10. Nonlinear Dependencies between Green Bonds and General Financial Market Indices

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Abstract

In the context of increasing awareness regarding the climate change negative effects, green bonds have gained increasing attention in the financial markets. The market dynamics of the green bond index represents a relevant proxy for the importance the general public assigns to the shift towards green economy. This paper investigates the dependence structure of green bonds and indices that represent the standard financial markets. We use a cross-quantilogram methodology to analyse the non-linear structure of these interlinkages and data covering corporate bond indices, world market index and emerging markets index for daily values spanning the time interval April 2011 to October 2022. Allowing for investigation of non-linear connections the employment of this methodology yielded significant results at various quantile levels for dependence stretching up to two lags.

Keywords: green bonds, financial market, climate change

JEL Classification: G17, Q50, C58

1. Introduction

Different economic sectors are affected by environmental issues, encouraging actions to temper and adapt to diverse consequences. The climate change represents a change in the average weather conditions and is reflected in disastrous consequences of extreme events. The United Nations experts have drawn attention in the Intergovernmental Panel on Climate Change Report (IPCC, 2022) that a global warming exceeding 1.5 C will affect Europe through extreme rainfall and flooding, Middle East and Australia through excessive heat,

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Africa and Western US through drought, islands through sea level rise. The spread, amplitude and multiplicity of effects are arguments for joint global action. The Paris Agreement represents a first worldwide agreement signed by 193 countries and the European Union in December 2015 in a joint effort to limit the temperature rise.

To address the climate change problems, an important role is held by green financing, which can participate both in mitigating and in adapting to the effects of climate change and attracted the attention of practitioners and academics in similar manner. Green finance developed as an alternate financial investment that has demonstrated noticeable potential over the last decade. Given the magnitude of the phenomenon, the need for financing is extremely high, requiring both public and private involvement, national and international investments. The most well-known financing instruments in this field are green bonds, debt swaps, guarantees, concessional loans, grants and donations.

As mentioned by the Organization for Economic Cooperation and Development (OECD) representatives, financial markets, in general, and green bonds, in particular, can help the efforts to fight against climate change (OECD, 2015). At that time, before the twenty-first session of the Conference of the Parties (COP 21), the United Nations Framework Convention on Climate Change (UNFCCC) recognized the green bonds as climate action.

Being a fixed-income security type, the green bonds are designed to fund different projects with beneficial effects for the environment, including mitigation and adaptation activities, biodiversity and resource preservation or actions that prevent pollution problems. More specifically, they may finance projects in areas like renewable and efficient energy, clean transportation, water management, ecological technology or green buildings. On the other side, they are emoted to fulfil investors options for sustainable finance.

To be declared as a green bond, these financial instruments must receive a certificate from a third party, namely the Climate Bond Standard Board.

The leading countries that issued green bonds are located on different continents: United States (America), Germany and France (Europe), China (Asia). From institutional perspective, Fannie Mae and World Bank are considered top issuers. The World Bank initiative regarding climate change launched in 2008 played a significant part in the development of the green bonds market, that increased from 104 billion USD in 2015 to 1 trillion USD in 2020 (Climate Bond Initiative, 2022).

The increasing importance of green bonds make them a promising financial instrument, which motivates our intention to research the links between these instruments and the financial market, represented by traditional indicators.

In order to investigate the non-linear structure of the relationship between green bonds and indices that represent the standard financial markets we use a cross-quantilogram methodology. The data covers corporate bond indices, world market index and emerging markets index for daily values spanning the time interval April 2011 to October 2022.

The article is structured as follows. The literature review is summarized in Section 2. Section 3 describes the data used and the applied methodology. Section 4 presents the empirical result, while Section 5 concludes.

2. Literature Review

Climate change issues affect economies and societies, including macroeconomic variables (Kahn *et al.,* 2021; Kadanali and Yalcinkaya, 2020), income inequality (Albu *et al.,* 2020), health services (Raymakers *et al*., 2022), etc.

