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Tail risk dependence, co-movement and predictability between green bond and green stocks

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ABSTRACT

This paper examines the coherence of extreme returns between green bonds and a unique set of green stocks. We use the novel quantile cross-spectral coherence methodology of quantile spectral coherency model, cross-quantile correlation approach, windowed time-lagged cross-correlation, and windowed scalogram difference models as estimation techniques. The study period spans from 28 November 2008 to 23 September 2020. Our measure of green stocks comprises the constituents of the MSCI Global Environment Price Index: Alternative Energy, Green Building, Pollution Prevention or Clean Technology while our green bond market is proxied by S&P Green Bond Index. We find the dependency between Green Bonds and green stocks to be weak, and this is high during market downturn periods in the short- to medium-term dynamics. This suggests that Green Bonds do act as a hedge, diversifier, or safe-haven instrument for environment portfolio in the short-term, medium-term and long-term dynamics during bearish market conditions. We conclude that green bonds and green stocks are two distinct asset classes with a distinct risk-return profile despite their common climate-friendly nature.

KEYWORDS

Green bond; environmental securities; cross-Quantile correlation; wavelets scalogram

JEL CLASSIFICATION



C22; G00; G12


I. Introduction

The 2007/2008 global financial crisis and the Covid-19 health crisis have disentangled market dependencies, thereby leading to seemingly unrelated financial markets. The market disentangling has further led market participants to further adopt portfolio diversification strategies to maximize profits on these asset prices. In 2007, another brand of portfolio diversifying bond, named ‘Green Bond’ was introduced as an entirely different asset from the traditional bonds. Since the time of its introduction to the global financial market, its market price has grown from \$0.8 billion to \$257.7 billion as of 2019 (Climate Bonds Initiative 2019). The asset came into being due to clamours for a low carbon economy in which the ‘green labelled’ bonds are financial variables that are necessary for friendly environmental projects that support the cost of alleviating the negative effect of climate change (Reboredo 2018; Chatziantoniou et al. 2022). In January 2014, the ‘Principles of Green Bond’ was declared by the

International Capital Markets Association (ICMA), and this led to more awareness of scholars, investors, and policymakers about the Green Bond. Larcker and Watts (2020) investigated ‘greenium’, that is, investors comparing green securities for societal green and non-green benefits by the same issuers on the same day and observed identical pricing for green and non-green issues, which is against the theoretical and experimental studies on Green Bonds. The authors further found that investors are often unwilling to forgo wealth in real markets to investing in environmentally friendly projects.

In recent years, emerging literature on the relationship between green bond market and other asset classes have gained considerable attention among scholars and the investment community using different methodologies (Tiwari et al. 2022; Kanamura 2020; Liu et al. 2020; Reboredo, Ugolini, and Aiube 2020; Le, Abakah, and Tiwari

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2021). Additionally, a strand of emerging studies highlights the diversification and safe haven benefits of green bond markets (Afri et al. 2021; Pham 2021). Green equity assets such as green stocks are shares of companies on beneficial impact on environments. These companies are made up of sectors such as alternative energy, clean transportation, water management, waste management and recycling. Both green bond and green stocks have witnessed massive surge since the 2015 Paris Climate Agreement due to massive capital flows entering into green investments as a result of investor's urge in seeking environmentally friendly investments (Ferrer, Benítez, and Bolós 2021). Green investments are security-specific risk and these are easier to diversify than systemic risks which form the list of economic policy uncertainty indices, industrial production index, inflationary and oil shocks etc. Green bond as a security-specific investment that renders environmentally friendly avenues and financial resources' opportunities to investors, and diversification opportunity for investors. Recently, stocks exchanges have included prominent green investments into their trading floors and these investments have been growing significantly since the introduction of the first green assets in 2007 (Reboredo and Ugolini 2020; Haq, Chupradit, and Huo 2021). Kanamura (2020) also notes that green bonds are likely to perform better than conventional bonds in the near future due to their rapid growth in their market capitalization and pricing. Investors and policy makers will be more interested in knowing the dynamic relationship between green bonds and other green investment since it does not often pay investors to include assets of similar pricing relationships in the same portfolio (Yaya, Vo, and Olayinka 2021). Furthermore, Haq, Chupradit, and Huo (2021) establish that green investments, if used in the same portfolio act as good diversifiers.

It is noteworthy to mention that even though several studies examine the relationship between green bond and conventional assets and emerging alternative assets from different standpoint leading to a comprehensive emerging literature, several

aspects of the green bond market remains unanswered. To this end, we contribute to the literature on sustainable finance by investigating the relationship between green bond and specialized eco-friendly equity markets from 28 November 2008 to 23 September 2020. We use S&P Green Bond Index as a proxy for the green bond market. For the green stocks, we use the component of the MSCI Global Environment Index: Alternative Energy, Pollution Prevention, and Green Building. Additionally, we use the Dow Jones Sustainable World Index which tracks the performance of leading firms in the field of corporate sustainability. We address these questions in this paper. (1) Does the behaviour between green bond and green stocks change under different markets states. (2) Is there any co-movement between green bonds and green stocks? Specifically, we differ our paper from prior studies and extend the limited literature on green bond markets by examining the tail risk dependence, co-movement and cross-quantile correlation between green bond and green stocks using the novel quantile cross-spectral coherence methodology of Baruník and Kley (2019), unique wavelet windowed cross-correlation and windowed scalogram difference and cross-quantilogram correlation model of Han et al. (2016) respectively. Analysis of this nature are essential in providing appropriate policies and strategies that will enhance and strengthen the diversification potential of green bond markets to investors.

Though Green Bonds have high liquidity compared to other financial assets, still, these asset prices are likely to continue to be useful in rating a low-carbon economy. The higher levels of liquidity in sustainable debt market have been attributed to several factors. First, the surge in sustainable debts market evidence by volume of issuance and product type is a tell-tale sign of a growing market and increased liquidity. By both measures, the sustainable finance market has steadily grown in recent years. For example, S&P Global Ratings projected a 40% year-over-year increase in sustainable debt issuance in 2021.¹ Second, another key sign of increasing market liquidity is the globalization of the market. Sustainable debt was issued in 32 different currencies in 2020.² While Europe and the U.S. are the dominant markets, it is

¹<https://www.spglobal.com/ratings/en/research/articles/210127-environmental-social-and-governance-sustainable-debt-markets-surge-as-social-and-transition-financing-take-11814121>.

²<https://www.spglobal.com/en/research-insights/featured/green-liquidity-moves-mainstream>.

noteworthy to mention that the largest sovereign social bond in 2020 was issued by Chile, and the largest corporate social bond was issued by a Japanese company. Thirdly, increased market liquidity is also often correlated with increased investor demand. More investors are beginning to incorporate ESG themes within their investment mandates. A survey of 728 fixed-income institutional investors carried showed that 77% of investors consider the ESG characteristics of issuers and investments as part of their investment process.³ Glomsrod and Wei (Glomsrød and Wei 2018) emphasized that Green Bonds reduced consumption of coal globally, thereby increasing the component of non-fossil electricity, which is a way of further reducing global CO₂ emissions.

During economic modelling, researchers attempt to quantify the dependence between economic variables. Although, correlated variables are often investigated, even if those are truly independent (Granger and Newbold 1974). Thus, there is the need to unleash the dependence that exists in different parts of the joint distribution of the paired series at different frequencies, whereas these dependencies are undetected when classical linear correlations are used (Fan and Patton 2014). Baruník and Kley (2019) proposed a quantile-based cross-spectral dependence measure. The approach is based on quantile coherence. The author proposed a class of cross-spectral densities for modelling dependence in quantiles of the joint distribution across frequencies, thus detecting common behaviour in similar behaviour of variables in a specified part of their joint distribution. This methodological approach is appealing in the sense that it is designed to detect any type of dependence structure in time series variables. This kind of complex dependency is possible in various economic and financial variables. For example, in financial markets, the price difference in a particular asset can cause irrational and extreme negative outcomes in the other assets. Thus, there are the possibilities that markets are strongly connected during calm periods. Historical financial series are often plagued with structural breaks, policy shifts, shocks, political

influence, wars, among others (Kyrtsov and Vorlow 2009). Putting everything together, we can say that all financial series under consideration are asymmetric and nonlinear and are heavy-tailed and with extreme values, and thus produce irregular noise in the model structure. Therefore, in such a context analysing results at different frequencies (noisy and relatively noise-free) is especially important for policymakers and investors. This has been accomplished by using an approach due to Baruník and Kley (2019). For examining the cross-quantile dependence between the series, Han et al. (2016) developed an approach referred as cross-quantilogram (CQs) in the literature. The methodological in this paper is novel and scarcely used jointly in modelling interdependencies among financial variables. Investigating interdependencies between Green Bonds and environmental securities could therefore interest researchers in economics and finance and policymakers in their trading strategies.

We document several findings. Regarding the quantile coherence between Green Bonds' alternative energy prices returns, we note that the magnitude of dependency is low in the short and long-term dynamics. On the other hand, we observed substantial risk spillovers in the short term between Green Bonds and the prevention pollution index compared to the long term. For Green Bonds and green building price returns, it is seen that during extreme market conditions, the level of coherency is marginal. For Green Bonds and sustainability price returns, we find that during the market downturn, the relationship is more negative. From the wavelet analysis, overall findings suggest that the co-movement between Green Bonds and environmental asset returns is high during market downturn periods especially in the short to medium-term dynamics. From the cross-quantilogram correlation, the cross quantilogram correlation plot and portmanteau tests confirm minimal directional predictability between Green Bonds and environmental securities in the short term during moderate market states.

³<https://www.spglobal.com/en/research-insights/featured/green-liquidity-moves-mainstream>.

The rest of the paper is structured as follows. Section II documents related works on green bond modelling, section III outlines the methodology while sections IV and V discuss the data and empirical results respectively. Finally, section VI renders concluding remarks.

