DEPENDENCE BETWEEN GREEN INVESTMENTS AND CONVENTIONAL ASSET CLASSES: A QUANTILE COHERENCY PERSPECTIVE

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Dependence between green investments and conventional asset classes: A Quantile Coherency perspective

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Abstract

This paper empirically examines the pattern of dependence between green financial instruments, represented by green bonds and clean energy stocks, and a set of major conventional asset classes, such as Treasury bonds, investment-grade and high-yield corporate bonds, general equities, crude oil and gold. To this end, the recent Quantile Coherency approach developed by Baruník and Kley (2019) that allows assessing the degree of dependence between assets over diverse investment horizons (very short-, medium- and long-term) and under different market conditions (relatively stable and extreme bearish and bullish states) simultaneously, is applied.

The empirical results show a close relationship between green bonds and Treasury and investment-grade corporate bonds, while clean energy equities are more strongly connected to general stocks and high-yield corporate bonds, irrespective of the investment horizon and market conditions. In contrast, a weak dependence is detected between both green markets and crude oil. Furthermore, no remarkable association is found between green bonds and clean energy stocks, which suggests that, despite their green common nature, green financial instruments cannot be viewed as a separate asset class. In general, the degree of dependence tends to be stronger under extreme bearish market conditions. These findings can have relevant implications for both investors and policy makers in terms of portfolio design, risk management and sustainability policies.

Key words: green bonds, clean energy stocks, conventional asset classes, dependence, Quantile Coherency

JEL classification: C58, G11, Q50

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1. Introduction

Rising concerns regarding climate change and the call for a shift to a lower carbon economy have become key issues on the agendas of policy makers in the last few years. The signature of the Paris Agreement in December 2015, the first-ever legally binding universal treaty on global climate change that was adopted by 197 countries worldwide, constituted a key milestone as nations committed to work together on the transition towards a climate-resilient economy. In the same vein, the 17 Sustainable Development Goals (SDGs) were set in 2015 by the United Nations General Assembly as part of a new agenda, aimed at promoting social development and economic growth at a global level while protecting the planet. According to the United Nations Intergovernmental Panel on Climate Change, held in October 2018, global warming is expected to reach 1.5ºC above pre-industrial levels between 2030 and 2052 if it continues to increase at current rate, which may have a critical impact on social welfare and may hamper sustainability and poverty eradication, among other aspects. Considering all of the above, the reduction of greenhouse gas emissions in the coming years has become an international priority in order to avoid potentially devastating consequences on nature and human life.

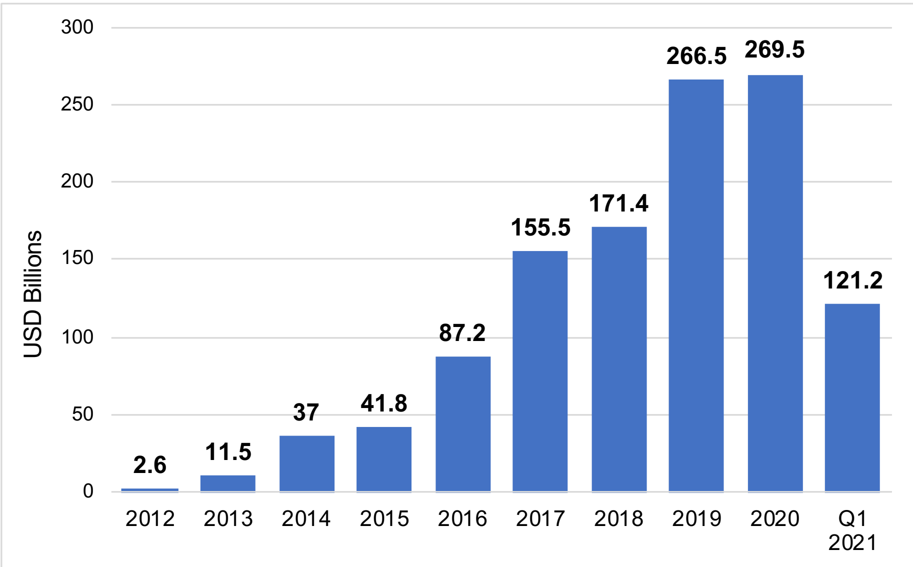
In this context, capital markets are called upon to play a crucial role mobilizing the vast amount of funds for climate-resilient, eco-friendly projects, which are indispensable to mitigate or, preferably, avoid the adverse side-effects of climate change. Green bonds and green stocks are nowadays the two major environmental-friendly financial instruments that channel financial resources to sustainable-oriented initiatives.