As Monasterelo and Raberto (2018) have shown, green bonds are considered as win-win for short term periods, while green fiscal policies may attract negative response from the economy as they imply a greater prompt distributive consequence.

As a consequence of increasing private and public interest for green bond markets, a growing body of research arise in this area.

One of the analysed issues is the existence of a premium for green bonds category. For the case of US, Baker *et al.* (2018) documented a premium for municipal green bonds when considering other bonds with similar features; this premium is even larger for green bonds that are certified by eastern parts. For other category of bonds, namely with institutional issuers, Bachelet *et al*. (2019) concluded that the green ones are characterized by higher liquidity.

This category can be considered both by investors pursuing financial objectives and by those considering investments in sustainable projects; it is interesting to analyse how it is placed in relation to other assets on the classic financial markets.

Applying a multivariate GARCH for the period 2010-2015, Pham (2016) has shown that green bond indices from S&P exhibit a higher volatility clustering than the general market. Employing a VAR model for the period 2014-2019, Roberedo and Ugolini (2020) demonstrated that the green bonds are linked to other fixed income assets (global treasury bond) and also to the USD currency markets, standing out as a receiver and less as a transmitter. A weak connection is observed as regards the high-yield corporate bonds, stock markets and energy related markets. Nguyen *et al*. (2021) used a Wavelet approach to analyse the co-movement between green bonds and other financial classes for the period 2008-2019. They documented a strong correlation during the global crisis period (2007-2009), confirming the general theory that correlations increase during periods of crisis, as pointed out by Lupu *et al.* (2019) and Anghel *et al*. (2020). Arif *et al*. (2021) confirm these relations for normal market conditions. Nguyen *et al*. (2021) draw attention to the role that green bonds may have in diversification, being little or negatively correlated with stocks and commodities. Combining VaR and copula models, Ejaz *et al.* (2022) suggested that Islamic bonds and oil markets are proper to address the hedging for green bonds; these are followed by conventional bonds and equities.

For nonlinear modelling of financial markets, sectoral dynamics default probabilities and MiDaS models were previously used (Albu *et al*., 2019; Uddin *et al.,* 2019) used the cross-quantilogram methodology to measure the dependence between stock of companies from renewable energy sector and other classes, such as general stock, exchange rates and oil and gold prices. While confirming the existence of a positive connection, they documented an asymmetric relationship for different quantiles and greater lags.

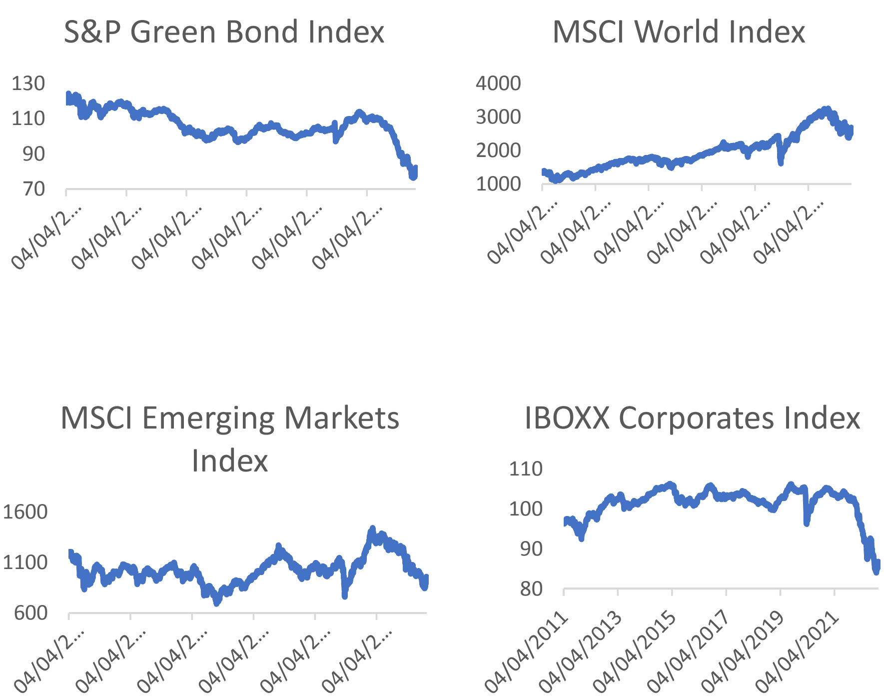
Pham (2021) applied a cross-quantile based methodology to investigate the frequency connection across green bonds and green equities, revealing the increase in co-movements in times of extreme market conditions, while in normal conditions the link is negligible. Using novel quantile-on-quantile and quantile coherency techniques, Jiang *et al*. (2022) emphasized the medium-term hedging role of green bonds for currency and stock markets.