II. Review of literature

Due to the recent inducement of the term ‘Green Bonds’, literature is still very few on the subject matter, particularly those that relate Green Bonds with environmental variables as well as their relationships to other economic and financial variables. Febi et al. (2018) investigated how the yield spread of Green Bonds is affected by liquidity risk and found a positive relationship between the yield spread and liquidity. The returns announcement and the real effect of issuing Green Bonds were investigated in Tang and Zhang (2019), where the authors noted positive responses of Green Bond issuance to stocks in a sample of stock firms across 28 countries. Kanamura (2020) examined Green Bonds with the energy index and found proof of a positive correlation between the two variables. Thus, ‘greenness’ is embedded in the Bloomberg Barclays Morgan Stanley Capital International (MSCI) and the Standard and Poors (S&P) Green Bond. Liu et al. (2020) examined dependency between Green Bond returns and several global and sectoral level energy series using constant and time-varying copula tests, with conditional value-at-risk in capturing the risk spillovers. Results showed evidence of positive time-varying dependence between Green Bonds and sectorial clean energy, with asymmetric risk spillovers. Reboledo, Ugolini, and Aiube (2020) investigated the interdependency between Green Bonds and other traditional assets and found evidence of strong coherency and volatility spillovers between Green Bonds and treasury and corporate bonds with Green Bonds found to be marginally connected with the high-yield corporate bonds. Ferrer, Benítez, and Bolós (2021) examined the interdependence between Green Bonds and green stocks by considering assets such as treasury, investment-grade, corporate bonds, general stocks, crude oil, and gold. Upon applying wavelet-based network analysis that allowed for the assessment of

interconnection in the variables, the results showed the linkage of Green Bonds to treasury and investment-grade corporate bonds, while green stocks are strongly connected to general stocks. Le, Abakah, and Tiwari (2021) using domain and time-frequency spillover estimation techniques investigated connectedness and spillover among Green Bonds, Fintech, and cryptocurrencies with results showing that Green Bonds is a net receiver of shocks from bitcoin and FinTech. Following from the above, the present paper is the first to apply quantile coherence model by Baruník and Kley (2019), cross-quantilogram correlation model, and windowed time-lagged cross-correlation methods in a unified framework to analyse tail dependence and causality in green bonds and green stocks. Also, with the fact that researchers are more inclined to analysing environmentally friendly asset prices, green bond and other green assets’ datasets are of interest recently.

III. Methodology

In this study, we use a number of estimations techniques to ensure robustness of our results including the novel quantile cross-spectral coherence methodology of Baruník and Kley (2019), unique wavelet windowed cross-correlation and windowed scalogram difference and cross-quantilogram correlation model of Han et al. (2016). Online Appendix 1 has detailed explanations of the models used.

IV. Data, summary statistics, and preliminary analysis

In this paper, we examine quantile connectedness and systemic risk transmission between Green Bonds price returns and environmental-related asset classes for the period of 28th November 2008 to 23rd September 2020. For our measure of the Green Bond market, we use S&P Green Bond Select Price Index. For the green stocks, we use the component of the MSCI Global Environment Price Index. Regarding the definition of the MSCI Global Environment Index, the index constitutes securities of firms with at least 50% of revenue derived from environmentally favourable services and products. Thus, the index comprises key

environmental themes: Green Building, Alternative Energy, Sustainable Water, Clean Technology, or Pollution Prevention. The MSCI Global Environment Index serves as the benchmark index for market participants seeking exposure to firms whose main source of income increases the efficient use of scarce natural resources or alleviates the effect of environmental dilapidation. For this paper, we use three measures of the MSCI Global Environment Index: Alternative Energy, Pollution Prevention, and Green Building. Additionally, we use the Dow Jones Sustainable World Index which tracks the performance of leading firms in the field of corporate sustainability. All variables used are obtained from Datastream, and daily log-returns of all these variables are used in the estimation.

Table 1A presents the summary statistics for the daily returns of variables examined in this paper. Regarding the mean of returns, we observe that the pollution prevention index has the highest mean value of 0.0172 followed by the green building index with a mean of returns value of 0.011. The alternative energy index recorded the least mean returns of 0.0003. The standard deviation estimates reveal a minimal amount of price fluctuations. Overall, we further confirm that the pollution prevention index has the largest standard deviation value. This is not surprising since the highest mean value was recorded by the pollution prevention index. On skewness, we observe that the skewness of most series is negative and statistically significant. For kurtosis, all the series examined in this study recorded kurtosis which exceeds threshold 3, which connotes that the returns series of variables examined have flatter tails. Table 1 further reports diagnostic tests of all series. We reject the null hypothesis of normality using the Shapiro Wilk test at a 1% level of significance. To check the integration order of each variable, we adopt the ADF test of Dicky and Fuller (1979), and the PP test to test for stationarity of examined variables. The ADF and PP statistics show that our series is stationary.

Figure 1 reports the time series plots of daily prices and returns for all variables under consideration. We observe from Figure 1 that the market price index for all the series is not stationary and has a trend in its movement. We note increasing

and decreasing trends throughout the whole sample period. We observed a sharp drop in prices of all series during volatile market conditions such as the recent COVID pandemic. For the daily log returns for all the indices, we note from Figure 1 sharp breaks in all the series throughout the period. Thus, there are sections of time where there is a high level of volatility and periods of time where volatility is moderately low which depicts an apparent volatility clustering in some periods. Table 2A displays the pairwise correlation among the variables under examination. We note a significant negative correlation between all components of MSCI Global Environment and Green Bonds. Analysis of correlation among variables under study shows that the environmental variables are correlated marginally among themselves and DJ Sustainability World Index returns. This lays a good foundation to investigate further the impact of the environmental asset class on Green Bonds.

V. Empirical estimation results

Quantile cross-spectral dependence analysis

Figure 2 presents the quantile cross-spectral dependence analysis of Green Bonds and each of the environmental variables under investigation. The right- and left-hand side plots represent real and imaginary parts of the coherency analysis across different quantiles, $-0.05-0.05$ and $0.95-0.95$ representing extreme negative to extreme positive returns, respectively. The frequency of the periods used include yearly, monthly, and weekly, and are denoted by Y, M, and W.

Focusing on the specifics, Panel A displays the real and imaginary coherence between Green Bonds and alternative energy price returns. Findings from the quantile spectral coherence plot displayed in Panel A show a moderately positive weak coherency between the Green Bond and alternative energy irrespective of the prevailing market condition ranges between -0.2 and 0.2 in the short-term dynamics (weekly cycles through to medium and longer time dynamics (yearly cycles). These results in other words reveal that there exists a significant low-level dependence in the short run and longer

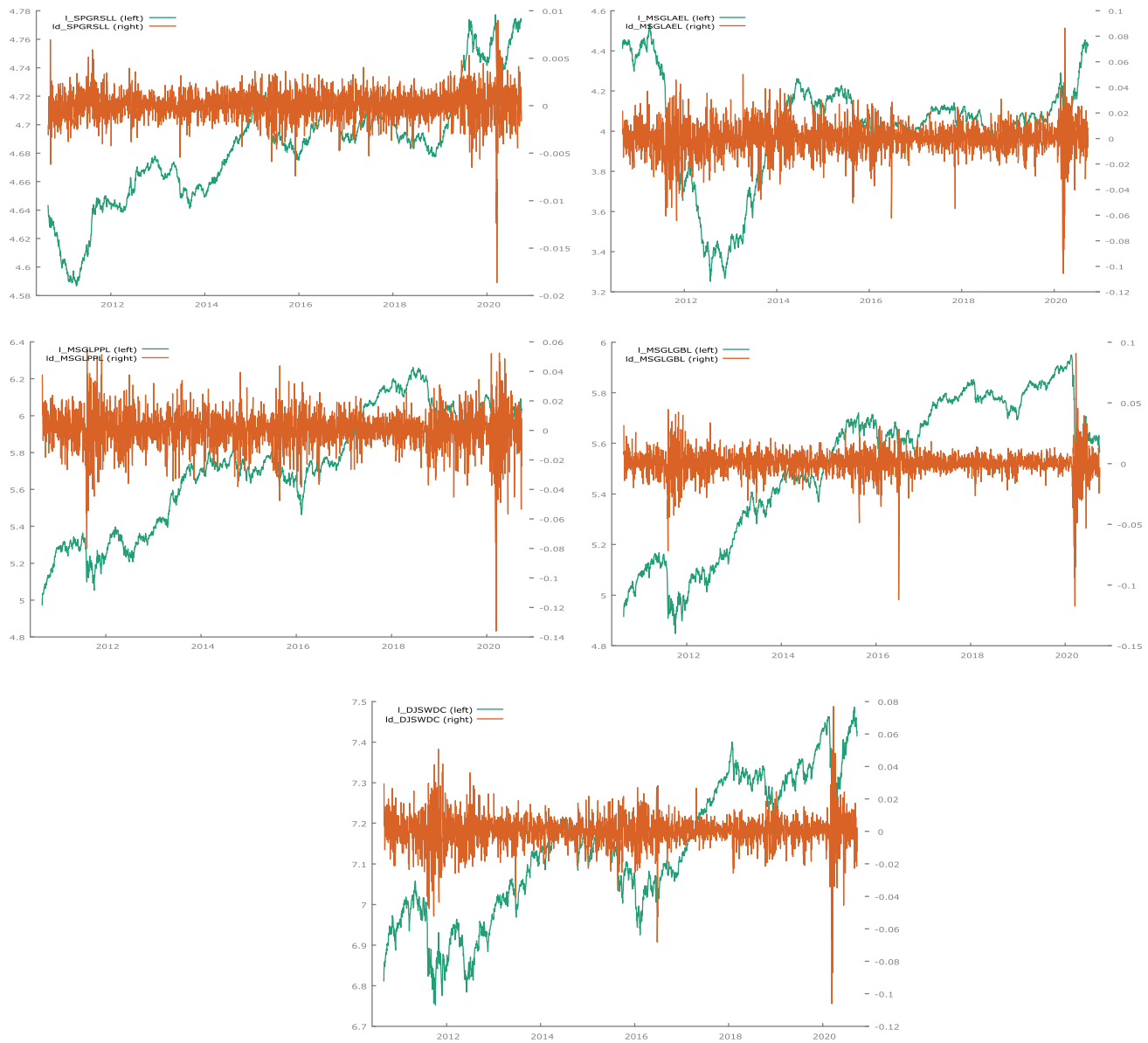


Figure 1. Time series and returns plots of price series.

