles of the GPR and green equity. However, the GPR Acts negatively affect the green equity in almost all quantiles, except the higher quantiles (0.85–0.95) of both variables. The findings from the Quantile-on-Quantile approach are consistent with our finding from the cross-quantilogram.

Fig. 5-Panels A, B, C, D and E show the response of the green bond to the different measures of GPR. The quantile-on-Quantile analysis confirms that the responses of green bonds to all measures of GPR are positive and identical expect to the GRP act, particularly from the lower-to-upper quantiles of GRP measures and the medium-to-higher quantiles of green bonds. Panel C of Fig. 5 highlights that the green bonds respond negatively to the GPR acts.

Our results show that the geopolitical risk, narrow, broad, and threats have almost identical effects on the green equity and the green bond markets. However, geopolitical acts have a significant adverse effect on the green markets. Our analysis shows the green bond investments are more responsive to the GRP measures than the green equity investments. One possible explanation for the results is that the equity and bonds have different risk natures. The equity markets are exposed to risks such as a country or geopolitical risk, currency risk, liquidity risk, or interest rate risk. On the other hand, the bonds are more exposed to risks such as inflation and interest rates. We observe that the green equity and green bonds respond to different geopolitical risk measures in different directions. Our empirical investigation shows that the general, threat, narrow and broad indices of the geopolitical risks transmit positive shocks to the green equity and green bonds under the lower and medium quantiles of the geopolitical risk and the lower and medium quantiles of the green equity and bonds.

Two different channels can explain the positive response of the green equity and bonds to the respective measures of geopolitical risks. First, several studies document that oil negatively responds to geopolitical risk (e.g., Henriques and Sadorsky, 2008; Dutta et al., 2020; Lee et al., 2021; Yang et al., 2021; Demirer et al., 2018; Bouoiyour et al., 2019; Liu et al., 2019; Bouras et al., 2019; Das et al., 2019; Hedström et al., 2020). Therefore, investors prefer the green equity and green bonds over the dirty energy market investments. Second, investors in the green markets are more environmentally concerned; hence, they are more responsive to the geopolitical events.

We find the geopolitical acts transmit adverse shocks to the green equity and green bonds. Geopolitical acts consider realization or escalation of adverse events, e.g., beginning of war, escalation of war, and terrorist acts, which adversely affect asset prices and returns. Hence, our finding corroborates the anecdotal fact and prior literature (Caldara and Iacoviello, 2018; Balcilar et al., 2018; Rigobon and Sack, 2005; Karolyi, 2006; Enamul Hoque et al., 2019; Smales, 2021).

Our findings also partially coincide with Lee et al. (2021) and Yang et al. (2021), who document that the green market significantly responds to geopolitical risks. We document that most of the measures of geopolitical risk transmit positive shocks to the green bonds and green equity through the channel of hydrocarbon prices. However, geopolitical acts negatively shock the green bonds and green equity at some extreme quantiles.

5. Conclusion and policy implications

Given the mounting interest in green investments to accelerate sustainable development and rising geopolitical risk around the globe, we investigate whether geopolitical risks transmit positive or negative shocks to green quality and bonds investments. To this end, we utilise recently developed various measures of geopolitical risks, including acts, threats, and narrow and broad indices to understand the transmission. Concerning the significant volatility in our respective series, we apply two novel approaches, the Cross-Quantilogram and the Quantile on Quantile, to measure the volatility spillover from the geopolitical risk indices to the green equity and green bonds markets under various market conditions.

Our empirical study demonstrates several important findings. First, we provide new insights underscoring that most of the measures of geopolitical risks transmit a positive spillover to the green equity and bonds investments. The Cross-Quantilogram also confirms that the connectivity between the geopolitical risks and the green markets follows a long memory, unlike the convention stock market. We argue that the geopolitical risks transmit a positive spillover to the green equity and bond markets through the substitution channel as investors might prefer green investments over dirty investments (fossil fuels) or other geopolitically exposed investments. During the geopolitical events, investors tend to diversify their portfolios using green investments to hedge against implied volatile investments. On the contrary, the geopolitical acts negatively affect the green equity and green bond markets. We argue that the geopolitical acts index transmits negative shocks to the green equity and green markets through the asset price and return channels as the beginning and escalation of the wars, and the terrorist acts adversely affect asset prices and returns.

The empirical findings also imply that the green equity and green bonds function as a safe haven during rising geopolitical turmoil periods. Geopolitical acts such as the beginning of a war, the escalation of a war, and terrorist acts transmit the risk to the green equity and green bonds, thus, investors and portfolio managers should consider these empirical findings in making portfolio and hedging decisions during those rising turmoil periods. The findings also show that all measures of geopolitical risk (except geopolitical acts) transmit positive spillovers to the green equity and green bonds at their bearish market conditions and during almost all geopolitical tensions. This means investors and portfolio managers should take advantage of low-priced green equity and bond investments under all levels of geopolitical risk. On the other hand, those investors should avoid investing in green equities and bonds when they are expensive and geopolitical tensions start to rise. These results can be helpful to investment decision makers. That is, the results suggest that the bullish state of the green equity and bonds responds negatively to the higher quantiles of all measures of geopolitical risks.

This study considers the time horizon analysis; hence, it remains a puzzle that which spike of geopolitical risk hits harder on the green equity and green bonds returns. Therefore, an event study can be conducted to identify the specific response to a certain geopolitical event.

Credit author statement

All authors have contributed equally.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2022.106068.

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