

Portfolios of Sustainable Assets and Real Estate - A time and Frequency Analysis of Reduced Diversification Effects.

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Abstract

The real estate sector typically offers good diversification effects for traditional portfolios. When investors focus more on sustainable assets, such as green bonds, clean energy and ESG stocks, the diversification effects might be different. The real estate sector itself and the production of concrete consumes more energy and omits more greenhouse gases compared to other economic sectors. Despite the known links between the real estate sector and sustainable assets, studies exploring co-movements and dependence between them are still scarce. The present paper contributes to this challenging problem by analysing non-linear dependencies over both time and frequency between real estate returns and different sustainable assets (green bonds, clean energy and ESG stocks). We adopt a modelling approach that combines the recently developed cross-quantilogram with the quantile coherency methods. Our empirical results indicate that there is unidirectional dependence from the real estate sector to most sustainable assets, in both tails and during normal market conditions but bi-directional dependence in lower quantiles. Once we include the Covid-19 period, green bonds are then tail-dependent both during boom and bust periods but when excluding this period, it shows higher dependency with the real estate sector during booms. Furthermore, the returns of the green bonds are less dependent on real estate returns compared to other sustainable assets. Our findings are potentially relevant for investment portfolio and public policy decision-making purposes.

Keywords: Cross-quantilogram, Portfolio investment, Public policy, Quantile coherency, Real estate, Sustainability

JEL Codes: C22, G11, Q48, Q56, Q58, R30

1. Introduction

The real estate sector typically offers good diversification effects for traditional well-diversified optimal portfolios. When investors focus more on portfolios with sustainable assets, such as green bonds, clean energy and ESG stocks, the diversification effects might be quite different. The real estate sector is a substantial energy consumer sector - accounting for over 40% globally - and greenhouse gas emitter, playing an important role in allocating capital towards energy efficient investments. Governments have strived to sustainability development through programs that aim to reduce energy consumption in the real estate sector, while market participants have increased their environmental concerns (e.g. investing in clean energy sources, buying green bonds). Consequently, the connection between real estate and sustainable investments is becoming increasingly larger and more relevant (IEA, 2019a, 2019b; WEF, 2016).

Aiming at limiting the energy consumption of residential and commercial properties, governments and institutions around the world have been pushing for sustainability through energy performance certificates (EPC) or other rating schemes (Fuerst, Haddad, & Adan, 2020). The main purpose of such certificates is to make sustainability-related information (e.g. energy consumption, carbon emissions) more transparent. Such initiatives are commonly translated into increasing incentives for both real estate companies and households towards more energy efficient and sustainable properties. In the case of real estate companies pursuing to switch from carbon intensive investments to more sustainable alternatives, financial markets may play an important role through capital raising (Tang & Zhang, 2020).

The financial literature is full of analyzes about the co-movements and connections between different asset classes. Yet little is known about how sustainable assets and the real estate sector is related from a portfolio perspective¹. This despite the growing importance of sustainability in the real estate sector and the increased focus on sustainability in investor portfolios. While previous

¹ In this paper, sustainable assets refer to the returns of clean energy stocks, ESG stocks and green bonds. With real estate sector, we refer to the returns of publicly traded Real Estate Investment Trusts (REITs) and real estate stocks and not the value of each companies underlying assets. For more information, see the data section.

literature has been investigating the dependence between sustainable assets and real estate with the overall stock markets, there is still idiosyncratic risks related to real estate and sustainable assets which makes them different from the aggregated market. The connection between real estate and sustainable assets is of essential importance for many institutional investors that have both real estate and sustainable assets in their portfolio, which could impact their diversification opportunities. In general, how different assets is related during turbulence could be essential information for investors looking for a safe portfolio composition. Without such knowledge, investors with real estate in their portfolio might be discouraged to add more climate friendly companies or assets that otherwise could helped in reducing the speed of climate change.

We argue that real estate assets can be connected to sustainable assets through several different channels. Firstly, there is intrinsic links between the sectors as presented above. Secondly, both real estate stocks and sustainable assets, such as clean energy and ESG stocks, belongs to the overall equity market and might therefore be impacted by common shocks. Likewise, uncertainty affecting the financial markets might lead to simultaneous effects on both real estate and companies involved in sustainable activities. Thirdly, real estate and sustainable assets might be impacted by the same macroeconomic factors. There is for instance common knowledge that the interest rate affects property values through the discount rate, which in the end might impact the returns of real estate companies. In addition, many ESG or clean energy firms is involved in large-scale projects and dependent on the low financing costs. For green bonds, a fixed income sustainable asset, it is directly linked to the interest rate through the discount rate. All these theoretical linkages can be hypothesized lead to co-movement between the real estate sector and sustainable assets.

To the best of our knowledge, there is no study yet exploring the dependence between real estate and sustainable assets (ESG, clean energy stocks or green bonds), through time. Therefore, our main aim of this paper is to answer the following questions:

- Is there any dependence between the real estate sector and sustainable assets?
- If so, what is the lead-lag relationship (i.e., direction) of such dependence?
- Is the dependence different during booms vs busts?

To properly answer these questions, we focus on methods capturing quantile dependence structures in both time and frequency. We apply the recently developed cross-quantilogram (CQC henceforth) introduced in Han et al. (2016) and the quantile coherency (QC henceforth) proposed in Baruník and Kley (2019). Firstly, we analyze the dependencies between the real estate sector and sustainable assets during different market conditions. Here we use an QCQ analysis to measure the quantile dependence across different combinations of our return series, hence, allowing us to investigate the

dependence during extreme market movements. Secondly, we use a recursive rolling window analysis to estimate the time-varying nature of the CQC correlations. This procedure allows us to observe shifts and structural breaks. Thirdly, we apply the QC to measure the joint distribution dependence structure within the frequency domain of the return series. In this context, this means that we could observe if the dependence varies depending on the investment strategy, i.e., for short term versus long term investors.

Our paper is somewhat related to different strands of earlier literature, relating sustainable investments and real estate to the overall stock market and macroeconomic factors. However, studies on the dependence between real estate and sustainable assets is lacking. Previous literature has for instance highlighted a dependence between clean energy investment alternatives and the stock market in general (Lundgren et al., 2018). Other studies focusing on real estate investment trusts (REITs) suggest a tail-dependence or co-movement with the stock market (e.g. Ling & Naranjo, 1999; Chang, 2018; Ding, Chong, & Park, 2014; Hiang Liow, 2012; Huang et al., 2016), and also that such a correlation appears to be time-varying (Heaney & Srikanthakumar, 2012). For green bonds, some evidence exists on its co-movement with other asset classes. Reboredo (2018) finds tail-dependence between green bonds and the corporate and treasury bond market but little or no dependence with the energy or general stock market. Similarly, Reboredo and Ugolini (2020) find that green bonds are influenced by price spillovers, treasury bonds, and the currency market, weakly linked to the stock market, not being affected by spillovers connected with the energy market. Regarding macroeconomics factor, some studies investigate the linkages clean energy stocks (Ahmad, 2017; Henriques & Sadorsky, 2008; Huang et al., 2011; Kumar, Managi, & Matsuda, 2012; Reboredo, 2015; Sadorsky, 2012; Managi & Okimoto, 2013; Uddin et al., 2019) and the oil market. Likewise is there a few studies on volatility transmission between REITs and the oil market (Nazlioglu, Gormus, & Soytas, 2016; Nazlioglu et al., 2020). Furthermore, there is also evidence on the linkage between REITs and other macroeconomics factors, such as interest rates or term structure (see e.g., Darrat & Glascock, 1993, Ling & Naranjo, 1997). However, none of these are directly linked to the object of this paper.

Our results indicate unidirectional dependence from the real estate sector to most sustainable assets, in both tails and during normal market conditions but bi-directional dependence during turbulent times. This indicates that the real estate sector is more influential in predicting returns of the sustainable assets than the opposite. We also observe that the influence of sustainable assets on the real estate market during periods of boom has increased over time. Another interesting finding is that when the Covid-19 crisis is included in our sample period, we find that green bonds are tail-dependent of sustainable assets, both in boom-and-bust periods.

Following this introduction, this paper is divided into four sections. Section two presents the methodology. Section three details the data. Section four contains the empirical results and discussion. Section five concludes.

2. Methodology

In this paper we apply two related methods to estimate quantile dependence, namely the CQC and the QC. Compared to quantile regressions, which is a common approach found in the literature to measure quantile dependence, the CQC and QC measure the dependence not only of specific quantiles of the dependent variable but also allow the specification of the quantile of the independent variable. Hence, using such methods we can then measure the dependence between arbitrary quantiles of both real estate market and sustainable assets indices.

Such a cross-quantile correlation performed through the CQC and QC is also distinctive when comparing to other common methods that measure dependence, such as the DCC-GARCH or copula modelling. In addition to applying the CQC and the QC only once, such a combination allows to properly capture the dependence in both time- and frequency domain. In the next subsections we present the mathematical framework behind the methods adopted in the present study.

2.1 Cross-quantilogram (CQC)

Firstly, we apply the CQC introduced in Han et al. (2016) and follow their notation by letting y_{it} be a different stationary time series $t = 1, 2 \dots T$. In the case below, we consider that $i = 1, 2$. The conditional distribution of the time series y_{it} given a series x_{it} can be defined as $F_{y_i|x_i}(\cdot | x_{it})$. From this, $q_{it}(\tau_i)$ then refers to the conditional quantile function, being defined as $q_{i,t}(\tau_i) = \inf\{v: F_{y_i|x_i}(v|x_{it}) \geq \tau_i\}$ with $\tau_i \in (0, 1)$, while the unconditional quantile function can be described as $q_{i,t}(\tau_i) = \inf\{v: F_{y_i}(v) \geq \tau_i\}$.

Han et al. (2016) define the serial dependence between two events as $\{y_{1t} \leq q_1(\tau_1)\}$ and $\{y_{2t-k} \leq q_2(\tau_2)\}$, with k being a positive integer determining the lag length, and τ_1 and τ_2 consisting of arbitrarily chosen quantiles. In our case, if y_{1t} is a real estate index, y_{2t} is then a sustainable asset index or vice versa. The CQC can be defined through Equation (1) as follows:

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

In which $\psi_\alpha = 1[u < 0] - \alpha$. A measure of the quantile exceedance process – also known as “quantile hit” – is defined as $\{1[y_{it} \leq q_{it}(\tau)]\}$, with $1[\cdot]$ consisting of the indicator function (e.g. Jiang et al., 2016). Hence, the CQC reflects a measure of the cross-correlation of quantile hits. By using the CQC approach it is possible to determine if an event affecting the return of a sustainability/ real estate asset that exceeds a certain quantile can predict if the next k -period return for the real estate/ sustainability asset will be greater or lower than an arbitrarily chosen quantile. If $\rho_\tau(k)$ is not statistically different from zero, then no significant directional predictability exists. The sample CQC is expressed in Equation (2):

$$\hat{\rho}_\tau(k) = \frac{\sum_{t=k+1}^T \psi_{\tau_1} [y_{1,t} - \hat{q}_{1,t}(\tau_1)] \psi_{\tau_2} [y_{2,t-k} - \hat{q}_{2,t-k}(\tau_2)]}{\sqrt{\sum_{t=k+1}^T \psi_{\tau_1}^2 [y_{1,t} - \hat{q}_{1,t}(\tau_1)]} \sqrt{\sum_{t=k+1}^T \psi_{\tau_2}^2 [y_{2,t-k} - \hat{q}_{2,t-k}(\tau_2)]}} \quad (2)$$

The $\hat{q}_{1,t}$ and $\hat{q}_{2,t-k}$ can consist of estimates of both unconditional and conditional quantiles of their respective return series (Cho & Han, 2020). In our study, the null hypothesis of $\hat{\rho}_\tau(k) = 0$ is then tested against $\hat{\rho}_\tau(k) \neq 0$ using the Ljung and Box (1978) significance test for autocorrelation. The test statistic performed is defined following Equation (3):

$$\hat{Q}_\tau(p) = T(T+2) \sum_{k=1}^p \frac{\hat{\rho}^2(k)}{T-k} \quad (3)$$

The results of the CQCs are presented both through heatmaps and recursive windows. The x - and y -axis of the heatmaps will be either the return series of a real estate index on the y -axis and an index of a sustainable asset on the x -axis or vice versa. The quantiles on the respective axis will consist of 11 quantiles ranging from 0.05 to 0.95. For the CQC heatmaps we report the results of estimations considering one- to five-day lags.

By also estimating a recursive window, we can then check if the CQC-dependence between real estate and sustainable assets changes over time. Such a procedure allows to observe the time-varying nature of the CQC correlation due to the fact that it captures shifts and structural breaks present in the respective time series. We adopt an initial window of 250 days that progresses in a daily basis. In accordance with Han et al. (2016), the confidence interval is derived from a bootstrap procedure.