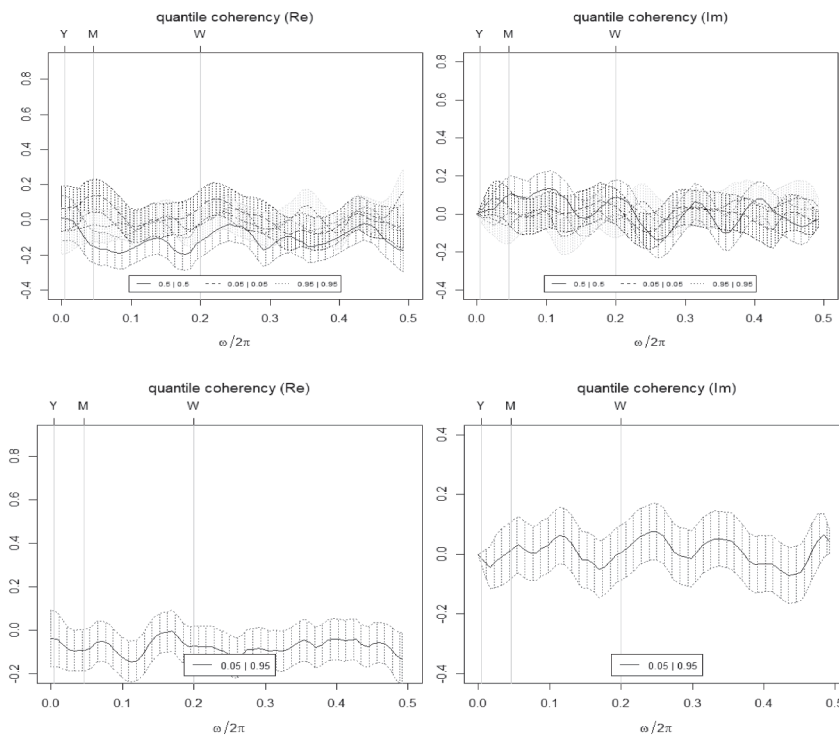
time dynamics. Thus, the Green Bond can serve as a good hedge against alternative energy due to the minimal transfer of risk between these two assets.

The quantile cross-spectral results between Green Bond and pollution prevention index returns reported in Panel B of Figure 2 reveal a significant negative correlation in the medium to long-term dynamics during bearish market conditions. The real and imaginary quantile coherency differ mainly in their long-run time domain—i.e., weak frequency. On average, the imaginary

coherence across these quantiles is approximately zero (0) in magnitude. In contrast, the real coherency estimates fluctuate between -0.4 and 0.2 in the short run and while it fluctuates between -0.2 and 0.1 in the medium to long term run. Thus, in the short run, we find a substantial spread of risk between Green Bond and prevention pollution index returns. Short-term investors may need to desist from holding these two assets in the short term.

In Panel C, we analyse the quantile coherency between Green Bond and green building price

PANEL A: S&P GREEN BOND SELECT vs. MSCI ALTERNATIVE ENERGY INDEX



PANEL B: S&P GREEN BOND SELECT vs. MSCI GLOBAL POLLUTION PREVENTION INDEX

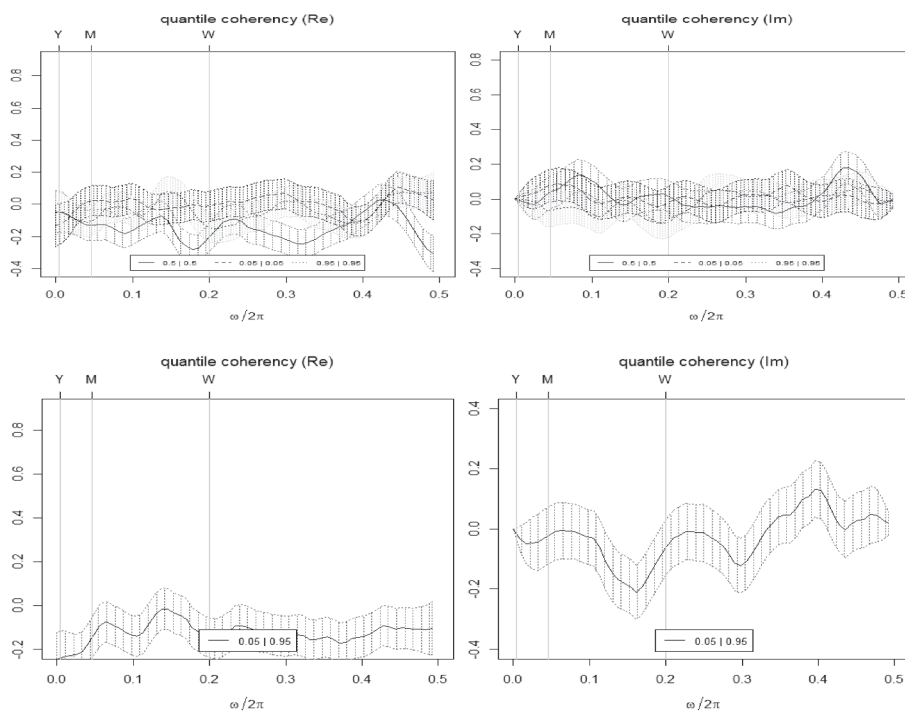
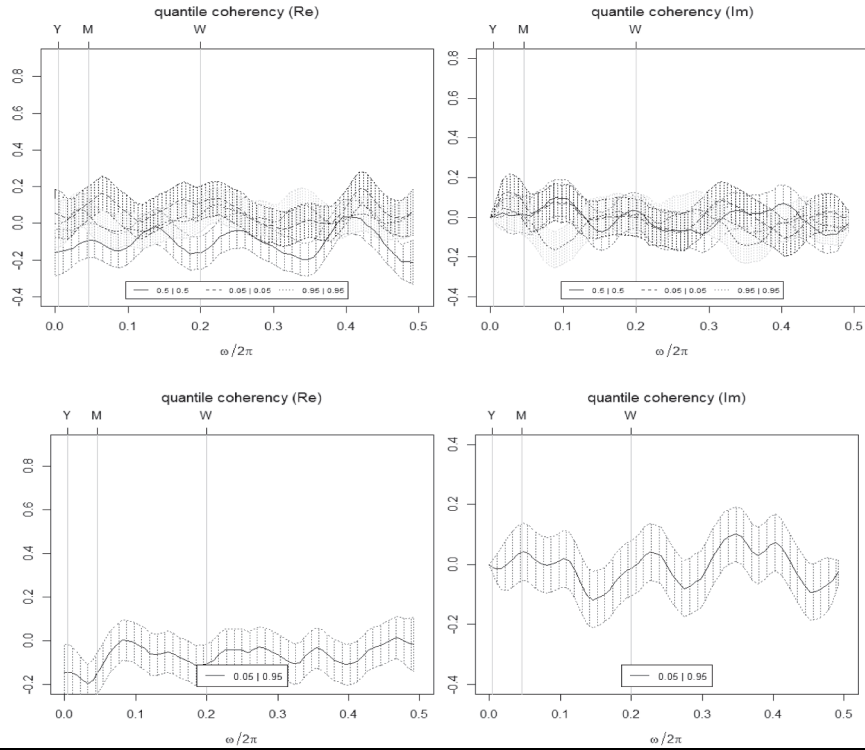


Figure 2. Quantile coherency analysis of green bonds vs environmental return.

PANEL C: S&P GREEN BOND SELECT vs. MSCI GLOBAL GREEN BUILDING INDEX



PANEL D: S&P GREEN BOND SELECT vs. DOW JONES SUSTAINABILITY INDEX WORLD PRICE INDEX

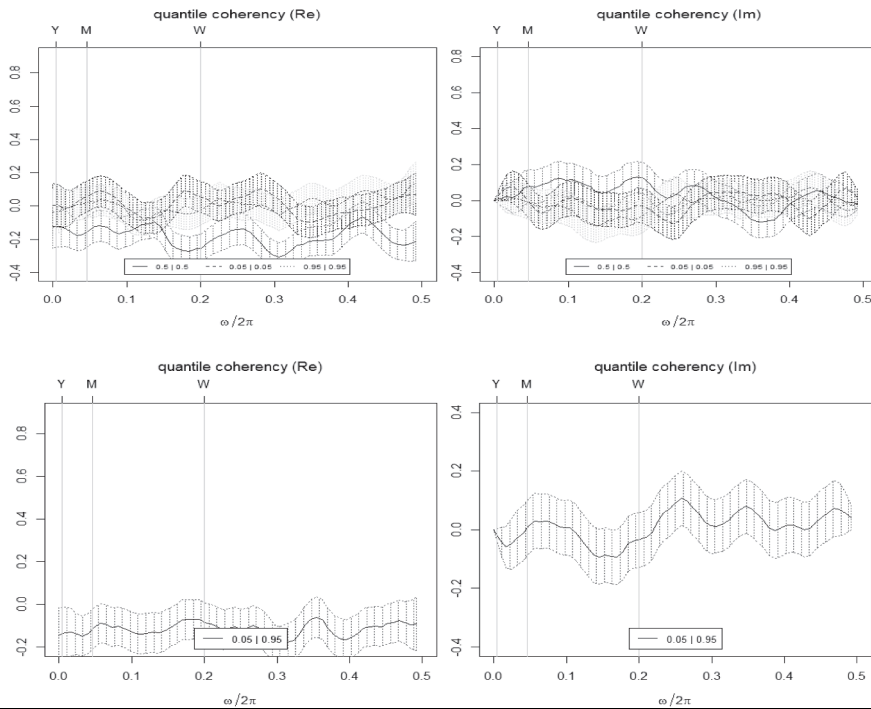


Figure 2. (Continued).

index returns. Under all market conditions, real coherency estimates ranged between -0.2 and 0.2 . However, in extreme quantiles, we observe a marginal level of dependency in the long run. This finding connotes that in bullish and bearish market conditions, holding a portfolio of assets consisting of Green Bonds and green building securities is not risky, in particular, for long-term investors. For the case of the quantile dependence between Green Bonds and sustainable index returns reported in Panel D, we observe that in the long term and during bearish markets states, the relationship is more negative compared to the short term. Thus, it is much riskier to keep a portfolio including these two assets in the short run.