However, the relationship between green bonds and financial markets remains not sufficiently addressed as the market evolves and general conditions change, including the overlapping crises that characterize the present moment. That is why we propose to analyse the green bonds market in connection with three other classic financial indices, for a period exceeding a decade.

3. Data and Methodology

Our data consists of daily closing values for stock market indices that reflect, on the one hand, the dynamics of green bonds and, on the other hand, the evolution of global equity and the global bond financial markets.

Figure 1. The Evolution of Selected Indices



The proxy we use for the green bonds market is the S&P Green Bond Index that tracks the bonds the proceeds of which have the main purpose to be used as financial support for projects that are “environmentally friendly”. The bonds included in the computation of this index are the ones considered “green” by the Climate Bonds Initiative due to the fact that they satisfy the criteria in “Eligibility Criteria” and “Sub-Index Rules” . The evolution of selected indices is presented in Figure 1.

The indices that we selected to represent the evolution of the standard financial markets are the MSCI World Index, the MSCI Emerging Markets Index and the IBOXX Corporates Index. Their closing values were provided by the Datastream database for the period April 2011 to October 2022. The descriptive statistics of log-returns for the used indices are presented in Table 1.

Table 1. Descriptive Statistics for the log-returns of All Indices

	S&P Green Bond	MSCI World	MSCI Emerging Markets	Corporate Bonds
Number Observations	3032	3032	3032	3032
Average	-0.0001	0.0002	-0.0001	0.0000
Standard Error of Average	0.0000	0.0000	0.0000	0.0000
Upper Confidence Interval	-0.0001	0.0002	-0.0001	0.0000
Lower Confidence Interval	-0.0001	0.0002	-0.0001	0.0000
Coefficient of Variation	-32.7497	43.0252	-139.4054	-51.7531
Range	0.0565	0.1885	0.1253	0.0334
Maximum	0.0256	0.0841	0.0558	0.0113
Minimum	-0.0309	-0.1044	-0.0694	-0.0221
Skewness	-0.3223	-0.9770	-0.4736	-1.0879
Kurtosis	8.8297	17.7410	7.4987	17.1648
Jarque Bera Statistic	4345.9079	27934.3654	2670.0783	25945.8899
Jarque Bera p-value	0.0000	0.0000	0.0000	0.0000
Mode	0.0000	0.0000	-0.0694	0.0000
Median	0.0000	0.0005	0.0004	0.0000

The cross-quantilogram methodology allows us to investigate the extent to which dependences of the green bonds index change across values of the other three stock market indices that span different percentiles to cover all their distribution. The application of this methodology follows the steps described in Han et al. (2016) and it does not necessitate moment conditions, which allows us to investigate variables with heavy-tails, such as the log-returns of our indices.

We denote by y_{st} to be a time series for which s is the counter for stock market log-return time series and t is time. We also consider $F_s()$ as the cumulative distribution function and $f_s()$ as the probability density function for these time series. In this framework we can set $q_{st}(\tau_s) = \inf\{x: F_s(x) \geq \tau_s\}$ as the quantile function for $\tau_s \in (0,1)$.