2.2 Quantile coherency (QC)

Following Baruník and Kley (2019), we let a stationary process be defined as $(\mathbf{X}_t)_{t \in \mathbb{Z}}$ with the components ranging from X_{t,j_1} to X_{t,j_n} . In our case, these refer to the real estate and sustainability

series. The matrix of quantile cross-covariance kernels can be defined following Equation (4) and Equation (5) below:

$$\Gamma_k(\tau_1, \tau_2) := (\gamma_k^{j_1, j_2}(\tau_1, \tau_2))_{j_1, j_2 = 1 \dots n} \quad (4)$$

$$\gamma_k^{j_1, j_2}(\tau_1, \tau_2) = \text{Cov}(\mathbf{I}\{X_{t+k, j_1} \leq q_{j_1}(\tau_1)\}, \mathbf{I}\{X_{t, j_2} \leq q_{j_2}(\tau_1)\}) \quad (5)$$

Where $\mathbf{I}(\cdot)$ is an indicator function, $\tau_1, \tau_2 \in [0, 1]$ and j_1 and j_2 are elements of the set $\{1 \dots n\}$. The terms q_{j_1} and q_{j_2} consist of the quantile functions of the marginal distributions (F_1 and F_2) of two stationary processes X_{t, j_1} and X_{t, j_2} , with the quantile functions defined as $q_j(\tau) = F_j^{-1}(\tau)$. Baruník and Kley (2019) then define the dynamic dependence, or quantile-coherency kernel for X_{t, j_1} and X_{t, j_2} , as detailed in Equation (6):

$$\Re^{j_1, j_2}(\omega; \tau_1, \tau_2) = \frac{\mathfrak{f}^{j_1, j_2}(\omega; \tau_1, \tau_2)}{(\mathfrak{f}^{j_1, j_1}(\omega; \tau_1, \tau_2)\mathfrak{f}^{j_2, j_2}(\omega; \tau_1, \tau_2))^{1/2}} \quad (6)$$

Where $\mathfrak{f}(\omega; \tau_1, \tau_2)$ is the matrix of cross-spectral kernels in the frequency domain, and $\mathfrak{f}^{j_1, j_2}(\omega; \tau_1, \tau_2)$ being calculated following Equation (7):

$$\mathfrak{f}^{j_1, j_2}(\omega; \tau_1, \tau_2) := (2\pi)^{-1} \sum_{k=-\infty}^{\infty} \gamma_k^{j_1, j_2}(\tau_1, \tau_2) e^{-ik\omega} \quad (7)$$

With $\omega \in \mathbb{R}$ and $\tau_1, \tau_2 \in [0, 1]$. As $\mathfrak{f}^{j_1, j_2}(\omega; \tau_1, \tau_2)$ is complex valued, it can then be decomposed into a real and imaginary part. In the present study we focus only on the real part. As mentioned in Baruník and Kley (2019), the QC is similar to the CQC because it focuses on serial dependence between two events. However, the former is defined in the frequency domain instead of the time domain. Therefore, by combining the QC method with the CQC is then possible to analyse in a greater deal of detail the quantile dependence between the real estate market and sustainable assets once such a methodological combination captures both frequency and time-domain².

3. Data

Five real estate indices capturing different parts of the market are used to explore the dependence between the real estate sector and sustainable assets. In the category of real estate assets, for the purpose of capturing particularly the real estate investment trusts (REIT) market, our indices include the United States Residential REIT Index (REITRES) and the United States Commercial REIT Index (REITCOM). To capture the remaining part of the US real estate market, our sample then includes the United States Real Estate Service Index (RESER) and United States Real Estate

² The QC has been applied to several studies within the financial literature and also in the field of energy economics. See, for example a study applying the QC for dependence between crude oil and exchange rates in Tiwari, Trabelsi, Alqahtani, and Bachmeier (2019), and a study on networks of stocks in Baumöhl and Shahzad (2019)

Development and Operations Index (REDEV)³. In addition, we include the MSCI Global Green Building Index (GBLD), which consists of companies deriving their incomes from green building, with many operating as REITs.

In the category of sustainable assets, four indices are included in our sample: the S&P Green Bond Select Index (GB), S&P Clean Energy Index (CLE), MSCI World ESG Leaders (ESG) and the Dow Jones Sustainability Index World (SI). Hence, our sample of sustainable assets includes securities from different types of sectors as well as distinct financial instruments. All data is daily continuously compounded returns in USD spanning from 30/04/2013 to 06/07/2020. After adjusting for holidays, the dataset includes 1,806 observations.

4. Empirical results

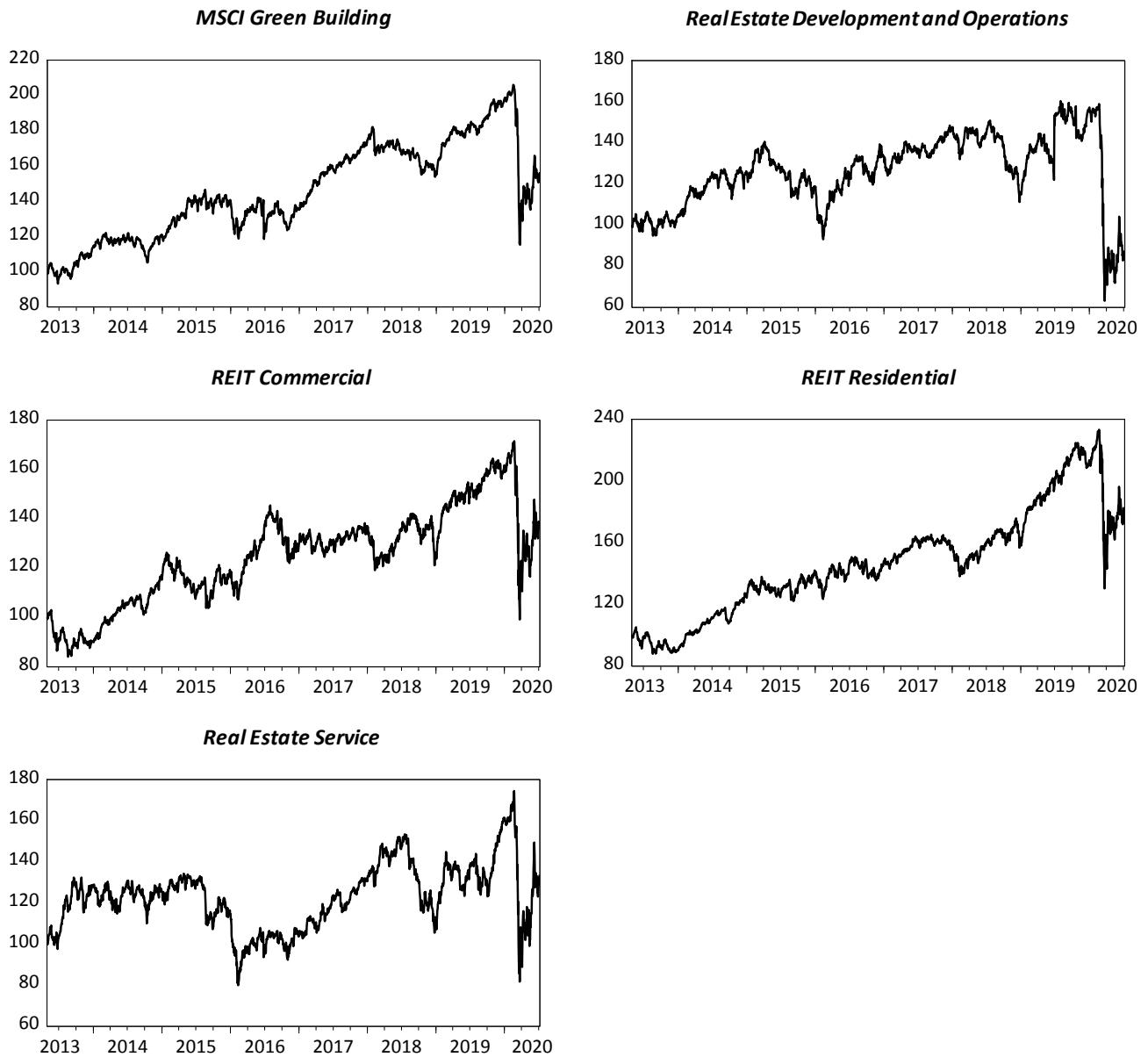
We present our empirical results in four subsections. The first subsection shows an exploratory data analysis. In the second subsection, we present the results of the cross-quantilogram (CQC) estimations. In the third subsection, we explore the time-evolution of the dependence structures by presenting the CQC correlation for the tails of the return distributions estimated with recursive rolling windows. In the fourth subsection, we then present the results of the QC analysis, showing the dependence in the joint distribution of returns of real estate and sustainable assets across different frequencies.

4.1. Exploratory data analysis

The time trends of real estate and sustainable assets over the sample period are depicted in **Figure 1** and **Figure 2**, respectively. In general, it is worth noticing that the Covid-19 pandemic severely impacts both real estate and sustainable assets level series, with the largest drop for the REDEV index. During our sample period, REITRES and GBLD show a superior performance compared to the remaining real estate indices.

³ Tickers are in parentheses: United States Residential REIT index (TRXFLDUSPREIR), United States Commercial REIT index (TRXFLDUSPREIC), United States Real Estate Service index (TRXFLDUSPREAS), and United States Real Estate development and operations index (TRXFLDUSPREAL).

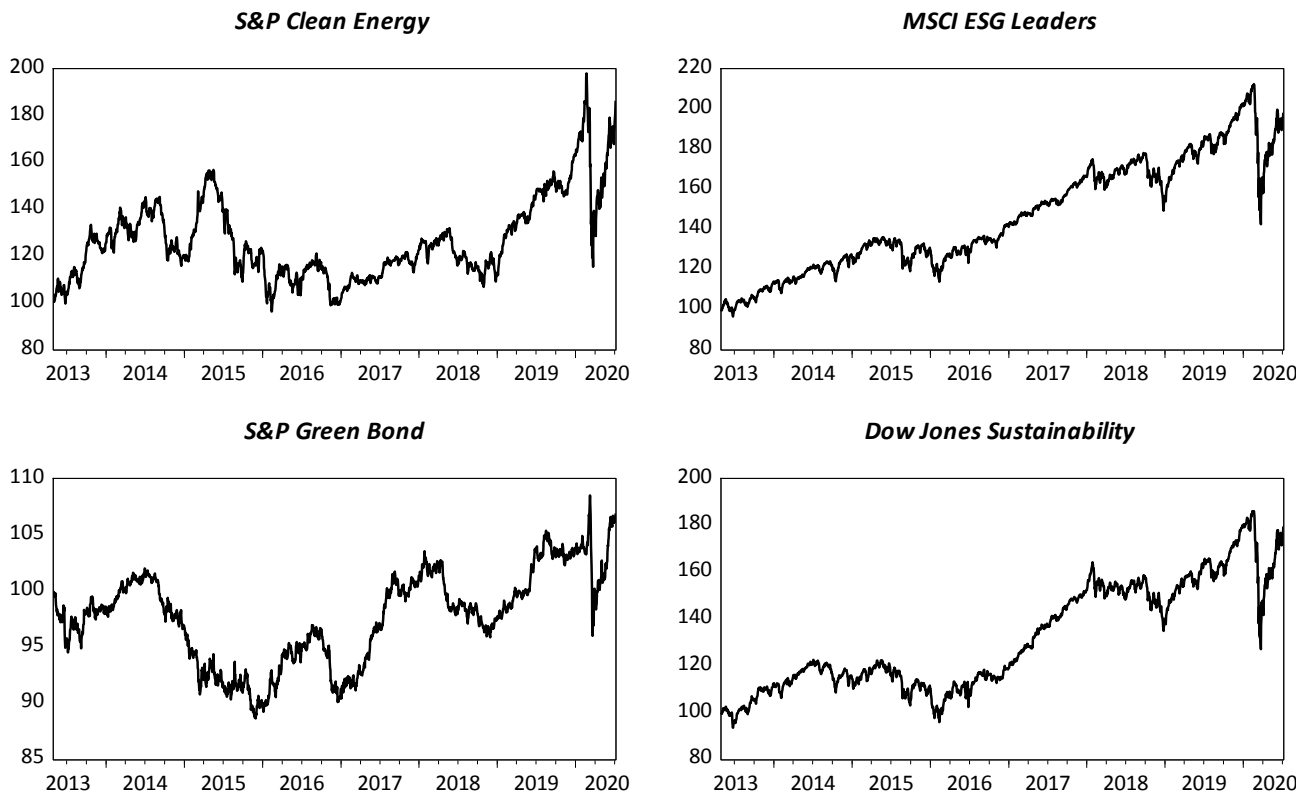
Figure 1. Level time series of real estate indices



Notes: the vertical axis denotes the index value, which is set to 100 in the first time point of the series (i.e. 30/04/2013).

As shown in **Figure 2**, the dependence between sample variables, the graphs suggest that the SI and ESG indices are more related to the real estate sector compared to the other sustainable assets with long term-increases in the return over the sample period. Regarding the GB and CLE, we observe decreasing returns during the years in the middle of our sample. Based on the substitutional arguments between oil and clean energy firms put forward in Managi & Okimoto (2013) and Uddin et al. (2019), one explanation of the low CLE returns might have been the low oil price during this period.

Figure 2. Level time series of sustainable asset indices

Table 1. Descriptive statistics

Notes: the vertical axis denotes the index value, which is set to 100 in the first time point of the series (i.e. 30/04/2013).