Overall, for most of the paired series, the findings in [Figure 2](#) suggest a marginal weak coherency between the negative shocks of the Green Bond returns and positive shocks of the environmental assets under different market states. This result is in consonance with the work of Ferrer, Benítez, and Bolós (2021) who examined connectedness between green bonds and several asset classes including green stocks using wavelets analysis. They find no significant association between green bonds and green securities despite their common climate friendly nature. In a related study, Nguyen et al. (2021) also found a weak comovement between green bonds and alternative energy stocks under different markets conditions. From the findings recorded using the quantile cross-spectral approach, we conclude that green bonds and green stocks even are distinct assets class which confirms the safe-haven prospective of green bonds. Recently, Chatziantoniou et al. (2022) showed that green bond is a receiver of shocks from MSCI Global Environment Index returns using the novel quantile time-frequency model.

Wavelets scalogram difference (WSD) analysis

To distinguish between the similarities and differences between the Green Bonds and environmental securities, we use the wavelets scalogram difference analysis which is regarded as an instrumental approach in establishing differences and similarities among asset returns. The visualized contour plot of the WSDs has the time and Fourier period

represented in the horizontal and vertical axes, respectively. For interpretation purposes, the Fourier period denoted by the vertical axis is converted into time units (days) ranging from a high-frequency scale of 2 days (top of the plot) to a low-frequency scale of 128 days (bottom of the plot). The magnitude of similarities across assets under examination is determined by colour coding. A low level of similarity is denoted by blue while a high level of similarity is denoted by the colour red. The sections surrounded by a thick black line denote areas where the WSD is statistically significant at the 5% level. The black line and white line sections display areas of high similarity (5% level of significance) and low similarity (95% level of significance) estimated using Monte Carlo simulations. In detail, the level of significance is estimated with 1000 pairs of random times of the same length and variance as the original series. The cone of influence, beneath which edge effects may misrepresent the results of the WSD, is labelled by a thin black line.

The WSD plots reported in Panel A of [Figure 3](#) between Green Bonds and alternative energy index returns reveal that the extent of connectedness is strong at two periods: (1) 2016–2018 and (2) 2020 for across all frequency bands. However, the strength of the similarity is high at high-frequency scales from day 2 to day 32. It is noteworthy to mention that the periods in which we observed dependency for these two assets are periods that were marked by global events thus Brexit and European debt crisis in 2016 and the outbreak of the novel coronavirus in 2020. This suggests that during volatile market conditions, it will not be prudent to have these two assets in the same portfolio of stocks in the short term. Panel B of [Figure 3](#) illustrates the WSD plot between Green Bond and pollution prevention index returns. We observe strong similarity around short to medium time scales. In the long term, we observe low similarity. Around 2012 and 2020 we observed strong linkages between Green Bonds and pollution prevention index returns in the medium time scale. However, from 2016–2018, we document a significant relationship in the short and medium time scales. Shifting to Panel C, we note that for the case of Green Bond and green building index returns, the strength of similarity is marginal across all time

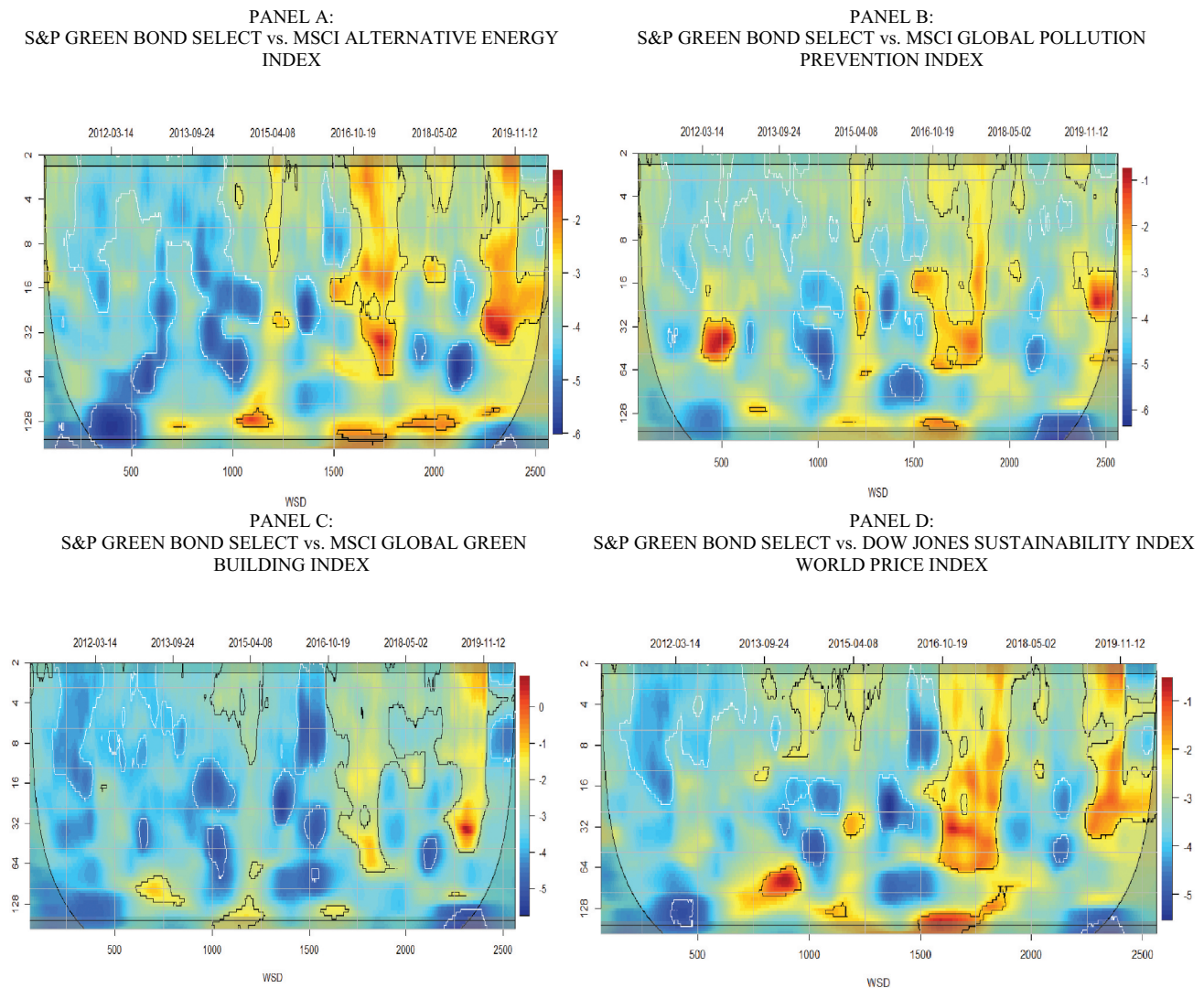


Figure 3. Windowed scalogram difference (WSD) plots between green bonds and other assets.

scales for the entire period. Though we observed some level of correlation in the short to medium term, the strength of the association is minimal. Green Bonds can be a safe haven for green building asset returns under all market conditions because even in 2020 where volatility was high, the relationship was marginal. Regarding the Green Bond and sustainability index, we find no significant dependency during normal market conditions. However, the similarity deepens tremendously during extreme market conditions in the short to medium to long term time scale. Thus, it will be prudent to avoid having these two assets together in a portfolio during bearish market conditions irrespective of the time scales.

Overall, from the WSD analysis, we established that the co-movement between Green

Bonds and environmental asset returns is high during market downturn periods especially in the short to medium-term dynamics. Our findings is in consonance with earlier studies such as Liu et al. (2021) who found dependency between green bond and clean energy stock markets. On the other hand, Ferrer, Benítez, and Bolós (2021) found a strong linkage between green financial instruments and other assets in the long term which differs from our findings. A key question that requires answering relates to the possible channels that may be driving our results. Thus, we link our results obtained from the WSDs to global events. We find low level of similarity between green bonds and green stocks evidenced by the deep blue colour during the European sovereign debt crisis