Green bonds are a type of fixed income instrument whose proceeds are earmarked exclusively for projects with environmental benefits, in areas such as renewable energy, energy efficiency, pollution prevention, clean transportation, and sustainable water management. It is, in fact, their green nature what distinguishes green bonds from conventional bonds, since both are structured the same way and share the same characteristics in terms of seniority ranking, rating, maturity, and pricing (International Finance Corporation, 2016). Green bonds are widely recognized as an appropriate financial investment vehicle to finance the transition to a low carbon economy (OECD, 2017; Monasterolo and Raberto, 2018) and to redistribute the cost of mitigating climate change across generations (Flaherty et al., 2017; Gevorkyan et al., 2016).

Since the issue of the first green bond in 2007 by the European Investment Bank (EIB), under the label of "Climate Awareness Bond", the green bond market has experienced an exponential growth in scale, especially following the publication of the Green Bond Principles (GBP) in January 2014 by the International Capital Markets Association (ICMA). The GBP are a set of voluntarily guidelines that set standardized rules for bonds to be labelled as green, thus promoting transparency, reporting, disclosure and integrity in the green bond market. They were designed with the aim of providing more precise information for both issuers and investors in terms of launching credible green bonds and evaluating the environmental impact of such investments, this way facilitating transactions, promoting capital allocation to green projects and ultimately fostering further development of such market (World Bank, 2017). The fact that third-party agents, such as the independent think tank Climate Bonds Initiative (CBI), offer certification services for potential green bonds, together with the development of criteria and green bond market indices by traditional credit rating agencies such as Moody's or Standard & Poor's, and the introduction of green bond ETFs, are other indicators of the increasing degree of maturity of the green bond market (Baker et al., 2018).

According to data extracted from CBI, as of April 2021, the cumulative green bond issuance since market's inception in 2007 amounted $1.202tn, with approximately $121.2bn corresponding to the first quarter of 2021. Despite the adverse impact of the outbreak of the COVID-19 pandemic in 2020, which put a temporary damper on the green fixed income market for some months, 2020 holds the issuance record to date of $269.5bn and maintains the trend of nine consecutive years of increased market growth. Figure 1 depicts the evolution of global issuance of green bonds over the last decade.

Figure 1. Historical evolution of global green bond market issuance



Source: Own elaboration based on data of Climate Bond Initiative (CBI)

Green bond issuance is expected to increase considerably throughout 2021 thanks to a combination of strong investor demand for green financial assets, standardization of regulations and supportive Environmental, Social and Governance (ESG) governmental policies in major jurisdictions. Moreover, the COVID-19 pandemic has highlighted the vulnerability of the environment and the need to step up the fight against climate change, which will further promote green bond market growth. With regard to government support, it is of great importance the expected return of "green multilateralism" as the United States, which tops the country rankings as the greatest issuer during the last years, commits to action on climate change and is likely to rejoin the Paris Agreement under the administration of President Joe Biden.

In addition, the “Next Generation” EU COVID-19 recovery fund is expected to include up to €250bn worth of green bonds as part of the €750bn total borrowing (that is, 30% of the total fund). This strategy, which falls within the scope of the eco-friendly EU action plan known as “The European Green Deal”, aims to boost the size of the green bond market while promoting both a sustainable recovery and the green transformation of the economy. Furthermore, the creation of an EU Green Taxonomy, a common classification system on which the EU Commission is also working on, is expected to improve the quality and security of the green fixed income market by providing appropriate global definitions to investors on which economic activities can be considered as environmentally sustainable.