The descriptive statistics and unit root tests are reported in **Table 1**. We can see positive mean returns for all indices except for the REDEV. In general, the real estate variables have a higher standard deviation compared to sustainable assets. This might reflect that there is a lower number of assets in their index composition, resulting in more fluctuations.

Variable	Mean (%)	SD (%)	Skewness	Kurtosis	Normality	ADF	PP
GBLD	0.020	1.066	-2.295	35.28414	80,016.05***	-14.132(9)***	-33.753***
REDEV	-0.007	1.693	-0.308	45.25374	13,4378.3***	-12.151(8)***	-42.127***
REITCOM	0.018	1.367	-2.133	38.57231	96,590.25***	-12.701(10)***	-47.727***
REITRES	0.032	1.361	-2.313	42.30933	11,7888.2***	-13.797(9)***	-45.929***
RESER	0.016	1.800	-0.908	18.56032	18,467.93***	-15.156(6)***	-41.216***
CLE	0.030	1.303	-1.167	19.0196	19,721.06***	-13.200(8)***	-39.266***
ESG	0.036	0.916	-1.456	28.5815	49,882.76***	-13.144(9)***	-45.109***
GB	0.003	0.359	-0.689	10.01255	38,43.224***	-17.639(6)***	-39.970***
SI	0.029	0.930	-1.517	24.20631	34,533.66***	-13.805(9)***	-42.529***

Notes: SD refers to standard deviation, Normality is the Jarque-Bera test for a normal distribution, ADF is the Augmented Dickey-Fuller test for unit root with both a constant and trend included (optimal lag length in parentheses), and PP is the Phillips-Perron unit root test. The null hypothesis for both unit root tests is that the tested variable has a unit root, while the Jarque-Bera null hypothesis is that the variable is normally distributed. The significance at 1% level is reflected as ***.

All indices have negative skewness, indicating that their distributions are skewed to the left. The rejection of the null hypothesis in the Jarque-Bera (Bera & Jarque, 1981) tests indicates that our variables are not normally distributed, which is consistent with the respective stylised fact found in the literature. The high values of kurtosis - much larger than three - indicate that large losses are more likely compared with what would be assumed under a Gaussian distribution.

In addition, the results of the ADF (Dickey & Fuller, 1979) and the PP unit root test (Phillips & Perron, 1988) suggest that the variables are stationary⁴. The linear correlation between all variables is reported in **Table 2**. In consonance with our previous observations, the correlation between ESG and SI as well as the real estate indices are greater compared with the CLE and GB. In some cases, such as between ESG and RESER, the correlation is considerably high.

⁴ In this case, we present the results from the ADF test using a maximum lag length of ten. It is worth mentioning that, in our case, changing the maximum lag does not impact any of such reported results.

Table 2. Pearson correlation matrix

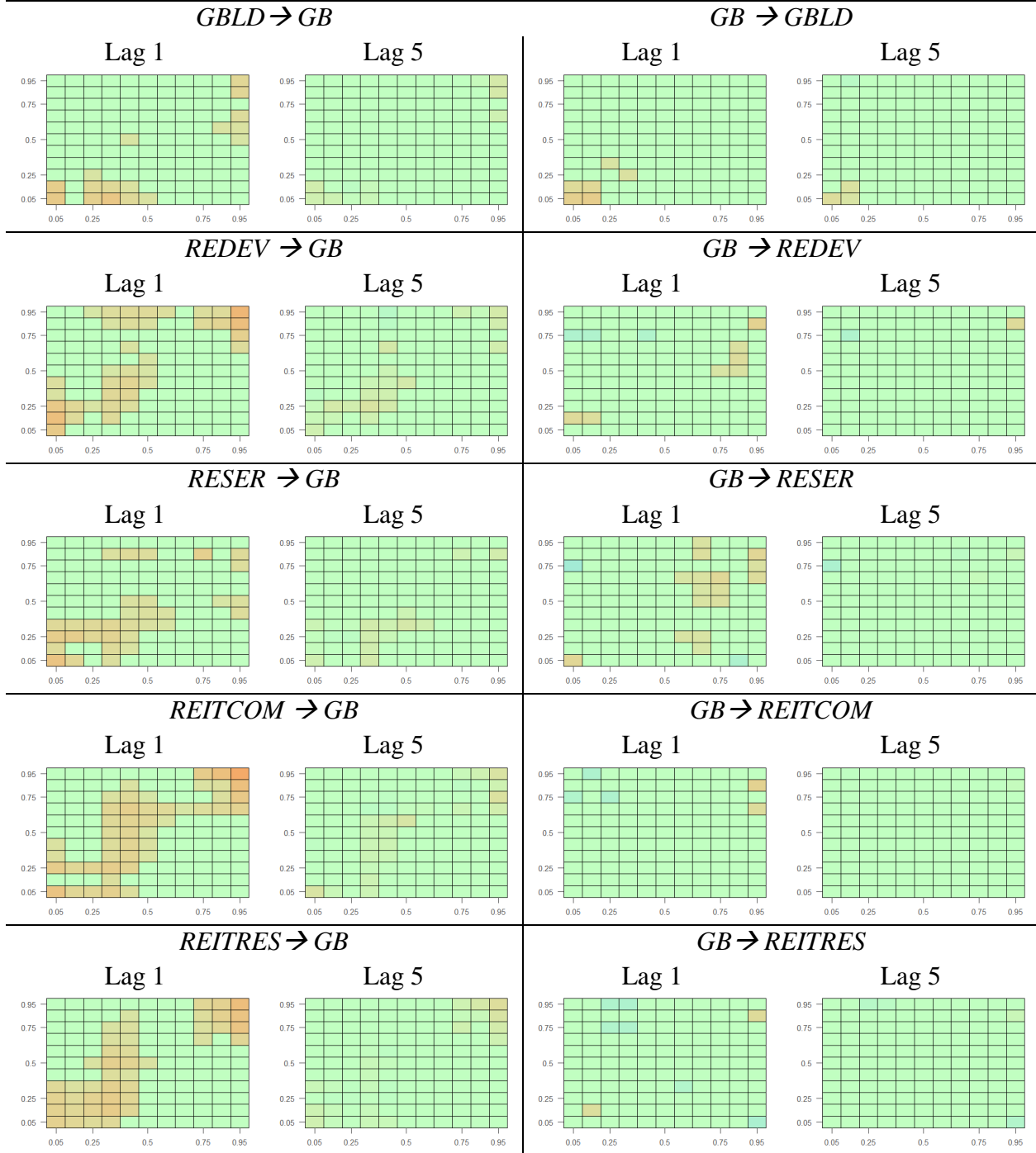
	CLE	ESG	GB	GBLD	REDEV	REITCOM	REITRES	RESER	SI
CLE	1.00								
ESG	0.76	1.00							
GB	0.12	-0.03	1.00						
GBLD	0.66	0.72	0.28	1.00					
REDEV	0.57	0.70	0.08	0.63	1.00				
REITCOM	0.55	0.72	0.13	0.63	0.74	1.00			
REITRES	0.48	0.63	0.14	0.57	0.67	0.88	1.00		
RESER	0.61	0.78	0.02	0.61	0.75	0.70	0.60	1.00	
SI	0.77	0.93	0.18	0.77	0.63	0.63	0.55	0.70	1.00

The GB index shows low correlation levels with most of the remaining indices – some of them close to zero, being its greatest correlation with GBLD (i.e. 0.28). Hence, this suggests that companies involved in green building may be more dependent on returns of GB in comparison with the rest of the real estate sector.

4.2. Cross-quantilogram (CQC) results

The results of the CQC analysis are depicted in **Figure 3** to **Figure 6**, being presented in heatmaps with the quantiles of respective variable reflected in the axes. In the heatmaps, red color indicates positive CQC-correlation while blue color is negative correlation. The arrow shows the direction of the correlation. The left side of the figures shows the direction from the real estate indices to the sustainability indices while the right part displays the correlation in the direction from the sustainability indices to the real estate indices. The quantiles on the axes consists of 11 quantiles ranging from periods of extremely low returns (quantile 0.05) to periods of extremely high return (quantile 0.95).

If we start by looking at CQC between the Green Bonds (GB) and the real estate indices in **Figure 3**, red color in the lower left corner indicates they are dependent in periods of extreme low returns (quantile 0.05 etc). This is most apparent on the left side of the figure, i.e., when the direction of dependence goes from the real estate sector to the sustainable assets and for the first lag. This can be interpreted as returns of sustainable assets being more likely to be low in the next trading day after low returns observed in the real estate sector. There is also a significant dependence in the top right corner for many of the heatmaps, suggesting a connection between these sectors during boom periods. However, such a correlation is weaker for the lower left corner and not as widespread. When looking at the reverse direction (right hand side of the figures), we do not see any significant pattern of dependence. Hence, extremely positive, or negative returns in GB is not followed by increased likelihood of extremely low or high returns in the real estate sector the next day.

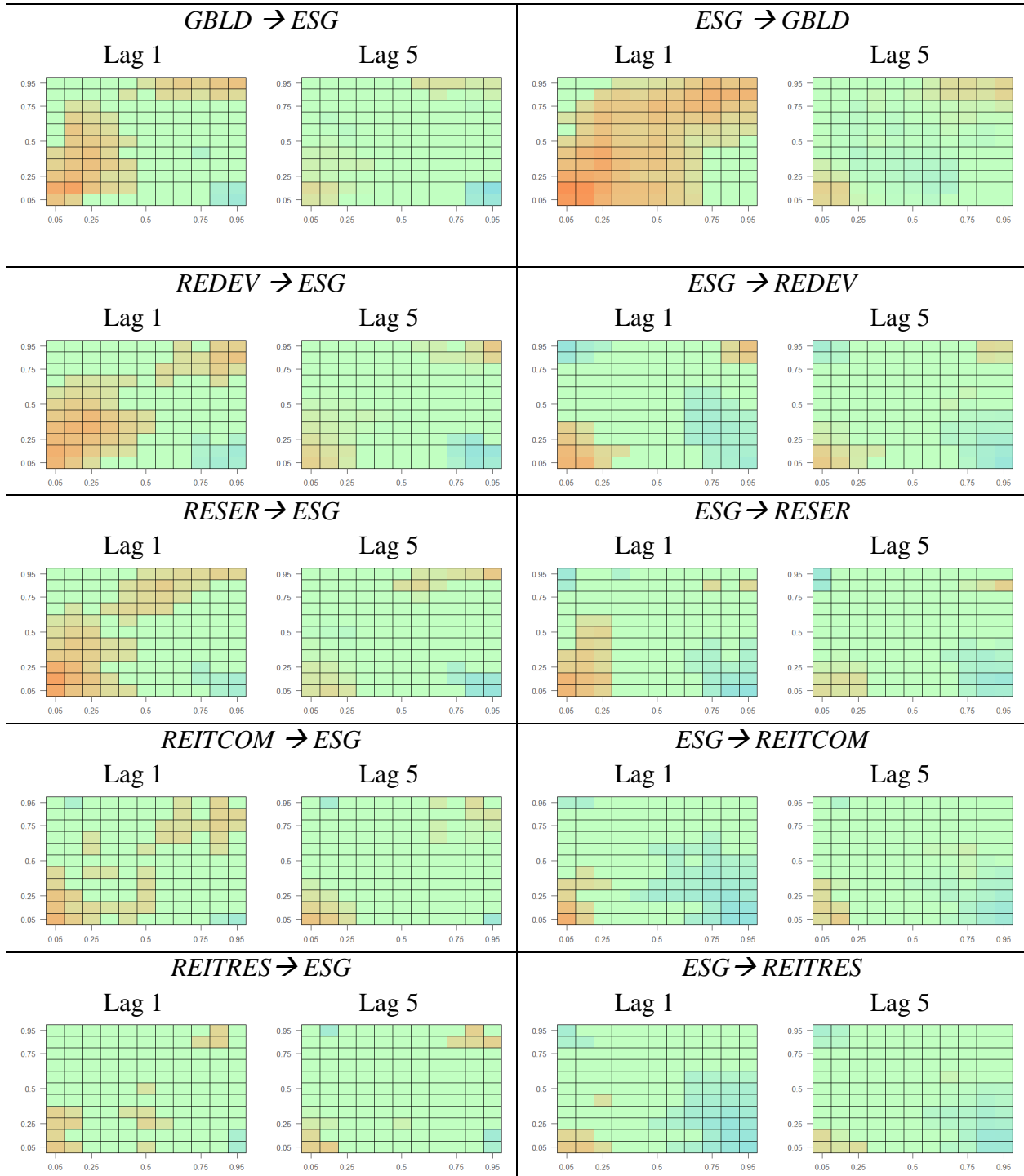
Figure 3. CQC estimations between the GB and real estate indices

Notes: the vertical axis is the quantile of the variable on the right hand side of the arrow while the horizontal axis is the quantile of the left hand side variable. The arrow shows the direction of the correlation. The green colour is displayed for quantile-combinations where the Box-Ljung test statistics is not significant while the red and blue colours display significant positive and negative correlations, respectively.