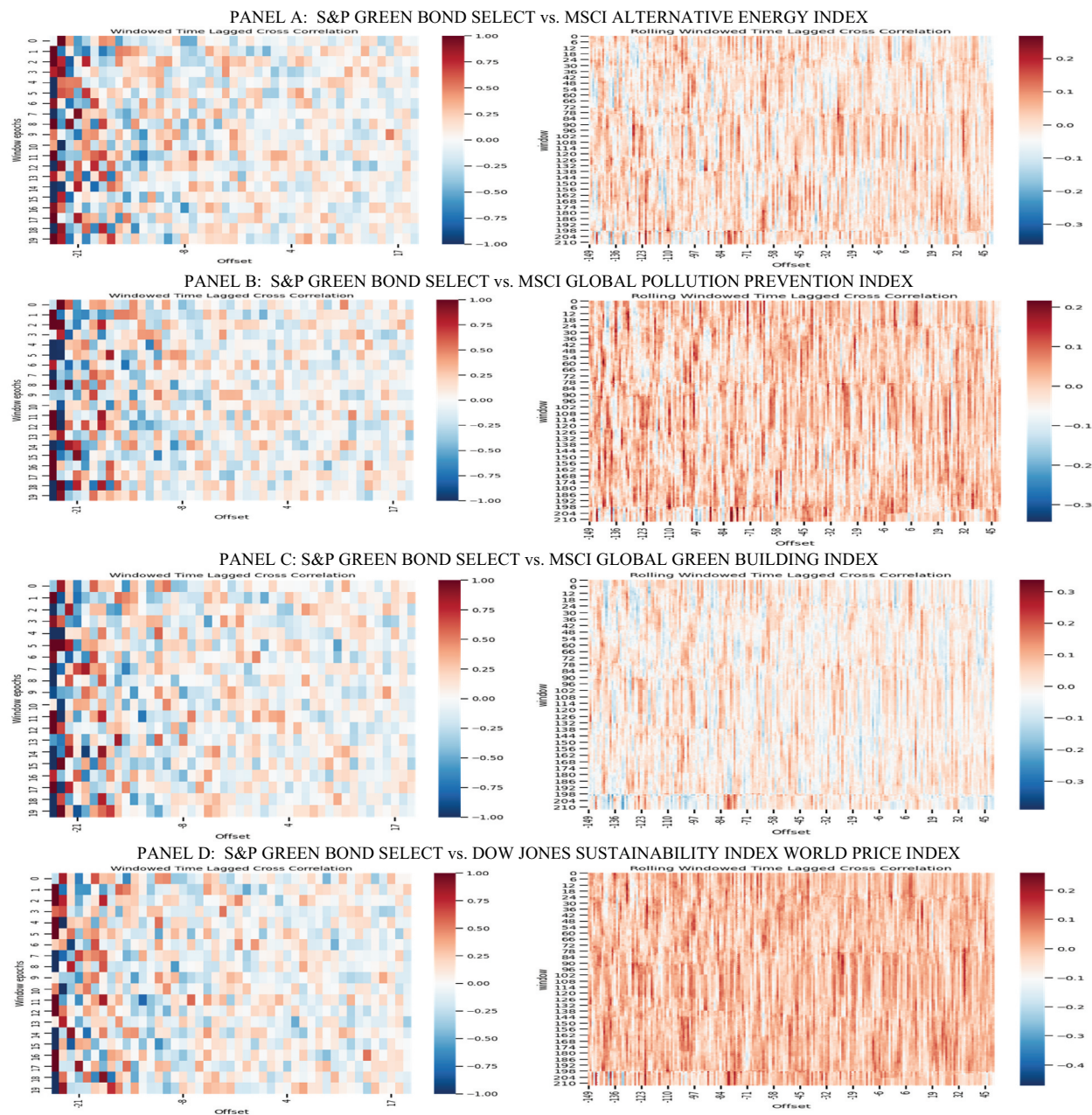


Figure 4. Windowed cross-correlation (WWCC) and rolling window time-lagged cross-correlation for continuous windows plots between green bonds and other assets.

from October 2010 to July 2012. However, we find opposite results during the oil price collapse of June 2014 to February 2016 and COVID-19 pandemic of January 2020 to September 2020. In particular, the extent of similarity increased tremendously during the outbreak of COVID-19 which is not surprising since the closure of schools and workplace coupled with restrictions on social interactions impacted the environment positively. For instance, Le Quéré et al., Nguyen

et al. (2021) find that forced confinement during the COVID 19 outbreak contributed significantly to the reduction in daily global carbon emissions.

Windowed time lagged cross-correlation (WTLCC) analysis

Next, we compute the WTLCC to assess further the fine-grained dynamics between Green Bond

and environmental securities. This process repeats the time-lagged cross-correlation in multiple windows of the signal. We then analyse each window to establish the leader-follower interactions between Green Bonds and the environmental assets under examination. From Panel A to Panel D of [Figure 4](#), the left side plot depicts the WTLCC between the Green Bond and each of the other assets under examination. The WTLCC plot splits the time series into 20 even chunks and computes the cross-correlation in each window. This gives us a more fine-grained view of what is going on in the interaction.

Focusing on WTLCC plots between Green Bonds and environmental securities displayed in Panel A to Panel D, we observe in the first window (first row), the red peak shifts to the right which suggests the price returns of environmental securities initially lead the interaction which continues to the later rows. Thus, green stocks lead green bonds in both the short and long run. Our results differ from the literature. [Reboredo, Ugolini, and Aiube \(2020\)](#) found strong connectedness between green bonds and treasury and corporate bonds in the short and long run and in both the EU and the USA, with green bonds receiving sizable spillovers from treasury and corporate bond prices and transmitting negligible effects. Additionally, [Le et al. \(2022\)](#) found green bond is a net receiver of shocks from other markets. Our results confirm the findings of earlier studies given that green stocks leads green bond. For a more fine-grained view, we also compute the windowed time-lagged cross-correlation continuously resulting in a smoother plot as shown in column 2 of [Figure 4](#) which further supports that the environmental securities lead the interaction. This is not surprising since proceeds from Green Bonds investment are invested in environment-related assets. Thus, Green Bonds lags the environmental securities as evident from [Figure 4](#). The WTLCC approach is a robust approach to establish the leader-follower interactions between two asset classes through visualization and how the interaction shifts over time.

Cross quantilogram correlation (CQC) analysis

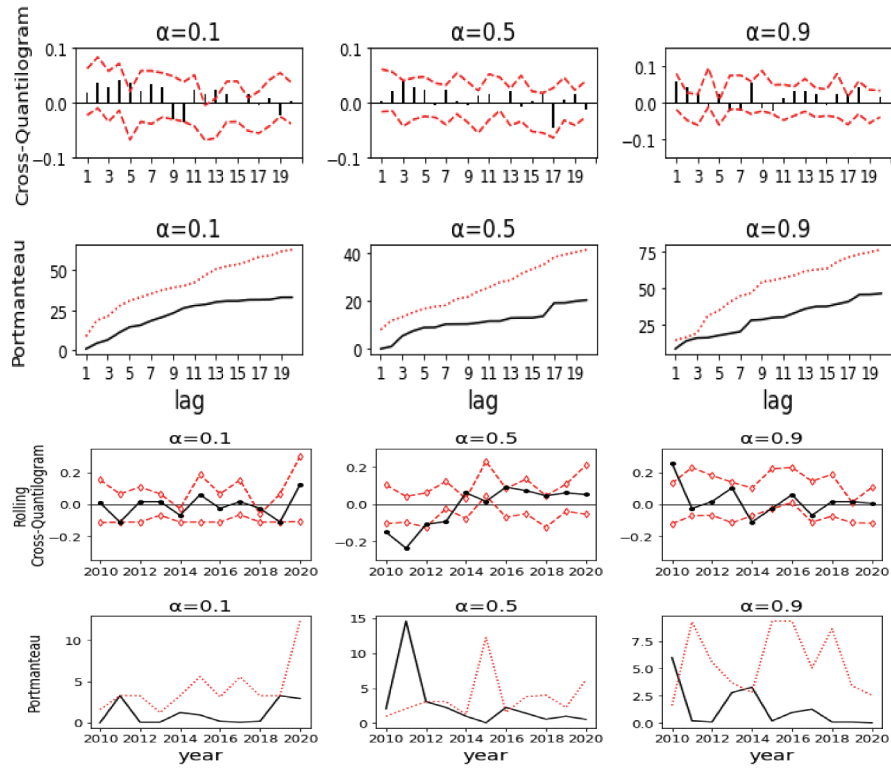
In this section, we discuss our results obtained from the cross quantilogram approach in two subcategories. In the first subsection, we discuss the cross-quantile dependence heat map between price changes in Green Bond and environmental variables. In [sub-section II](#), we present results for CQC estimates between Green Bonds and assets examined in this study.

Cross-quantilogram correlation (CQC) heat map

We provide the cross-quantilogram results for directional predictability between Green Bonds and other asset returns under examination from Panel A to Panel D in [Figure 5](#). For each pair, the cross-quantilogram correlation results are outlined across all market states denoted by bearish, normal, and bullish market conditions in quantiles of 0.1, 0.5, and 0.9, respectively. Through this approach, the directional predictability between each pair of asset returns under examination across all market conditions or quantiles can be observed. In each plot, the red-dashed line presents the 95% bootstrapped confidence interval for no predictability with 1,000 repetitions. The resultant Box-Ljung (Portmanteau) statistics to test the null of non-predictability are displayed in [Figure 4](#) below the CQC plots for each asset pair. We also report the Rolling CQC and its corresponding Portmanteau statistics beneath the CQC of each market pair.