According to Han et al. (2016), the cross-quantilogram that measures the dependence between two situations $y_{1t} \leq q_{1t}(\tau_1)$ and $y_{2t-l} \leq q_{2t-l}(\tau_2)$, where l is the lag length, for a pair τ_1 and τ_2 is defined as:

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

where the quantile process is denoted by $\psi_z(u) = 1[u < 0] - u$. We can therefore conjecture that the cases where $\rho_\tau(l) = 0$ indicate situations where there is no cross connection or predictability established between the situations investigated here.

The same methodology allows for computation of statistical significance of these metrics ($\rho_\tau(l)$) by means of a Ljung-Box test in which the test statistic has the following expression:

$$Q_\tau(p) = T(T+2)\sum_{l=1}^{p} \hat{\rho}_\tau^2(l)/(T-l)$$

where $\hat{\rho}_\tau^2(l)$ denotes the value of the cross-quantilogram for a particular sample. The approximation of the distribution that characterizes the null hypothesis for this Ljung-Box statistic is estimated by use of a stationary bootstrap procedure.

4. Results

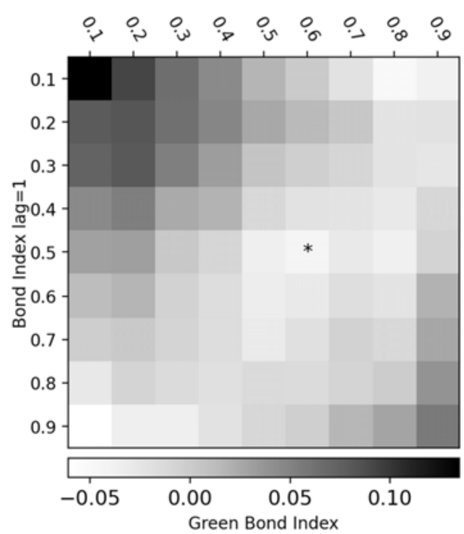
Our analysis consists in the exploration of the quantile dependence of log-returns for the Green Bonds index on lags of log-returns of the three indices that proxy the dynamics of the equity markets at a global scale and for the emerging markets separately and the evolution of the global corporate bond markets.

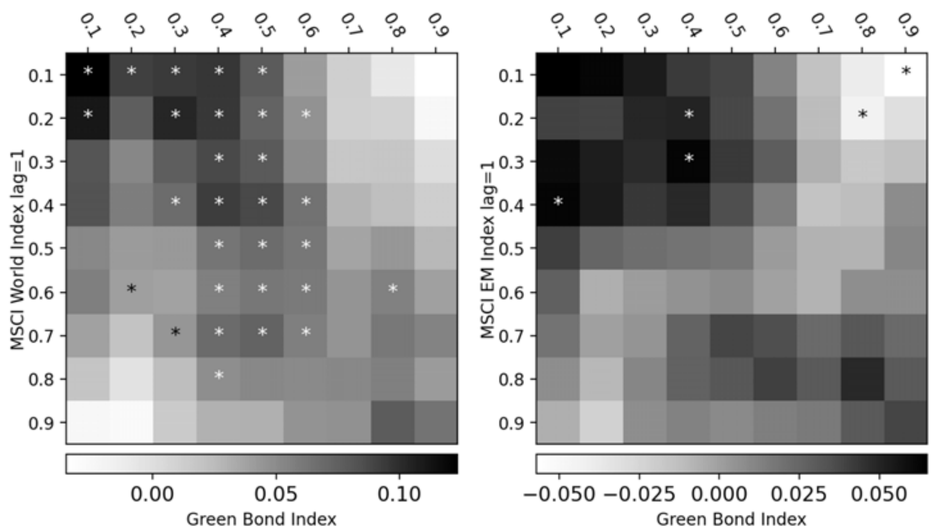
This investigation allows us to understand the impact the standard markets have on the dynamics of the green bonds markets for a short time horizon at one- and two-days distance (lags).