When looking at the CQC between the real estate indices and the rest of the sustainable assets in **Figure 4-6**, one may realize a positive dependence concentrated in the lower left corner for almost all heatmaps in both directions (i.e. in both left and right side of the figures). Hence, the connection between the real estate and sustainable assets is bi-directional during turbulent times, meaning that both sectors are influencing and impacting each other. This is in accordance with the findings for

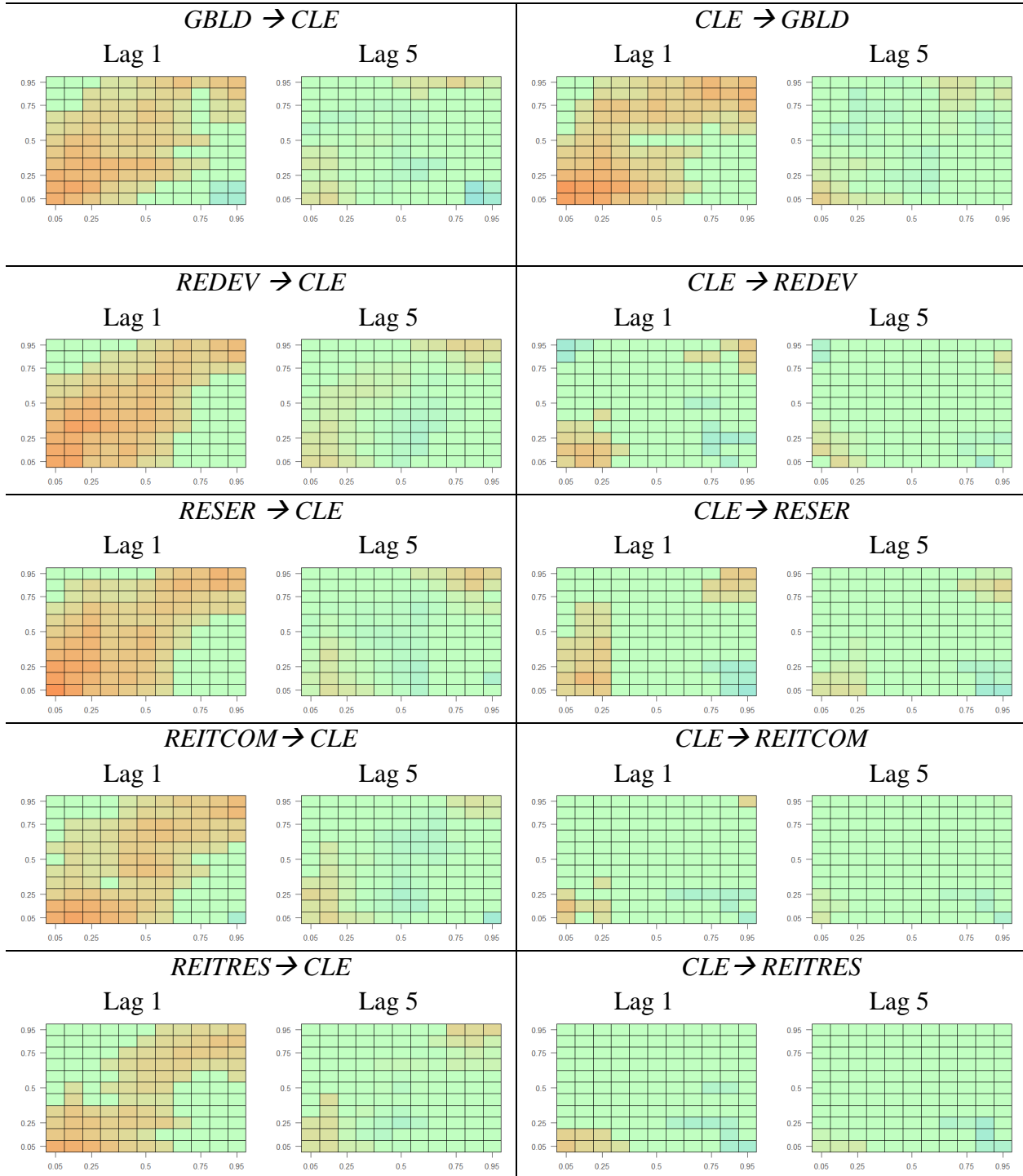
REITs, where has been found a tail-dependence with the stock market (e.g. Chang, 2018; M. Huang et al., 2016; Rong & Trück, 2014).

Figure 4. CQC estimations between the ESG and real estate indices



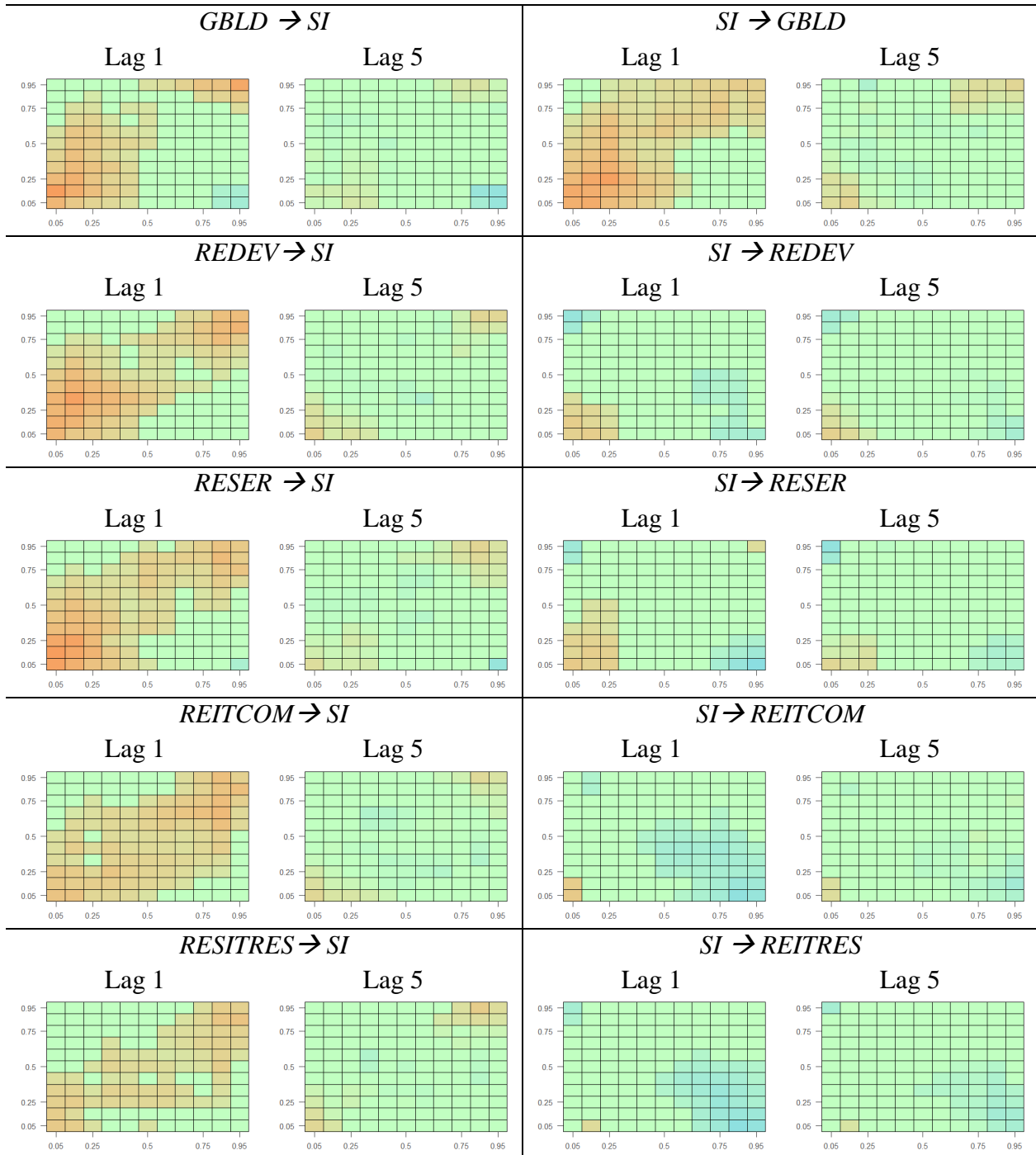
Notes: the vertical axis is the quantile of the variable on the right hand side of the arrow while the horizontal axis is the quantile of the left hand side variable. The arrow shows the direction of the correlation. The green colour is displayed for quantile-combinations where the Box-Ljung test statistics is not significant while the red and blue colours display significant positive and negative correlations, respectively.

In general, when looking at quantile combinations except for the lower left corner, the directionality is coming from the real estate to sustainable assets but not the other way around. Regarding the results of CLE (**Figure 5**) and SI (**Figure 6**) in the same direction, we see significant results in most of the quantiles. Thus, this indicates that the real estate sector is leading sustainable assets movements in most of quantile combinations.

Figure 5. CQC estimations between the CLE and real estate indices

Notes: the vertical axis is the quantile of the variable on the right hand side of the arrow while the horizontal axis is the quantile of the left hand side variable. The arrow shows the direction of the correlation. The green colour is displayed for quantile-combinations where the Box-Ljung test statistics is not significant while the red and blue colours display significant positive and negative correlations, respectively

In contrast to other real estate variables, the GBLD shows a bi-directional connection with the CLE, SI, and ESG, suggesting a close dependence. Considering that the GBLD comprises companies that promote sustainability, environmental, and governance practices, such a result is not surprising.

Figure 6. CQC estimations between the SI and real estate indices

Notes: the vertical axis is the quantile of the variable on the right hand side of the arrow while the horizontal axis is the quantile of the left hand side variable. The arrow shows the direction of the correlation. The green colour is displayed for quantile-combinations where the Box-Ljung test statistics is not significant while the red and blue colours display significant positive and negative correlations, respectively.

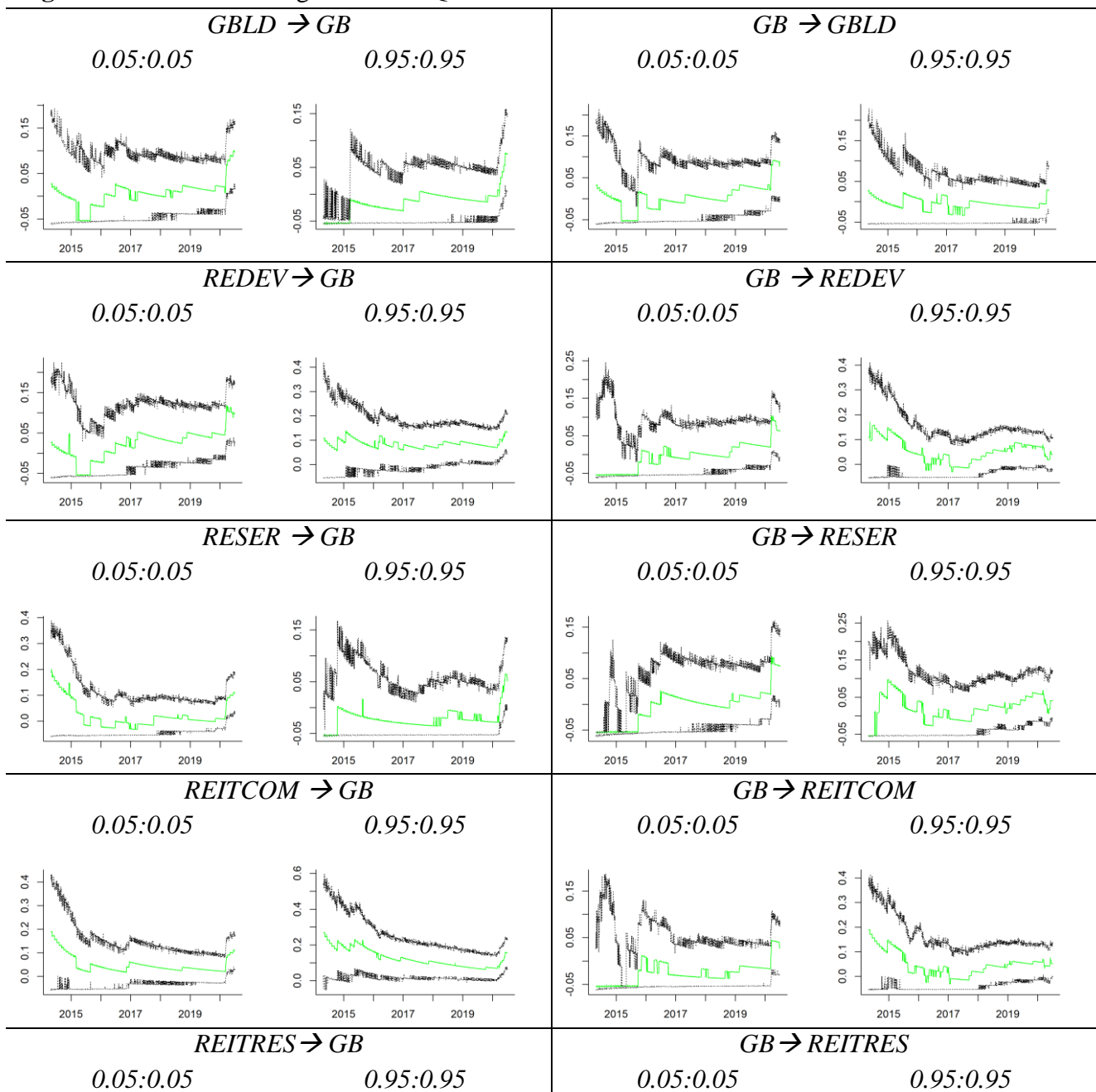
4.3. Recursive rolling window estimations

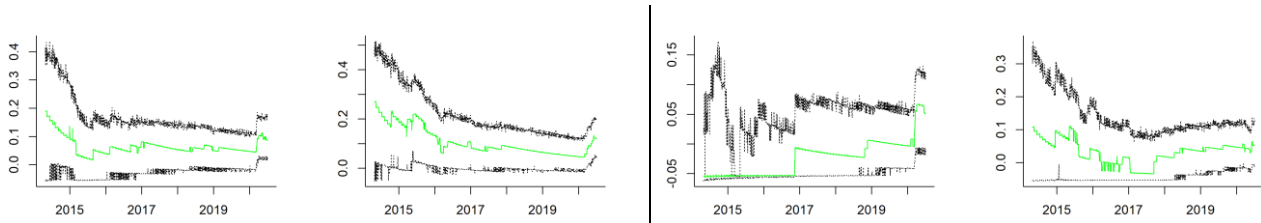
In **Figure 7** to **Figure 10**, we present the rolling window estimations when both real estate and sustainable assets are in their respective lower (0.05:0.05) and upper tails (0.95:0.95). Recursive rolling window works by estimating the CQC correlation for the initial window - which is set to 250

days - that advances daily and it is then estimated again for the new window. This is to observe the time-varying nature of the CQC correlation by capturing shifts and structural breaks in the correlation series through the sample period. The correlation is captured by the green lines while the black lines refer to the 95% confidence interval.