In Panel A of [Figure 5](#), the results for daily return spillover from the Green Bond to alternative energy index returns indicate that there is no directional predictability irrespective of the market conditions. Thus, even in bullish market conditions, we find no directional predictability from Green Bond price returns to other markets examine. The evidence of no predictability from the CQC model is somehow in agreement with the result [Pham \(2021\)](#) who examined the cross-quantile dependence and time frequency connectedness between green bond prices and green stock markets and find that there exist a weak relationship between green bond and green stock during normal market periods. The portmanteau test statistics confirm the insignificance of the quantile correlations. From the rolling CQC plots, we further observe negative

PANEL A: S&P GREEN BOND SELECT vs. MSCI ALTERNATIVE ENERGY INDEX



PANEL B: S&P GREEN BOND SELECT vs. MSCI GLOBAL POLLUTION PREVENTION INDEX

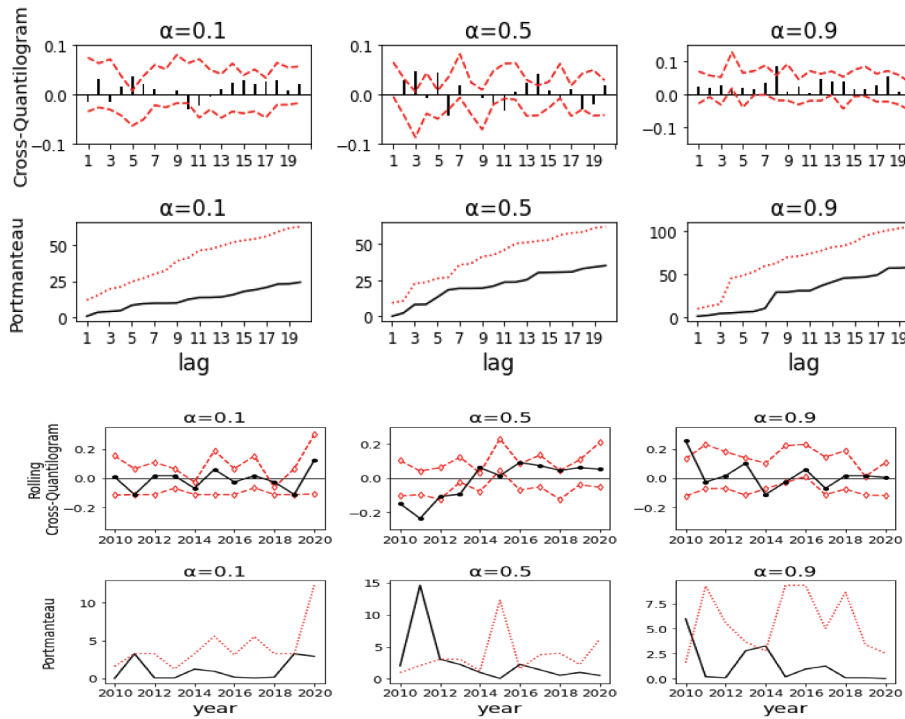
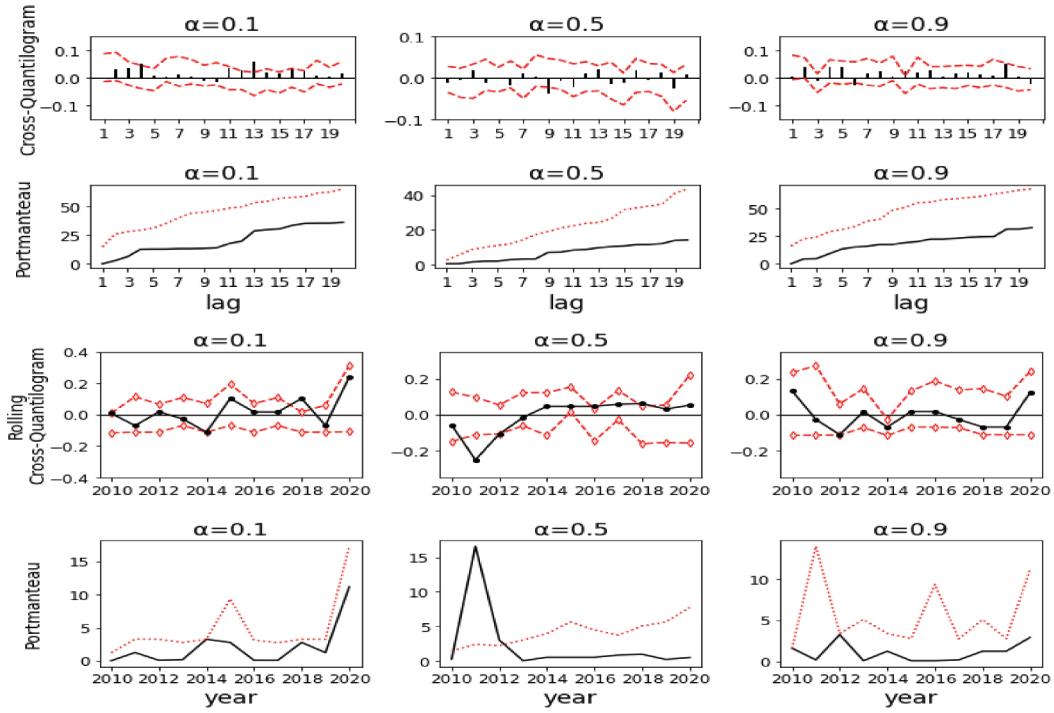


Figure 5. Cross-Quantilogram correlation (CQC) between green bonds and environmental asset returns.

PANEL C: S&P GREEN BOND SELECT vs. MSCI GLOBAL GREEN BUILDING INDEX



PANEL D: S&P GREEN BOND SELECT vs. DOW JONES SUSTAINABILITY INDEX WORLD PRICE INDEX

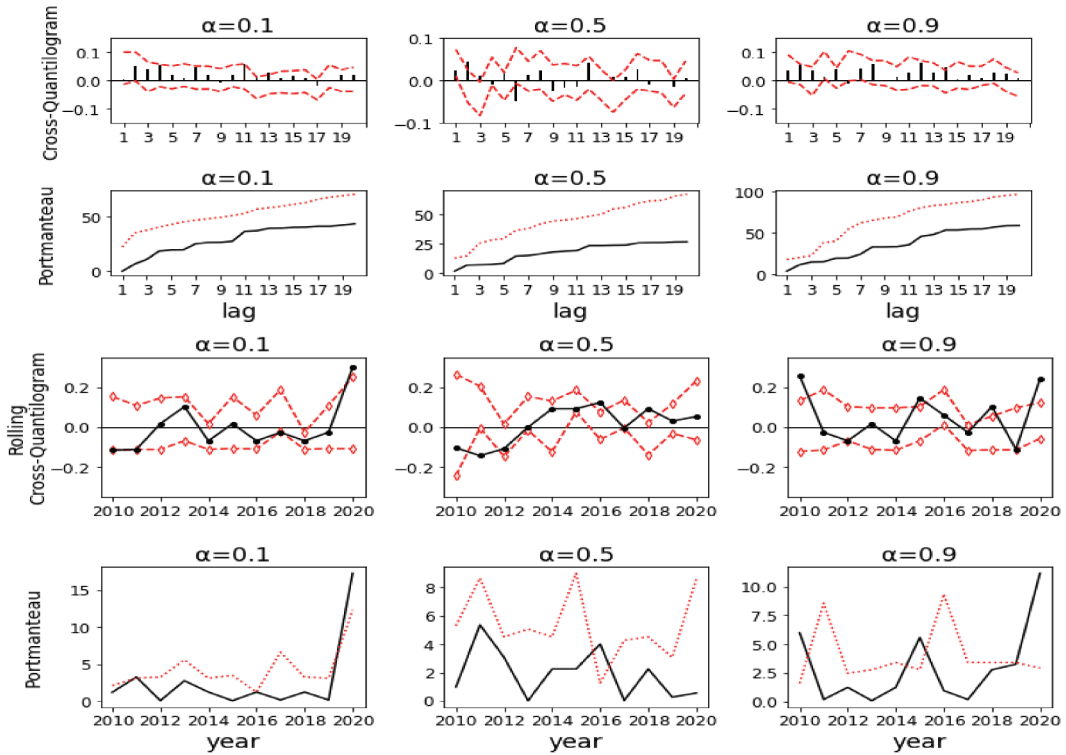


Figure 5. (Continued).

and positive spillovers from Green Bonds to other assets for the period 2010–2012 during moderate and upturn market conditions. The portmanteau test statistics confirm the significance of the quantile correlations. In terms of the daily return spillover from Green Bond price returns to pollution prevention reported in Panel B of Figure 5, we find a positive and negative directional predictability from Green Bonds to pollution prevention during moderate market conditions in the short to medium terms. In the long run, we find no significant predictability throughout the entire period. Thus, risk spillover can be positive or negative in the short run which suggests short-term investors should not hold this asset in a portfolio during

moderate market conditions. The predictability between the Green Bond and green building shows causality during bearish conditions in the short term from the CQC and portmanteau test. Results obtained from Panel D between Green Bond and sustainability index returns are like what was documented in Panel C. In all, the cross quantilogram plots and portmanteau tests confirm minimal directional predictability between Green Bonds and environmental securities in the short term during moderate market states. This suggests that Green Bond securities can serve as a safe-haven to environmental stocks, similar to the