In this analysis we keep track of the relevance of the green bonds market as means to understand the expectations of investors at the global level as far as the evolution of structural changes towards a clean economy is concerned.

Our first layer of analysis shows the dependence of the green bonds index on the other three indices at one-day distance (one lag). The analysis of dependence on the global bond index reveals only one significant case i.e., the one that corresponds to the situation where the median (quantile 0.5) of the one-lag series of log-returns for the global bond index influences the 60% percentile of the contemporaneous log-returns for the green bond index.

Figure 2. Dependence of Green Bonds Index on First Lag of Standard Financial Markets for Large Percentiles



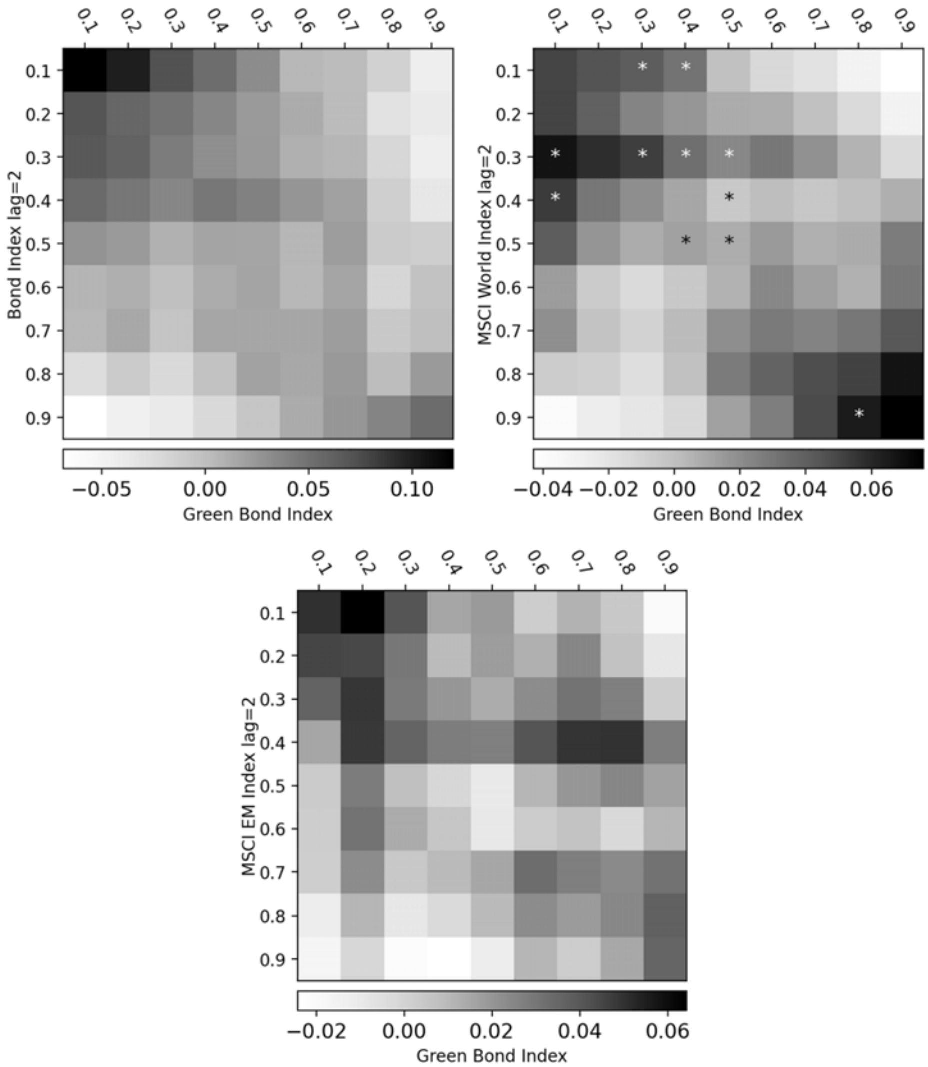


Such a connection could have been picked up by the common correlation analysis, which provides information about the extent to which the average of one observation manages to be connected in a linear manner to the mean of the other variable. In our case we have the broad picture of connections corresponding to all percentiles, which shows that actually the connection is not present at any other level.