In general, the most notable event occurs at the end of the sample period, during the outbreak of the Covid-19 pandemic, in the year of 2020. The correlations when the returns are both in their lower (0.05:0.05) and higher quantiles (0.95:0.95) increase substantially during almost all return combinations. The increased correlation levels in the lower quantiles may be explained by financial market crashes observed in the early 2020, affecting most markets.

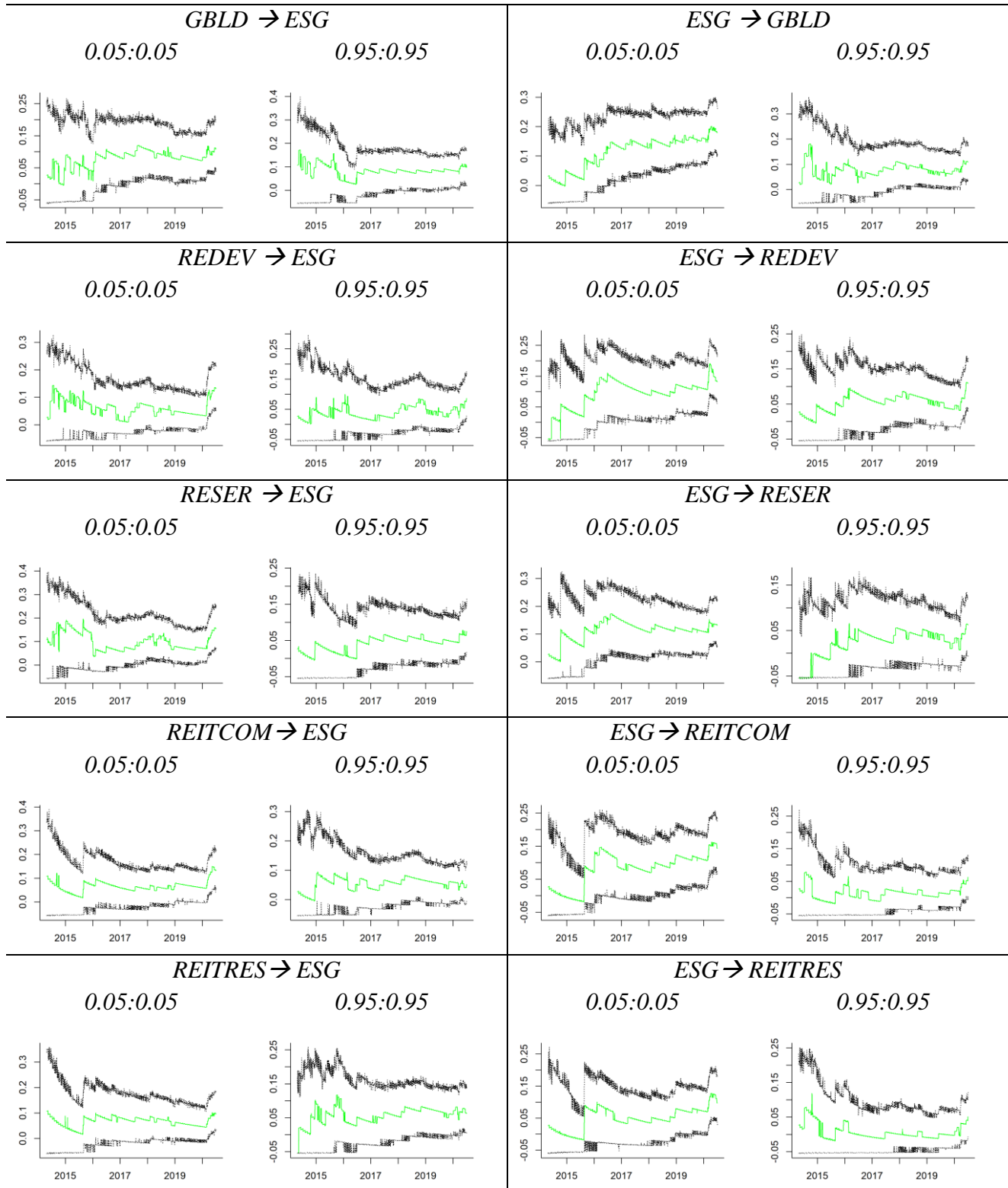
Figure 7. Recursive rolling-window CQC estimations between GB and real estate indices





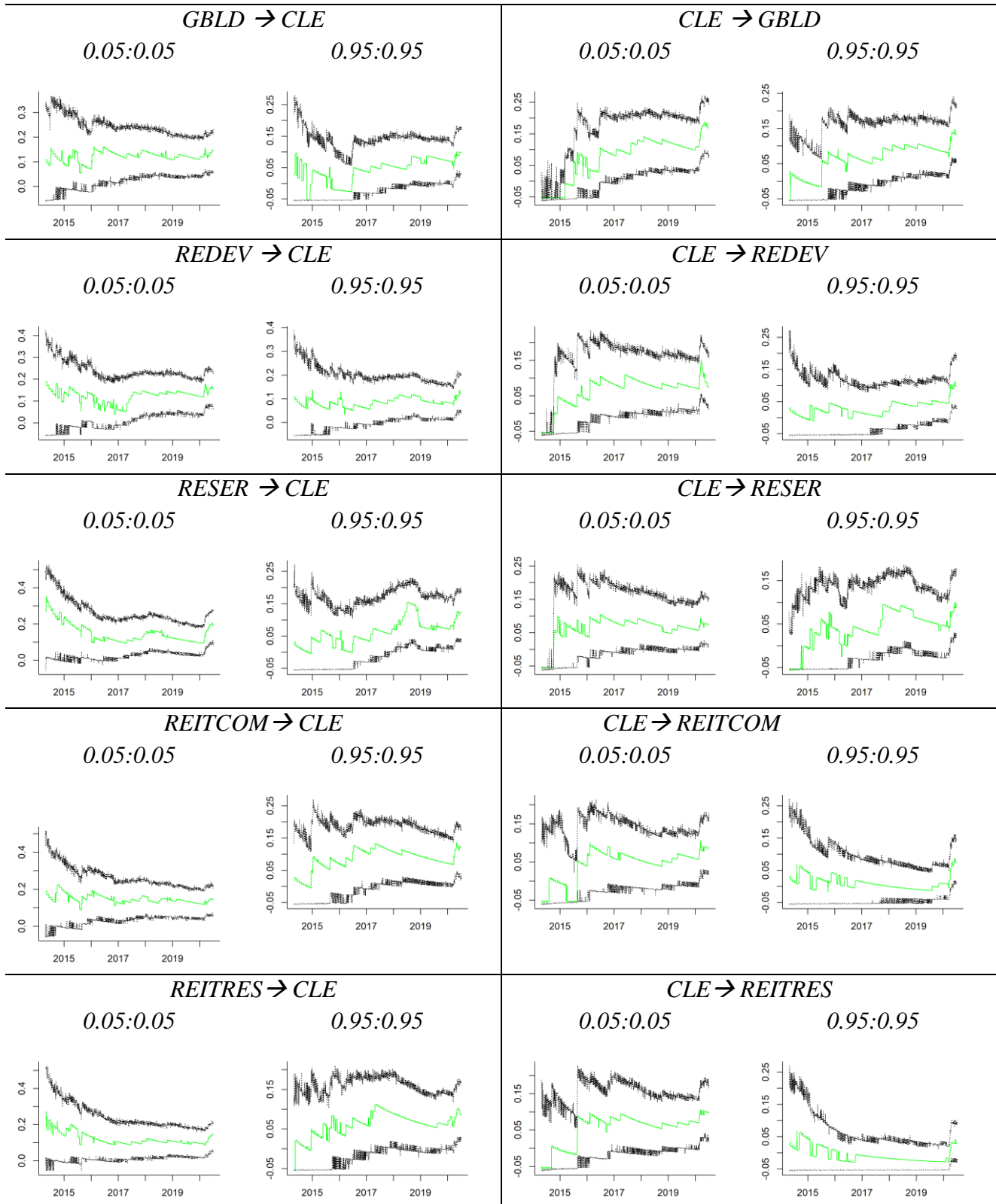
Notes: this figure shows the CQC correlation for the recursive subsamples when both returns series are in the left (0.05:0.05) and right tail (0.95:0.95) of the return distributions. The arrow reflects the direction of the correlation. The initial window length is 250 days, which then advances with one day at the time. The green lines are the correlation while the black lines represent the 95% confidence intervals calculated by a bootstrap method.

One interesting finding of the recursive rolling window estimations may be found in the results from the real estate sector to the GB shown in **Figure 7**, when both returns series are in their lower quantiles (0.05:0.05). Before the Covid-19 crisis, for most combinations the lower confidence band was below zero and should not have indicated any significant tail dependence in the CQC. However, when the recursive window also spans the time of the turbulence involving the Covid-19 pandemic, then the confidence interval is greater than zero, indicating unidirectional dependence from the real estate sector to GB.

Figure 8. Recursive rolling-window CQC estimations between ESG and real estate indices

Notes: this figure shows the CQC correlation for the recursive subsamples when both returns series are in the left (0.05:0.05) and right tail (0.95:0.95) of the return distributions. The arrow reflects the direction of the correlation. The initial window length is 250 days, which then advances with one day at the time. The green lines are the correlation while the black lines represent the 95% confidence intervals calculated by a bootstrap method.

Due to the fact that all returns decrease concomitantly, the correlation is then positive. For the increased correlations in the higher quantiles (0.95:0.95), this may be explained by the reversal of the markets a couple of weeks after the beginning of the Covid-19 crisis.

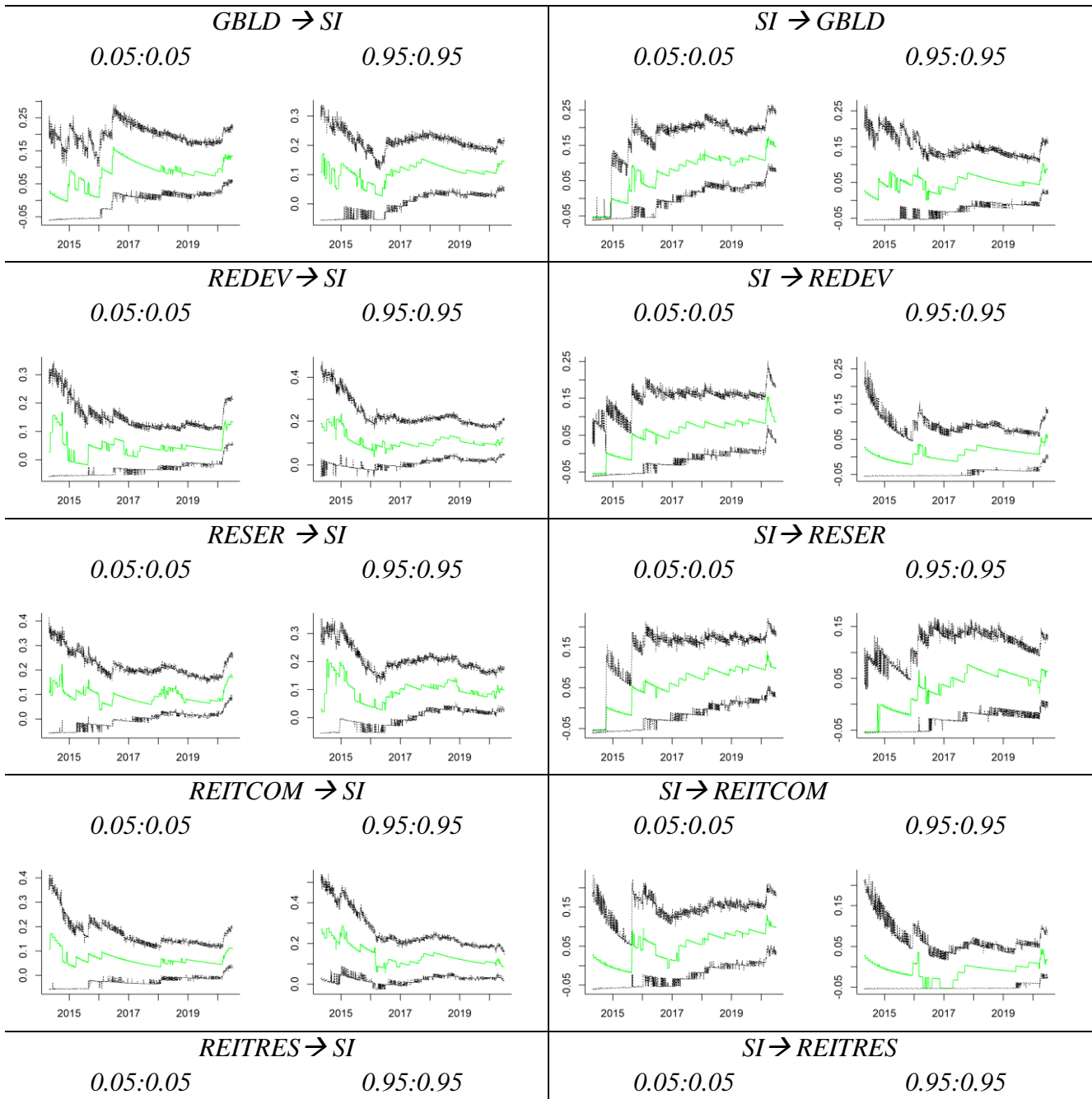
Figure 9. Recursive rolling-window CQC estimations between CLE and real estate indices