PANEL A: S&P GREEN BOND SELECT vs. MSCI ALTERNATIVE ENERGY INDEX

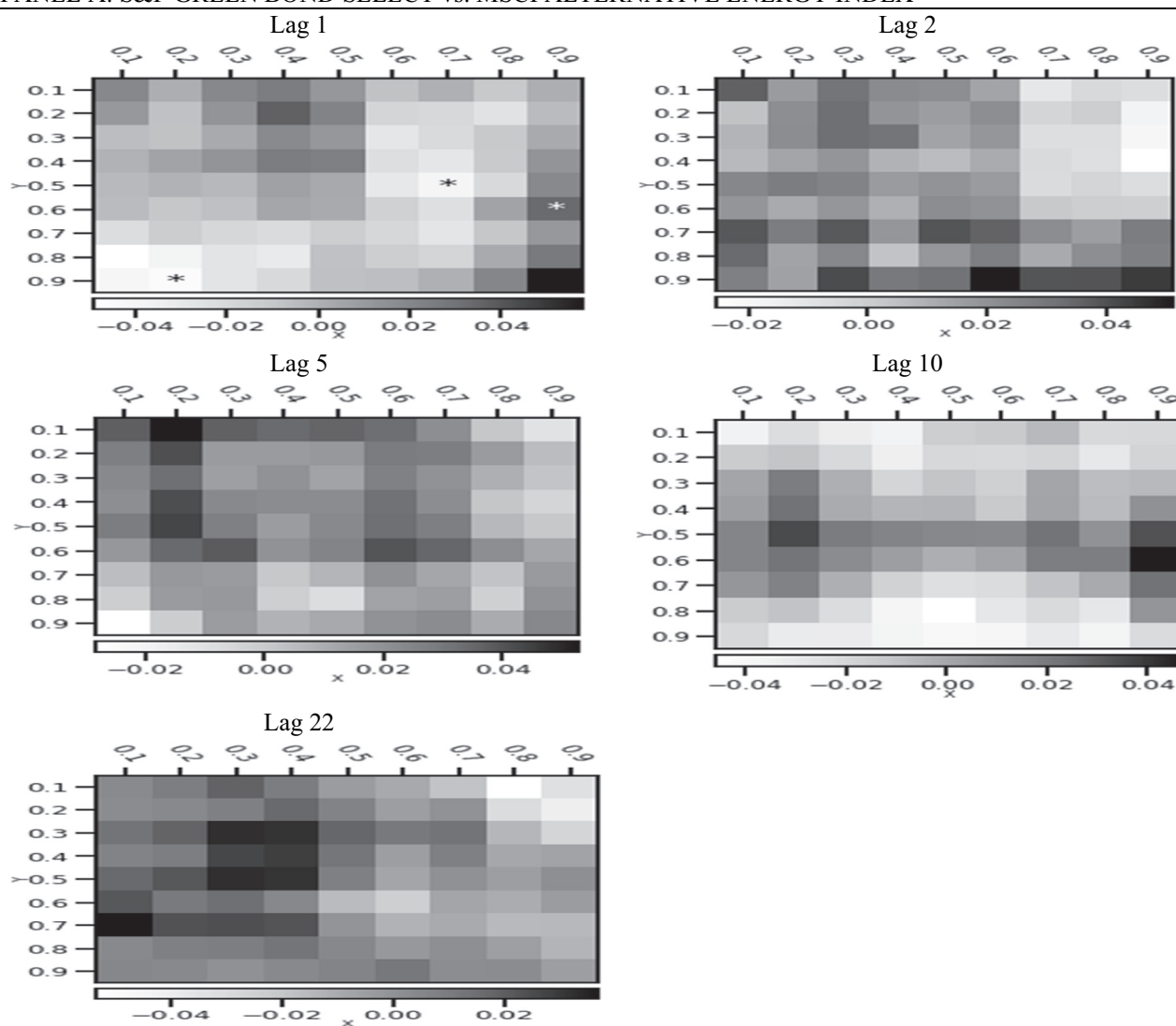


Figure 6. Cross-Quantilogram correlation (CQC) heat map between green bonds and other asset returns.

PANEL B: S&P GREEN BOND SELECT vs. MSCI GLOBAL POLLUTION PREVENTION INDEX

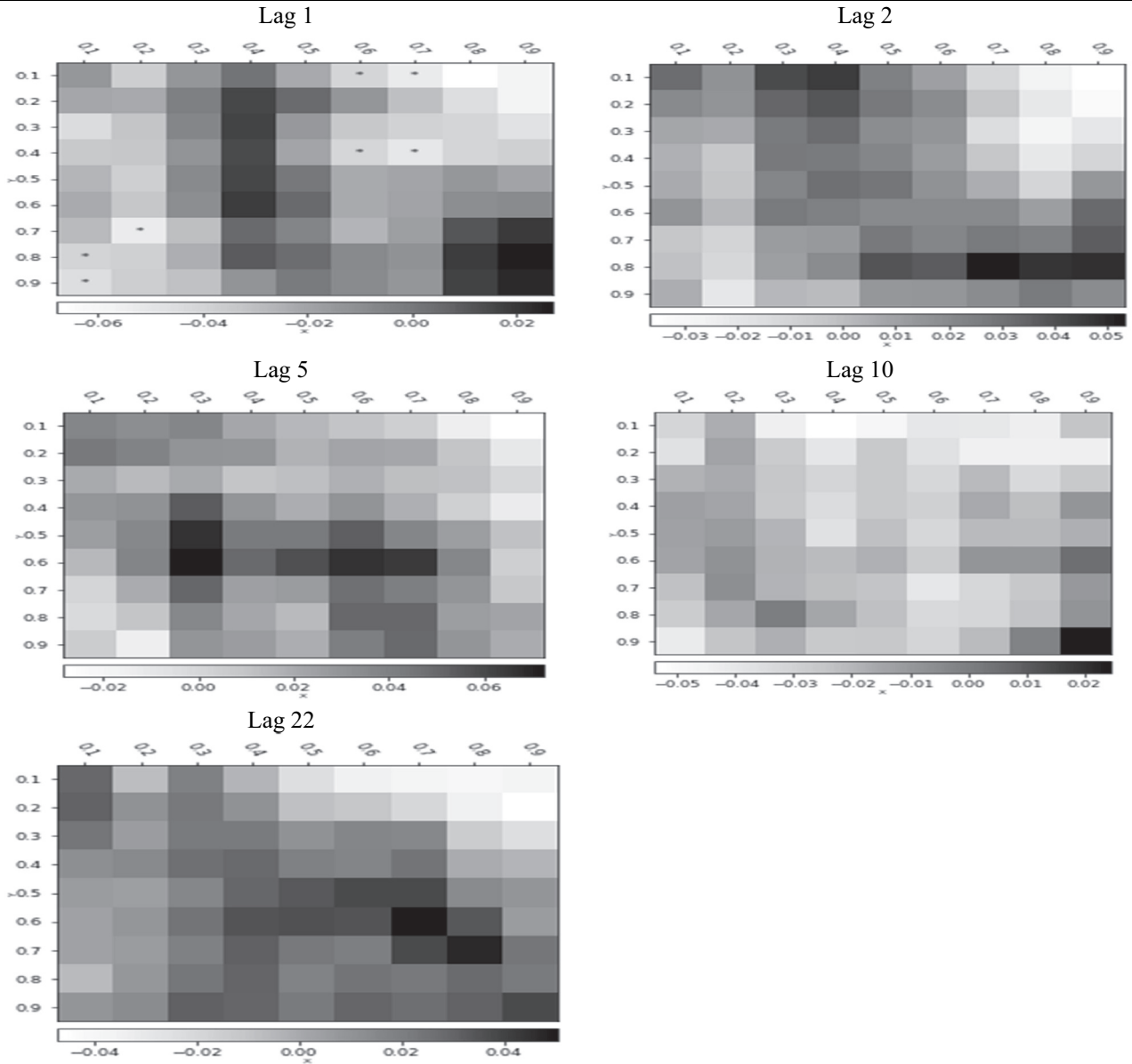


Figure 6. (Continued).

PANEL C: S&P GREEN BOND SELECT vs. MSCI GLOBAL GREEN BUILDING INDEX

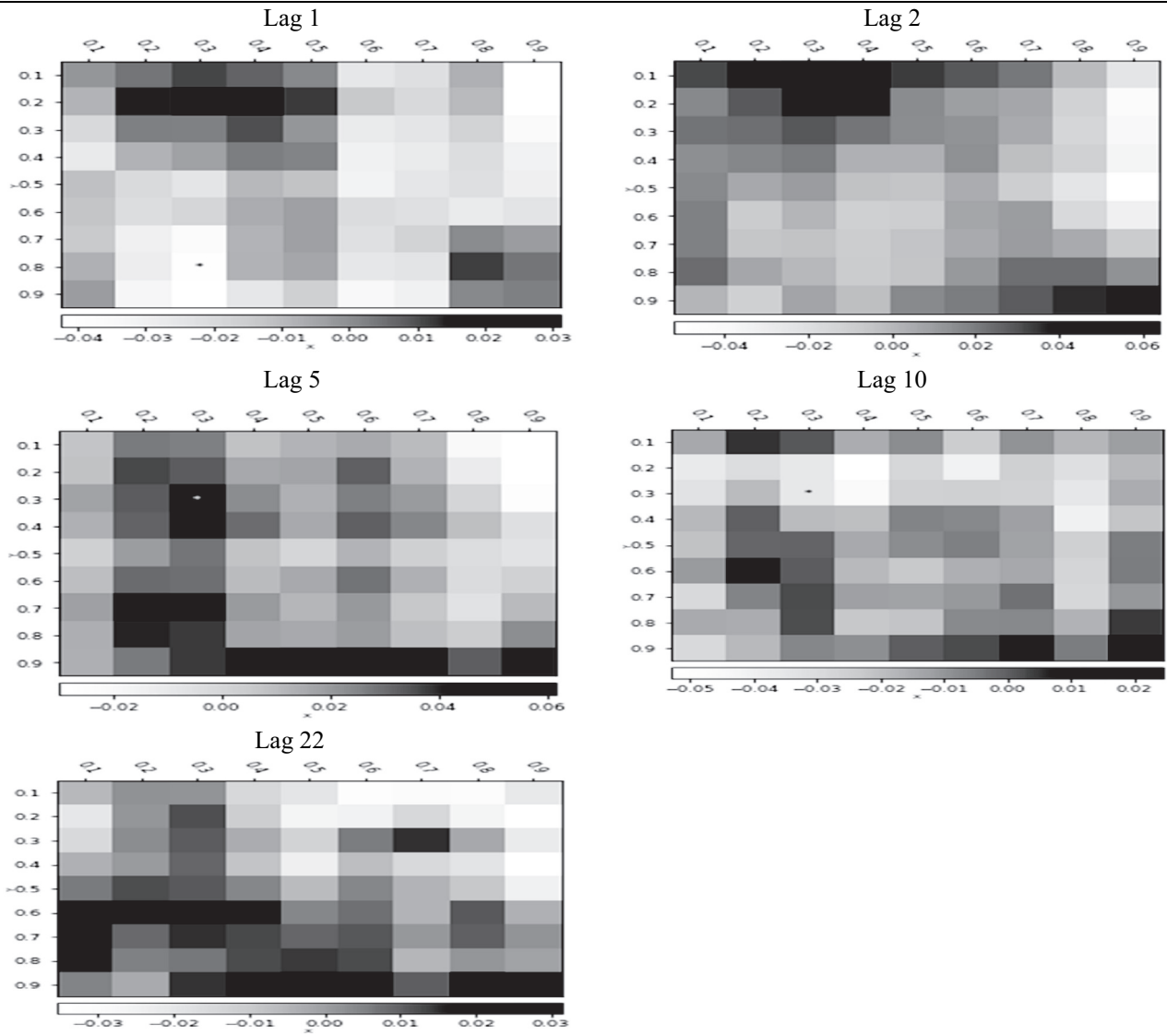


Figure 6. (Continued).