A totally different situation is depicted by the analysis of the green bonds in terms of dependence on the log-returns of the World Index. We notice in Figure 2 that these dependencies extend far more to other percentiles than only the ones situated around the median or average.

An interesting effect is that the dependence looks very clear when we notice the values in the lower tail of the distribution, *i.e.* 10% for the bond index and 20% for the lags of the world index.

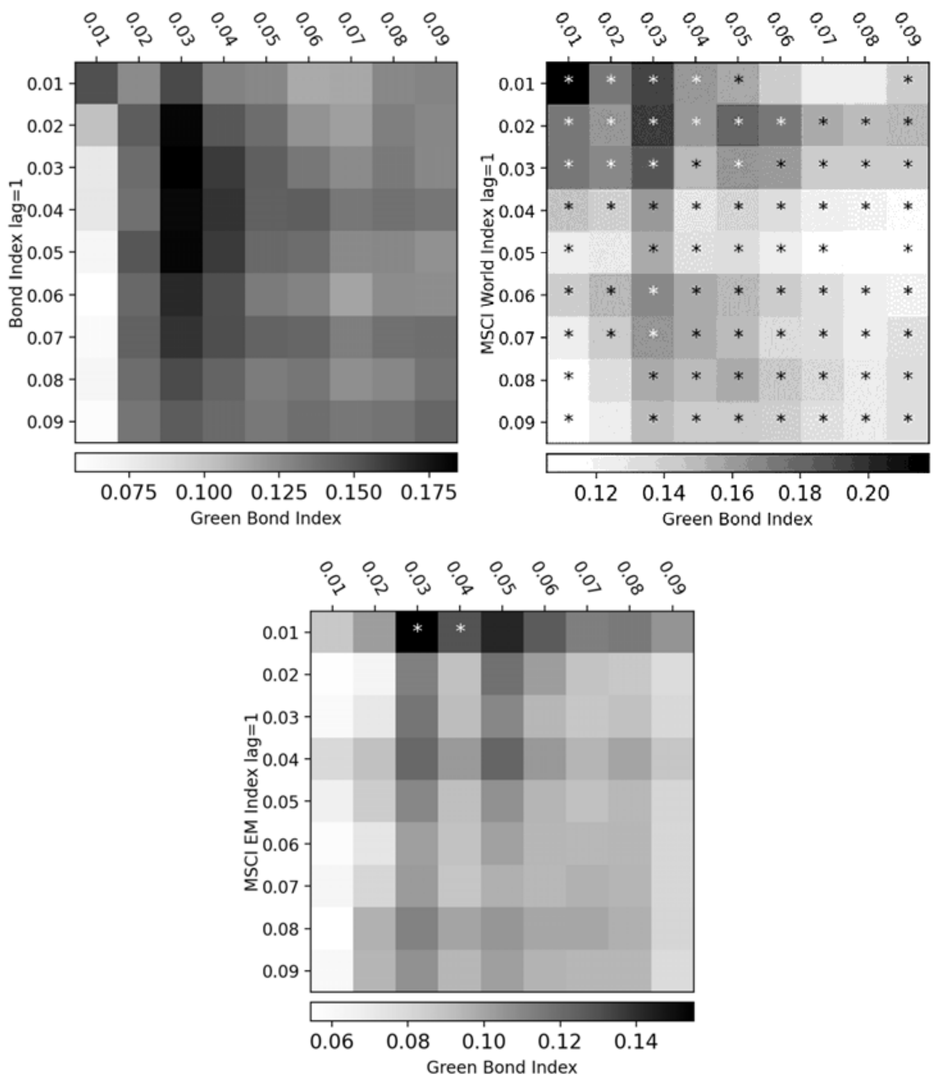
Figure 3. Dependence of Green Bond Index on first lag of standard financial markets for tail percentiles



Looking at the same analysis for the two-lag time distance, we notice that the effect for the dependence on the global bonds index disappears at this level, while the dependence on the world index still exists and also extends to the other tail of the distribution, i.e., to connections between 90% for the world index and 80% for the green bonds index. However, in the case of the second lag, we could not identify any connection as far as the dependence between the green bonds index and the emerging market index is concerned. For the first lag though we notice a stronger relation especially in the mid points of the distributions.