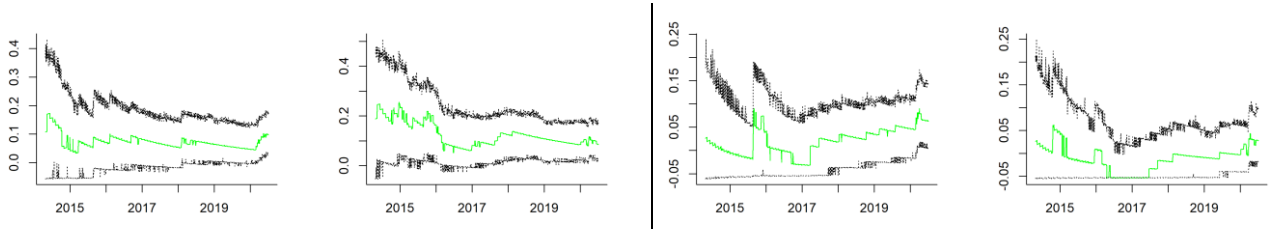
Notes: this figure shows the CQC correlation for the recursive subsamples when both returns series are in the left (0.05:0.05) and right tail (0.95:0.95) of the return distributions. The arrow reflects the direction of the correlation. The initial window length is 250 days, which then advances with one day at the time. The green lines are the correlation while the black lines represent the 95% confidence intervals calculated by a bootstrap method.

Hence, this could explain the significant tail-dependence found for GB and the real estate sector in the CQC heatmap (**Figure 3**), as such an estimation is based on the full sample window. The tail-

dependence between real estate and GB in the left tail is mostly connected to the crisis caused by the Covid-19 pandemic. If we instead analyse the dependence between GB and real estate when they are in their right tail (0.95:0.95), we then observe that the confidence interval is above zero, even before the beginning of the Covid-19 crisis for some of the indices (REDEV, REITCOM, and REITRES). Therefore, the returns of GB seem to be more influenced by the real estate sector during boom rather than bust periods.

Figure 10. Recursive rolling-window CQC estimations between SI and real estate indices





Notes: this figure shows the CQC correlation for the recursive subsamples when both returns series are in the left (0.05:0.05) and right tail (0.95:0.95) of the return distributions. The arrow reflects the direction of the correlation. The initial window length is 250 days, which then advances with one day at the time. The green lines are the correlation while the black lines represent the 95% confidence intervals calculated by a bootstrap method.

In general, the correlations in both lower and higher quantiles in most combinations vary over time. Our empirical results also indicate that the relationship between real estate sector and the sustainable portion of the stock market is also time-varying in the tails. Another finding is that, when the returns are in the lower quantiles (i.e. direction from sustainable assets to the real estate market), the correlation then increases over time. Thus, the influence of the sustainable assets over returns of the real estate market intensifies during bust periods.

4.4. Quantile coherency (QC) results

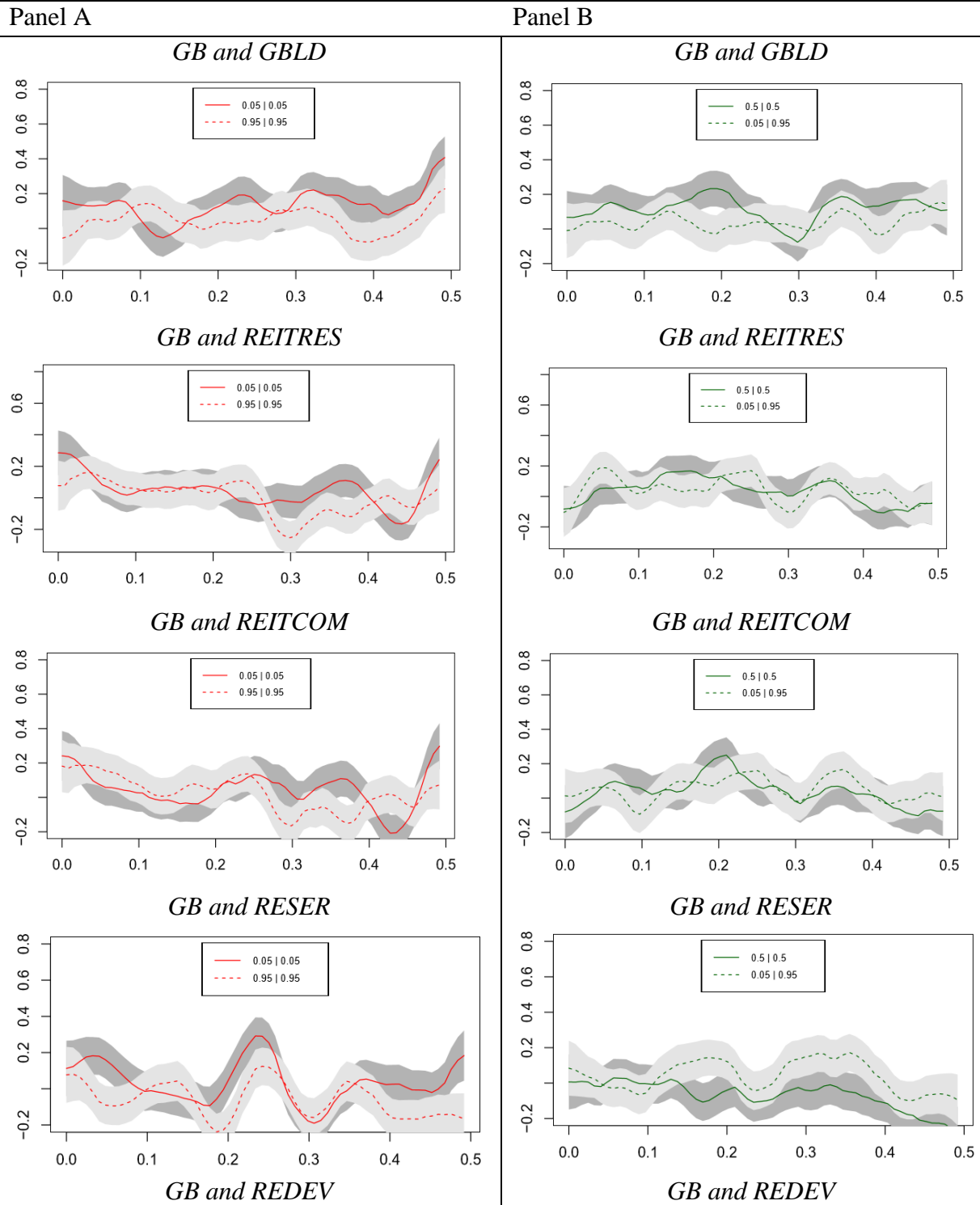
The results of the QC estimations are depicted from **Figure 11** to **Figure 14**. Each figure is divided into two panels, A and B. In Panel A, we present the coherency when both of the series are in the same tail of their return distribution - i.e. left tail (the 0.05 quantile of both series, hereafter denoted as 0.05:0.05) and right tail (the 0.95 quantile of both series, hereafter denoted as 0.95:0.95). In Panel B, we present the results when both series are in the median of their distributions (0.5:0.5) and in opposite tails (0.05:0.95). If a high value of QC is found when both series are in their left tails, then this indicates that the series are dependent when the returns are very low, whereas a high value in the right tails indicates dependence when returns are very high.

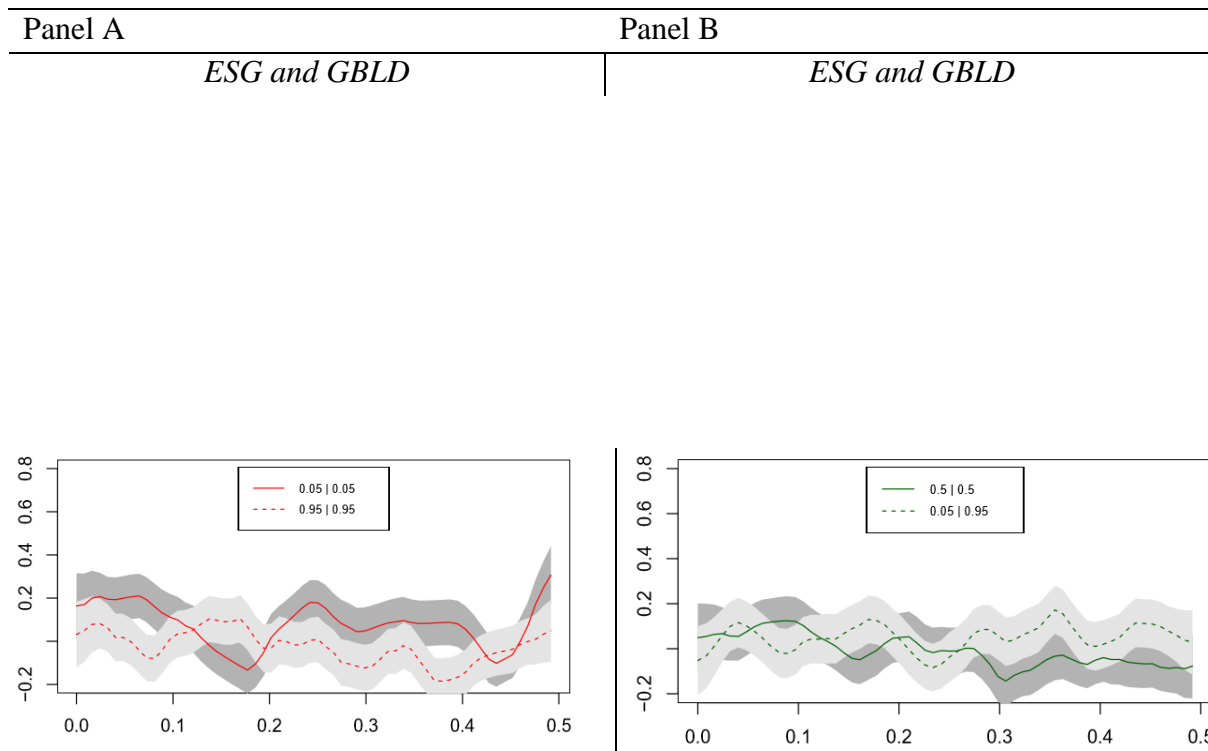
We present the QC on the y-axis and the frequency on the x-axis. Given our daily dataset, the frequency represents the number of daily cycles. A daily cycle of 0.5 represents a two-day period, an 0.2 cycle refers to a weekly frequency, and 0.004 consists of a yearly frequency. Hence, the x-axis spans from long-term periods on the left part of the axis to shorter-term periods on the respective right part.

In Panel A of **Figure 11**, we observe the greatest quantile coherency when both returns series are in their lowest quantile (0.05:0.05). Thus, the return of the real estate sector shows greater dependence with GB during extreme negative turmoil in comparison with when the returns are very high, which is commonly found in financial time series. In general, the dependence is stronger for short-term periods compared to middle or long-term ones. In this context, the frequencies might be interpreted

as different investment strategies. Hence, this results suggest a higher connection between the sectors for investors involved in shorter term strategies compared to longer term.