PANEL D: S&P GREEN BOND SELECT vs. DOW JONES SUSTAINABILITY INDEX WORLD PRICE INDEX

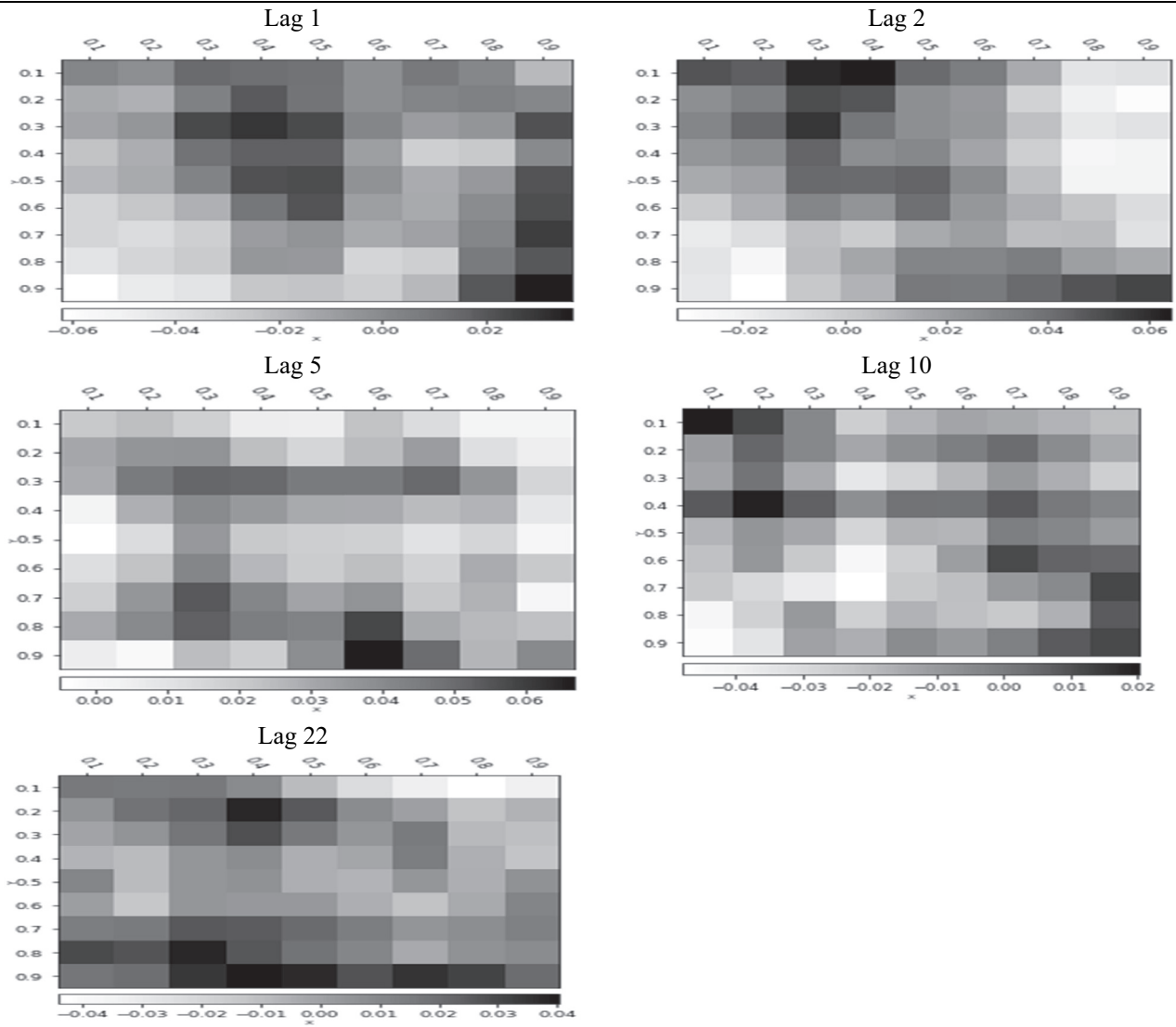


Figure 6. (Continued).

findings of Nguyen et al., 2021 and Tiwari et al. (2022). The portmanteau test statistics confirm the significance of the quantile correlation.

V.IV.II. Cross-quantilogram correlation (CQC) estimates

Following Uddin et al. (2019), we next examine the cross-quantile correlation (CQC hereafter). Using different lag lengths, the heatmap allows us to capture a wide range of dependence structures in the CQ approach. For this section of the analysis, we use quantile distributions of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 of two time series variables. These are shown on the x-axis and y-axis in the Heatmap. Each Heatmap presents 121 cells of the bivariate quantile combinations. Here, the association is designated by a colour scale, and all statistically insignificant correlations are set to zero. In Figure 6, we show the joint directionality, that is, the CQC between Green Bond price and environmental assets returns from Panel A to Panel D for five different lags. We use the Box-Ljung test to test for the significance of predictable directionality and set all insignificant correlations to zero. From Panel A to Panel E, in each Heatmap, the vertical axis shows the quantiles of Green Bond price, while the horizontal axis presents the environmental variables.

Panel A shows the directionality going from Green Bond to alternative energy. For lag 1, we observe strong dependency when in similar upper and lower quantiles (0.04:0.04; 0.9:0.9). However, strong dependence decreases when different low quantiles (0.2:0.9; 0.7:0.5; 0.8:0.1). On the other hand, the dependency of alternative energy on Green Bond continues in lag 2, lag 5, and lag 22 across different low quantiles which suggests synchronicity between the Green Bond and alternative energy in the long run. Panel B reports between Green Bond and pollution prevention index returns depict that in the short run, the Green Bond has a significantly weak influence on the pollution prevention index across different quantiles (0.5:0.1; 0.7:0.1; 0.1:0.9). In the long-term dynamics, the relationship deepens across all quantiles especially at lag 2 and lag 22. From Panel C and Panel D which document the impact of Green Bonds on green building and sustainability index

respectively, we show through the CQC plots that the predictability is more profound in the long term across all quantiles. The overall results for the dependency structure between Green Bonds and environmental asset returns examined in this study indicate that the dependency is concentrated in different quantiles and deepens in the long run similar to the findings of Pham (2021) who found that the spillovers between asset classes and green bonds vary widely across the quantiles, indicating that the hedging benefits of green bonds against conventional asset classes differ across extreme and normal market conditions.

VI. Discussion

Conclusion and policy implications

This paper provides first-time evidence on the connectedness between Green Bonds and a unique set of environmental securities or green stocks under different investment horizons. In doing so, novel quantile cross-spectral dependence approach of Baruník and Kley (2019), cross-quantilogram correlation model, the unique windowed time-lagged cross-correlation, and windowed scalogram difference models are used.

Comparing the findings from quantile cross spectral and cross-quantilogram estimation techniques, both approaches reveal low level of dependence between green bonds and green securities in the long run. However, the cross-quantile coherency approach further shows that the marginal dependence is prevalent in extreme quantiles. Both approaches show that green bonds can act as a good diversifier for green stocks. On differences in results, we find that the results from cross-quantile correlation is more revealing in that we are able to examine the extent of risk spillovers in two parts thus the real and imaginary part. For example, we find for the case of green bond and pollution prevention index returns show that the real coherency ranges between -0.4 and 0.2 in the short run and varies between -0.2 and 0.1 in the medium to long term run while the imaginary coherence across all quantiles is approximately zero (0). This reveals significant spread of risk in the short run. Next, we compare the results on co-movement between

green bonds and green stocks using wavelets scalogram difference (WSD) and Windowed Time Lagged Cross-Correlation (WTLCC). Both results show extreme co-movement in the short run. Comparing findings obtained from the various approaches, we note from the WSD that dependency between green bonds and assets under examination is high during extreme market conditions like the findings from quantile cross spectral approach.

The empirical evidence reported in this paper has several important implications. First, for portfolio investors, our findings suggest that green bond may not offer significant diversification benefits to green stocks during bearish market conditions. In particular, the weak association between green bonds and green stocks implies that climate-conscious investors can benefit from interesting diversification opportunities by including both types of green financial products in their portfolios without compromising their environmental values. In addition, the hedging and safe-haven potential of green bonds against green stocks can be exploited by investors in times of turbulent market. Second, for policymakers, who are engrossed in the development of a powerful financial sustainable system that will support the achievement of climate-change goals, should focus on the importance of policies promoting the expansion of the green bond and green stock market. In addition, efficient and mature green bond and equity markets will increase confidence of investors and issuers in these markets and will help reduce their vulnerability during episodes of financial turmoil, helping not to interrupt the mobilization of capital to sustainable investment. Specifically, the lack of a close link between green bonds and green stocks is positive from the standpoint of policy makers as it translates into lower fragility of the green financial system to external shocks. Our findings may help in strategy formulation during extreme market conditions to ensure a smooth recovery process. Further studies are therefore recommended to consider global uncertainty and macroeconomic variable that can distort economic agent's decisions and the overall national economy to shed further insights on factors that can influence the predictability between Green Bonds and environmental securities. Future research may also consider

other robust estimation techniques such as the Markov-switching dependence model (Tiwari et al., 2021) as well as fractional integration analysis techniques (Abakah et al. 2020; Gil-alana, Abakah, and Abakah 2020).

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