These results might show the fact that the global debt market, represented by the global bond index is mainly driven by factors that are not related to the ones that guide the evolution of the green initiatives.

Figure 4. Dependence of Green Bonds Index on Second Lag of Standard Financial Markets for Large Percentiles



These factors will not be considered leading indicators for the dynamics of the green debt market, which means that such drivers are generally specific to bonds markets and could be the root cause for the evolution of both the standard bond market and the green bonds market.

The dependence on the global equity market shows that this variable is driven by factors that can be considered leading drivers for the green bonds market with an impact that persists up to two lags (days).

Given the fact that the global equity market reflects the evolution of financial markets as a whole, and not all companies listed on stock exchanges have outstanding bonds issued, we can conjecture that the factors that drive these markets include elements that cover the general set of root causes that characterize the shift towards a cleaner and (as a consequence) greener economy. The risks of transition to this type of economy are encapsulated in the set of such features that dictate the evolution of the general equity markets.

Another result of this analysis is the fact that the connection with the emerging markets equity index is higher than with respect to the bond index but lower than with respect to the global equity index. We can explain this through the fact that these markets are less represented by global equity indices and they are driven by particular factors that mostly reflect the effort to develop economic features which are not yet present in such economies as is the case for the developed countries (better represented by the global equity index).

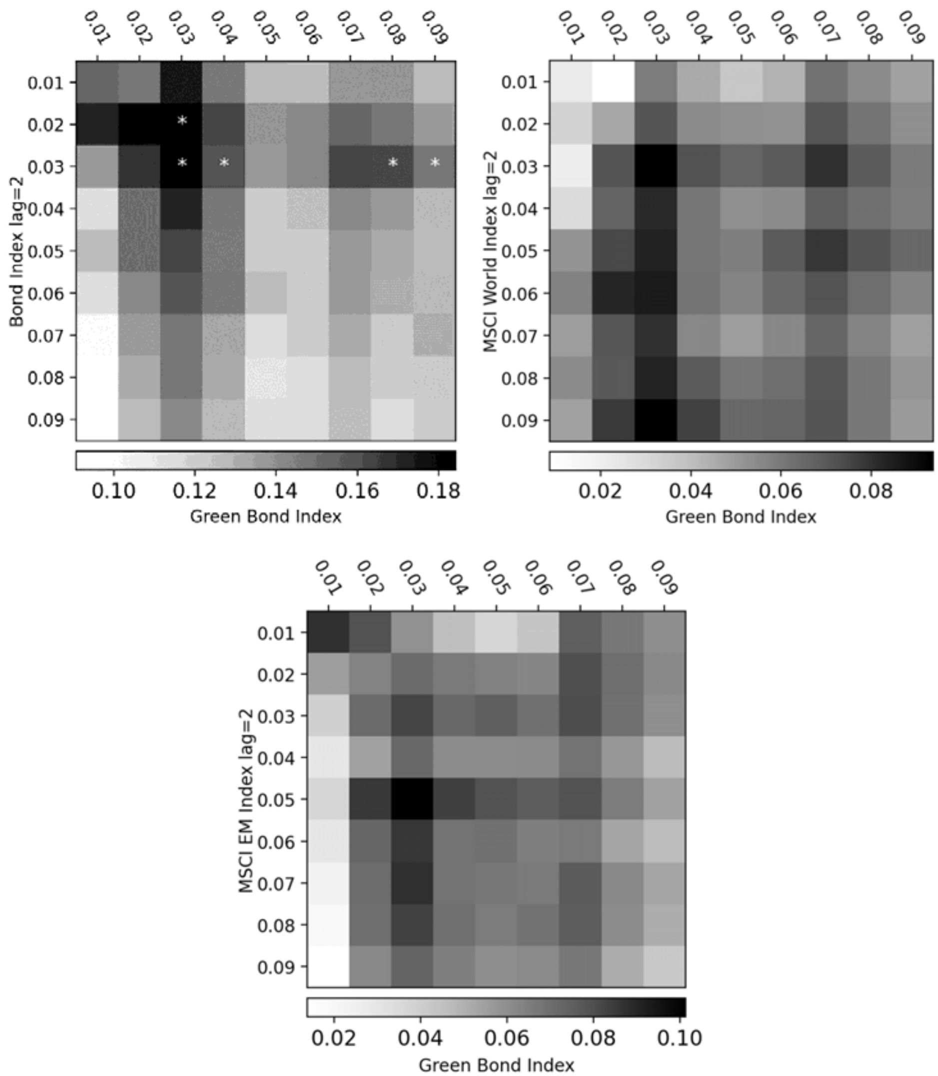
However, the emerging markets benefit from the same level of technology as the developed markets and large corporations tend to invest in the developing regions in pursuit of cheap resources. This phenomenon can explain the relatively strong dependence that characterizes the connection between the emerging markets equity index and the green bonds index.