Figure 11. QC between GB and real estate indices



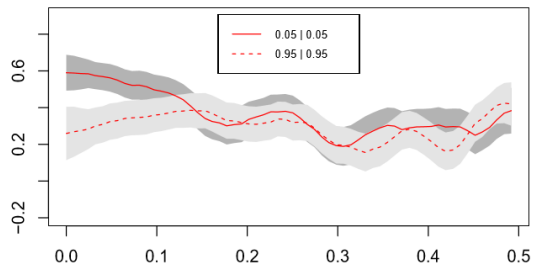
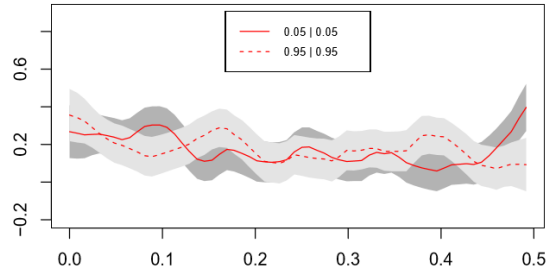
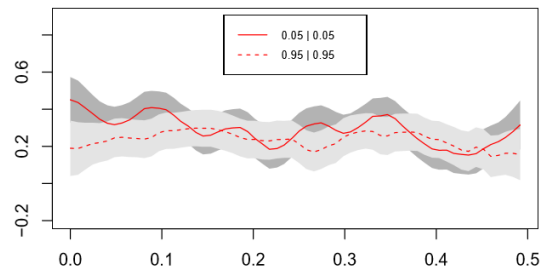
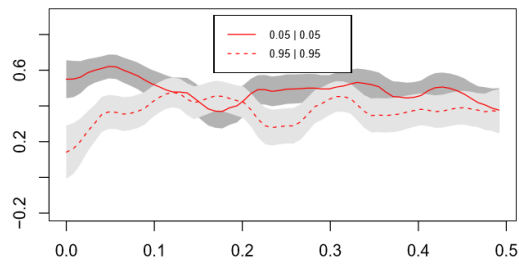
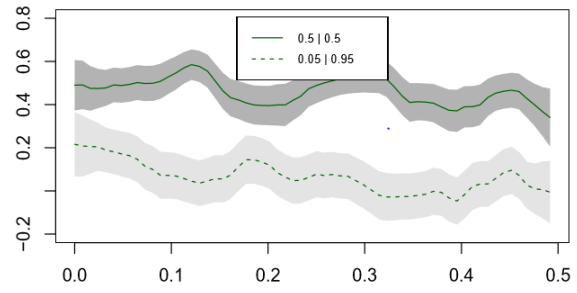
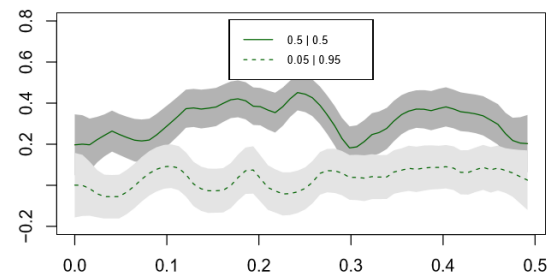
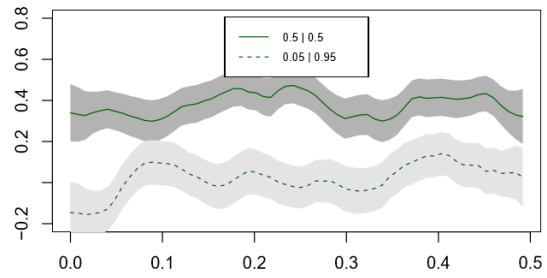
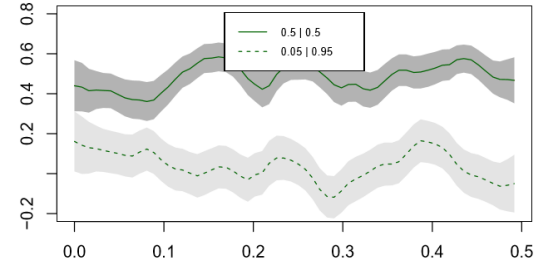


Notes: the vertical axis represents the strength of the coherence and the horizontal axis refers to the frequency. Panel A (left hand side) shows the coherence of the tails while Panel B (right hand side) shows the coherence in the median and when the return series are in opposite tails. In both panels, the light grey colour represents the 95% level confidence band for the dotted lines while the confidence band in dark grey relates to the filled lines.

For many other frequencies, both the low and high return cases, especially in medium-term periods, the QC is close to zero. However, the RESER shows high dependence with GB during medium-term periods. In the short run, the GBLD shows a greater QC with GB returns compared to other indices. Apart from that, there is no large differences in the strength of quantile coherency with GB returns for related to the real estate sector.

In comparison with Reboredo (2018), who that did not find any tail-dependence between GB and the stock market, our results indeed suggest tail-dependence when focusing on the real estate segment of the stock market. The QC in Panel B of **Figure 11** mostly fluctuates around zero for both median quantiles (0.5:0.5) and the quantiles in the opposite tails (0.05:0.95). Weak coherency is, however, found between the returns of GB with the median quantiles of REITCOM and GBLD in the medium-term periods.

However, in Panel A of **Figure 12**, we indeed observe high QC in the long-term when the returns are very low (0.05:0.05) for to the real estate sector. Compared to GB (**Figure 11**), the coherency is considerably larger across frequencies, both when the returns of the series are low and high.

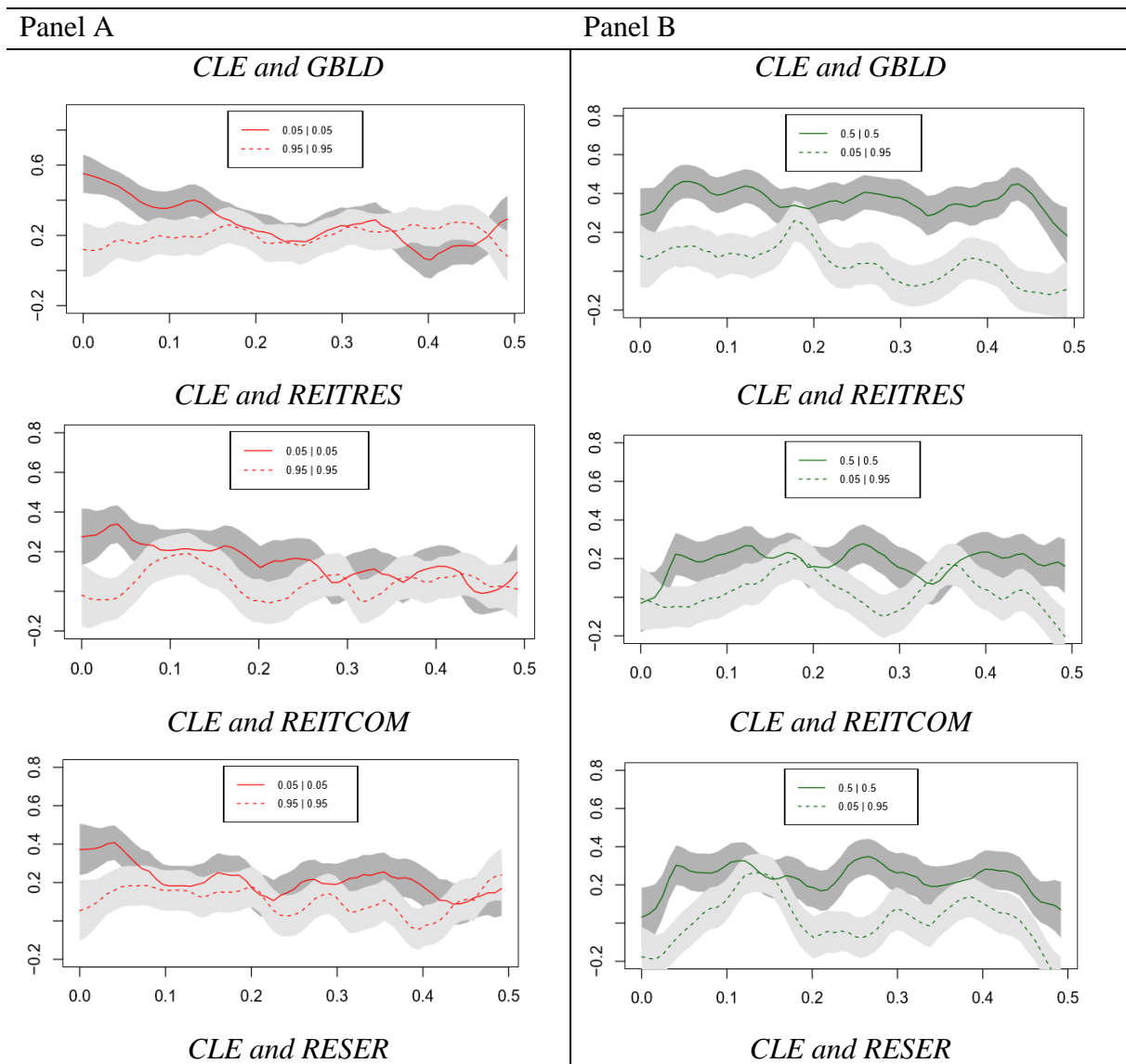
*ESG and REITRES**ESG and REITCOM**ESG and RESER**ESG and REDEV**ESG and REITRES**ESG and REITCOM**ESG and RESER**ESG and REDEV*

Notes: the vertical axis represents the strength of the coherence and the horizontal axis refers to the frequency. Panel A (left hand side) shows the coherence of the tails while Panel B (right hand side) shows the coherence in the median and when the return series are in opposite tails. In both panels, the light grey colour represents the 95% level confidence band for the dotted lines while the confidence band in dark grey relates to the filled lines.

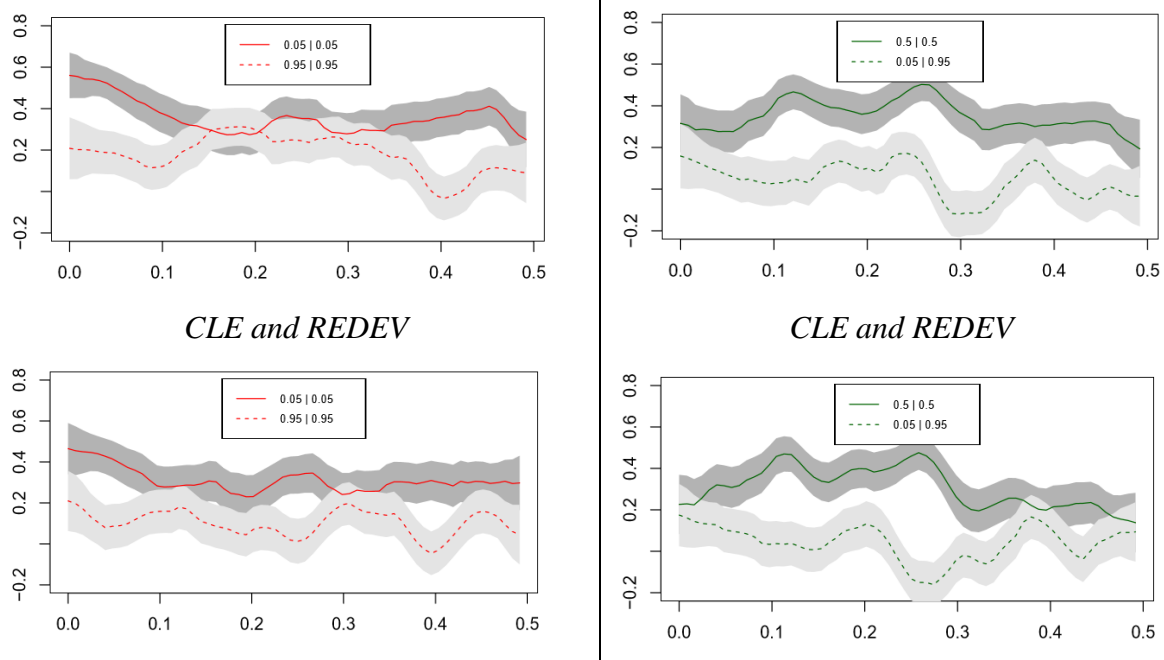
Compared to other real estate indices, REIT indices seem to be less dependent with the ESG across most frequencies. In Panel B of **Figure 12**, we observe high QC when the returns are in their median quantiles, while weak to no dependence when they are in opposite tails. The coherency is, however, weaker for REITRES.

The QC of real estate indices and CLE, depicted in panel A of **Figure 13**, shows that coherency is greater compared to the results of GB (**Figure 11**) but lower than for the real estate sector with ESG (**Figure 12**). While Ivarsson Lundgren et al. (2018) find high dependence for clean energy with the overall stock market, we find high coherency for the real estate part of the market when the returns are very low at higher-term frequency. In short-term frequencies, the coherency is lower for REIT

Figure 13. QC between CLE and real estate indices



indices.



Notes: the vertical axis represents the strength of the coherence and the horizontal axis refers to the frequency. Panel A (left hand side) shows the coherence of the tails while Panel B (right hand side) shows the coherence in the median and when the return series are in opposite tails. In both panels, the light grey colour represents the 95% level confidence band for the dotted lines while the confidence band in dark grey relates to the filled lines.

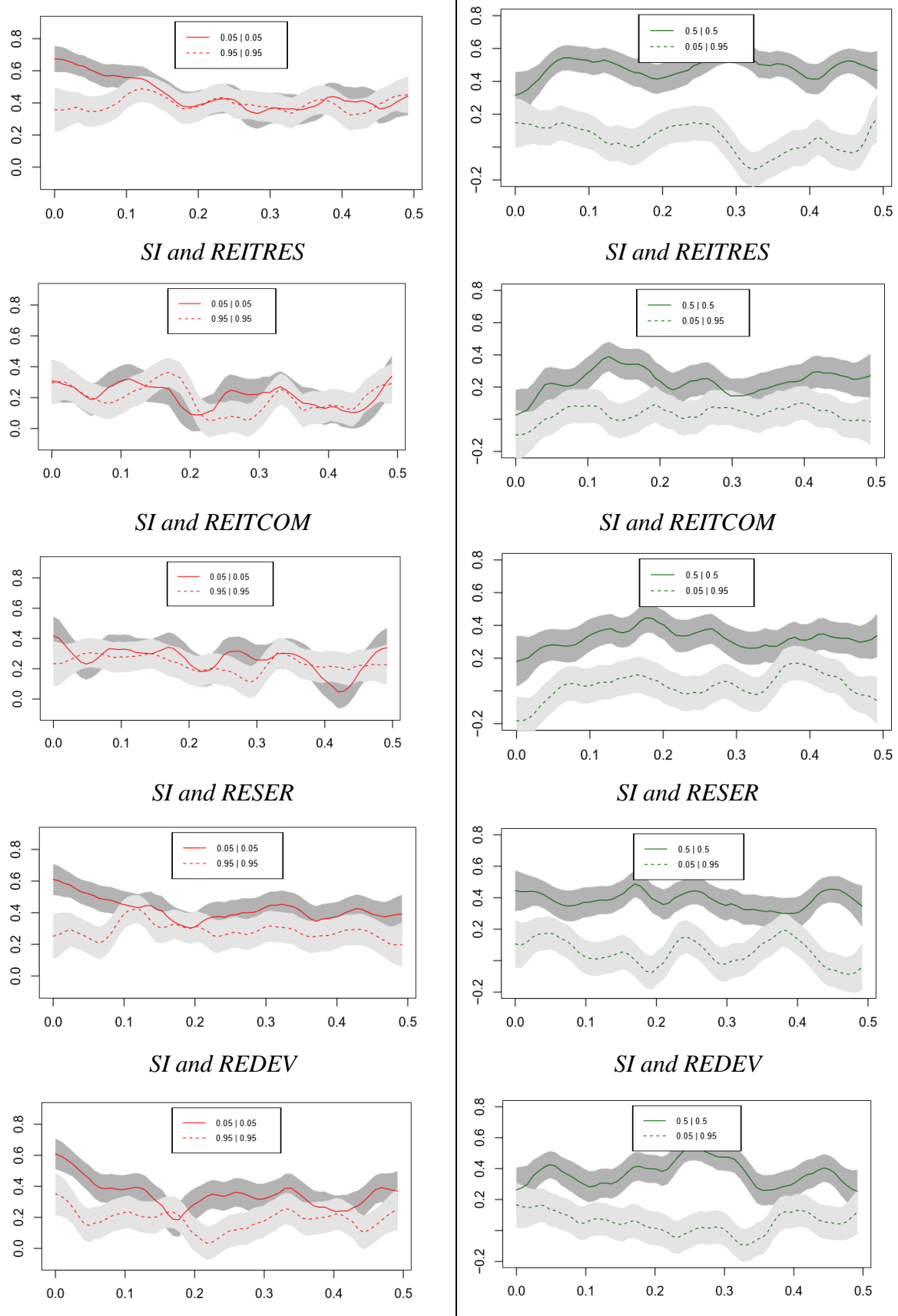
Interestingly, there is no substantial differences in the QC of the CLE with GBLD compared to the remaining real estate indices, despite of the fact that green building and clean energy activities may arguably be intrinsically connected to each other. Furthermore, in general, when the returns are very high (0.95:0.95), the coherence is weak in the longer-term frequencies. In the short-term, the effect is neither strong nor considerably deviating from the results of the left tail. Therefore, the results indicate that CLE crashes rather than booms together with the real estate sector at long-term frequencies.

The QC of real estate indices and SI, depicted in **Figure 14**, shows that the dependence in the left tails is, overall, very high in long-term frequencies while weaker for REIT indices. In panel B of **Figure 14**, we observe some dependence in the median for medium-term frequencies but low to no dependence when the returns are in opposite tails. The QC in the short-term frequencies is weaker

Figure 14. QC between SI and real estate indices

Panel A	Panel B
<i>SI and GBLD</i>	<i>SI and GBLD</i>

but follow the same pattern.



Notes: the vertical axis represents the strength of the coherence and the horizontal axis refers to the frequency. Panel A (left hand side) shows the coherence of the tails while Panel B (right hand side) shows the coherence in the median and when the return series are in opposite tails. In both panels, the light grey colour represents the 95% level confidence band for the dotted lines while the confidence band in dark grey relates to the filled lines.

In comparison with the results of the CLE, we observe the highest dependence for the GBLD. The coherence in the right tail (0.95:0.95) is, in general, weak for most real estate indices. This suggests that the dependence is commonly more pronounced during turbulent times, especially in longer-term frequencies. Interestingly, the dependence is also stronger when the returns are in the median quantiles (Panel B of **Figure 14**) compared to boom periods (0.95:0.95), considering most frequencies.

5. Conclusion

Despite of known linkages between real estate and clean energy assets, studies exploring co-movements or dependence between them are still scarce. Such an information could be relevant in terms of risk management, investment diversification, and public policy purposes. In the present study we investigate the dependence between the real estate sector and sustainable assets. In order to capture the non-linear dependence over both time and frequency, we then apply the recently proposed CQC and QC methods on real estate and sustainable assets time series data.

Our empirical results indicate unidirectional dependence from the real estate sector to most sustainable assets, in both tails and during normal market conditions but bi-directional dependence in lower quantiles - i.e. during turbulent times. This indicates that the real estate sector is more influential in predicting returns of sustainable assets than the opposite. However, such a dependence structure varies over time, both in terms of frequency and between subsectors of the real estate sector.

We also observe that the influence of sustainable assets over the real estate market during periods of boom has increased over time. Another interesting finding is that when the Covid-19 period is included in our sample period, we find that GB is tail-dependent of sustainable assets, both during boom and bust periods. If we exclude such an unusual period, then we find greater dependency with the real estate sector during periods of boom. Therefore, the dependence in the left tail might be explained by a widespread downturn, leading to a positive correlation between asset classes.

Compared to other sustainable assets, we also find that the return of GB is less dependent on the returns of the real estate sector. For companies involved in green building (GBLD), we find a bi-directional dependence with most sustainable assets in a considerable part of our CQC heatmaps. This suggests that green building may be more connected to the real estate market during most market conditions compared to the rest of the real estate sector, as both sectors are mutually influencing each other.

From a portfolio perspective, our results may be relevant to investors with real estate and/or sustainable assets in their holdings. The tail-dependence found in lower quantiles means that ESG

or CLE assets do not improve diversification for real estate investors, or vice versa, during periods of turbulence. However, given the variation across frequencies, the diversification opportunities is conditional on the investment strategy.

References

- Ahmad, W. (2017). On the dynamic dependence and investment performance of crude oil and clean energy stocks. *Research in International Business and Finance*, 42, 376-389.
- Baruník, J., & Kley, T. (2019). Quantile coherency: A general measure for dependence between cyclical economic variables. *The Econometrics Journal*, 22(2), 131-152.
- Baumöhl, E., & Shahzad, S. J. H. (2019). Quantile coherency networks of international stock markets. *Finance Research Letters*, 31, 119-129.
- Bera, A. K., & Jarque, C. M. (1981). Efficient tests for normality, homoscedasticity and serial independence of regression residuals: Monte Carlo evidence. *Economics Letters*, 7(4), 313-318.
- Chang, K.-L. (2018). Asymmetric downside and upside co-movements between stock and REIT markets. *Applied Economics Letters*, 25(2), 78-82.
- Cho, D., & Han, H. (2020). The tail behavior of safe haven currencies: A cross-quantilogram analysis. *Journal of International Financial Markets, Institutions and Money*, 101257.
- Darrat, A. F., & Glascock, J. L. (1993). On the real estate market efficiency. *The Journal of Real Estate Finance and Economics*, 7, 55-72.
- 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.
- Ding, H., Chong, T. T.-I., & Park, S. Y. (2014). Nonlinear dependence between stock and real estate markets in China. *Economics Letters*, 124(3), 526-529.
- Fuerst, F., Haddad, M. F. C., & Adan, H. (2020). Is there an economic case for energy-efficient dwellings in the UK private rental market? *Journal of Cleaner Production*, 245, 118642.
- Han, H., Linton, O., Oka, T., & Whang, Y.-J. (2016). The cross-quantilogram: Measuring quantile dependence and testing directional predictability between time series. *Journal of Econometrics*, 193(1), 251-270.
- Heaney, R., & Srikanthakumar, S. (2012). Time-varying correlation between stock market returns and real estate returns. *Journal of Empirical Finance*, 19(4), 583-594.
- Henriques, I., & Sadorsky, P. (2008). Oil prices and the stock prices of alternative energy companies. *Energy Economics*, 30(3), 998-1010.
- Hiang Liow, K. (2012). Co- movements and correlations across Asian securitized real estate and stock markets. *Real Estate Economics*, 40(1), 97-129.
- Huang, A., Cheng, C.-M., Hu, W.-C., & Chen, C.-C. (2011). Relationship between crude oil prices and stock prices of alternative energy companies with recent evidence. *Economics Bulletin*, 31(3), 2434-2443.
- Huang, M., Wu, C.-C., Liu, S.-M., & Wu, C.-C. (2016). Facts or fates of investors' losses during crises? Evidence from REIT-stock volatility and tail dependence structures. *International Review of Economics & Finance*, 42, 54-71.
- IEA. (2019a). *The Critical Role of Buildings*. Retrieved from Paris: <https://www.iea.org/reports/the-critical-role-of-buildings>
- IEA. (2019b). *Renewables*. Retrieved from Paris: <https://www.iea.org/reports/renewables-2019>
- Jiang, H., Su, J., Todorova, N., & Roca, E. (2016). Spillovers and Directional Predictability with a Cross-Quantilogram Analysis: The Case of U.S. and Chinese Agricultural Futures. *Journal of Futures Markets*, 36(12), 1231-1255.

- Kumar, S., Managi, S., & Matsuda, A. (2012). Stock prices of clean energy firms, oil and carbon markets: A vector autoregressive analysis. *Energy Economics*, 34(1), 215-226.
- Ljung, G. M., & Box, G. E. (1978). On a measure of lack of fit in time series models. *Biometrika*, 65(2), 297-303.
- Ling, D. C., & Naranjo, A. (1997). Economic risk factors and commercial real estate returns. *Journal of Real Estate Finance and Economics*, 14, 283-307.
- Ling, D. C., & Naranjo, A. (1999). The integration of commercial real estate markets and stock markets. *Real Estate Economics*, 27, 483-515.
- Lundgren, A. I., Milicevic, A., Uddin, G. S., & Kang, S. H. (2018). Connectedness network and dependence structure mechanism in green investments. *Energy Economics*, 72, 145-153.
- Managi, S., & Okimoto, T. (2013). Does the price of oil interact with clean energy prices in the stock market? *Japan and the World Economy*, 27, 1-9.
- Nazlioglu, S., Gormus, N. A., & Soytas, U. (2016). Oil prices and real estate investment trusts (REITs): Gradual-shift causality and volatility transmission analysis. *Energy Economics*, 60, 168-175.
- Nazlioglu, S., Gupta, R., Gormus, A., & Soytas, U. (2020). Price and volatility linkages between international REITs and oil markets. *Energy Economics*, 104779.
- Phillips, P. C., & Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika*, 75(2), 335-346.
- Reboredo, J. C. (2015). Is there dependence and systemic risk between oil and renewable energy stock prices? *Energy Economics*, 48, 32-45.
- Reboredo, J. C. (2018). Green bond and financial markets: Co-movement, diversification and price spillover effects. *Energy Economics*, 74, 38-50.
- Reboredo, J. C., & Ugolini, A. (2020). Price connectedness between green bond and financial markets. *Economic Modelling*, 88, 25-38.
- Rong, N., & Trück, S. (2014). Modelling the Dependence Structure between Australian Equity and Real Estate Markets—a Copula Approach. *Australasian Accounting, Business and Finance Journal*, 8(5), 93-113.
- Sadorsky, P. (2012). Correlations and volatility spillovers between oil prices and the stock prices of clean energy and technology companies. *Energy Economics*, 34(1), 248-255.
- Tang, D. Y., & Zhang, Y. (2020). Do shareholders benefit from green bonds? *Journal of Corporate Finance*, 61, 101427.
- Tiwari, A. K., Trabelsi, N., Alqahtani, F., & Bachmeier, L. (2019). Modelling systemic risk and dependence structure between the prices of crude oil and exchange rates in BRICS economies: Evidence using quantile coherency and NGCoVaR approaches. *Energy Economics*, 81, 1011-1028.
- Uddin, G. S., Rahman, M. L., Hedström, A., & Ahmed, A. (2019). Cross-quantilogram-based correlation and dependence between renewable energy stock and other asset classes. *Energy Economics*, 80, 743-759.
- WEF. (2016). *Environmental sustainability principles for the real estate industry*. Retrieved from