These new investments spur effects that create information which drives these emerging markets to the same extent as the global equity markets. It is likely that their faded influence to be due to local factors, intrinsically rooted in the evolution of these emerging markets in their attempt to specialize in various domains according to the specifics of their foreign investments.

The extension of this analysis to the lower tail of the distributions of these time series produces effects that broaden to some extent the knowledge we gained by the previous investigation.

As previously discussed, we develop this analysis at the one and two-lag levels and investigate the effects separately.

Figure 5. Dependence of Green Bond Index on Second Lag of Standard Financial Markets for Tail Percentiles



In general, the results confirm the findings of the previous analysis. However, some particularities are found and they have the strength to amplify our conjectures.

We notice therefore that the global corporate bonds index does not show significant influence on the evolution of the green bonds index when the tails are analysed. We can observe some significant values at the second lag, especially when we compute the dependence at the 3% level on both variables.

In contrast, we notice a strong relation with the evolution of the world equity index at the first lag. In this case almost all levels of the distributions yielded significant results, which means that the extreme values are strongly dependent on factors that reflect the shifts towards a green economy (the “risk of transition”). Additionally, we can also interpret this strong dependence as the result of the fact that extreme values of the global equity market (which reflect situations when the whole economy becomes unstable) also have an impact on the green bonds index, as it reiterates the possibility that the newest investments may not be successful and eventually generate defaults.

The dependence on such levels of the distribution do not have the chance to persist to more than one day since the two-lag dependence does not show any significance.

In the case of emerging equity markets the effect is even lower than the one for the global corporate bonds index and it disappears at the second lag. This shows that the low levels of these markets do not necessarily have an impact on the dynamics of the green bonds market, which may be the result of the fact that many of the green bonds are issued by companies from the developed markets.

5. Conclusions

Our paper studies the nonlinear connections that over a short time horizon for one and two lags by employing the cross-quantilogram methodology.

We investigate these relations for a long-time interval that spans from 2011 until 2022 and noticed that, in general, the green bonds index is highly dependent on the percentiles of the world equity index and to a lower extent on the dynamics of the emerging markets equity index. We also provide evidence that these dependences fade out as we move from a one-lag to a two-lag period and they are stronger when the tail values are considered.

Our investigation can be extended by using the same methodology to study the dynamic changes of these dependences in a rolling window framework. This investigation may provide evidence on the impact of economic events on the strength and persistence of these dependences.

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