All of this being said, sustainable bond issuance will comprise about $375bn of green bonds by 2021 according to Moody’s Investor Service. Other market estimates, including NN Investment Partners and HSBC, predict similar record figures (€300bn and $360bn respectively). While green bonds still represent only around 2% of the total bond market, they were responsible for almost 17% of bond flows in 2020, excluding sovereign issuers (according to the site Institutional Asset Manager). Therefore, the strong upward trend of the green bond market seems quite likely to continue in the upcoming years.

For their part, clean energy stocks can be defined as shares of environmental-friendly companies whose primary business has a beneficial climate impact. According to FTSE Russell estimates, as of December 2020, green economy companies constituted around 5% of global market capitalization ($4tn approximately), with more than 3,000 global listed companies and even overtaking the size of the oil and gas sector. The same source also claims that the green equity sector has grown faster than the overall equity market since 2009. According to Refinitiv data, equity issuance from sustainable companies reached $13.8bn during 2020 and $11.2bn during the first quarter of 2021, this last becoming an all-time quarterly record. Moreover, it is particularly remarkable the fact that, according to Morningstar data, inflows into American ESG funds grew from 1% of total US funds in 2014 to 25% in 2020, accounting for $51.5bn on net new money in 2020. Despite the sharp market downturn during March and April of 2020 due to the COVID-19 global pandemic, the 2020 figure accounts for more than double compared to 2019, which evidences the investors’ appetite for sustainable instruments and the tremendous growth potential of the green stock market.

In this backdrop, the primary aim of this paper is to analyze the dependence between green investments, represented by green bonds and clean energy stocks, and a set of major conventional assets, including Treasury bonds, high-yield and investment-grade corporate bonds, general stocks, crude oil and gold, over diverse investment horizons and under different market conditions. A central research question is to determine whether the climate-friendly nature shared by green bonds and clean energy stocks makes these two financial instruments able to be treated as a separate green asset class or whether, on the contrary, they have a greater closeness with their respective mainstream counterparts, i.e., ordinary bonds and general stocks.

Understanding the interdependence between green financial instruments and the main classes of conventional assets at different time horizons and under diverse market circumstances provides valuable information to investors, particularly to those concerned with responsible investment and ESG scores, about how they can benefit from adding green investments to their portfolios in terms of diversification and hedging opportunities, while contributing to green transition. This aspect becomes even more relevant in times of market turmoil, in which instruments that exhibit safe-haven properties get special interest. Knowing the pattern of dependence between green investments and traditional assets is also relevant for issuers, since the issuance of green bonds and clean energy stocks allows them to enhance their corporate social responsibility and further expand and diversify their long-term investor base. Lastly, the knowledge of the extent of linkage between green and conventional asset classes in distinct time horizons and various market states can be also very useful for policy makers, who are interested in the development of a solid sustainable-oriented financial system that facilitates the achievement of governments' climate change goals. A proper understanding of this issue will help them design the best policies to enhance the resilience of the green bond and equity markets to economic and financial shocks in the short, medium and long-term and, hence, to boost issuers and investors confidence in green financial markets.

The Quantile Coherency (or Quantile Cross-spectral) approach recently developed by Baruník and Kley (2019) is applied in this study to examine the nexus between green investments and traditional asset classes. This method provides a unified framework to measure the general dependence structure between any two variables at different time horizons (short-, medium- and long-term) and under different market conditions (represented by various quantiles of the joint distribution of variables) simultaneously. Therefore, the Quantile Coherency provides a richer and more complete characterization of the dependence structure than standard time-domain and mean-based methods.

In the present paper, we will focus on median and tail dependence by estimating the Quantile Coherency in the median and in lower and upper quantiles of the joint distribution of returns of green and conventional assets in order to capture the dependence under relatively stable, bearish and bullish market states. This is prompted by the fact that the level of interdependence between assets may vary depending on market conditions. For example, previous literature suggests that assets and financial markets tend to be more strongly connected under situations of market stress, since negative events in one asset or market can cause irrational behavior and subsequent risk contagion to other assets or markets (Bae et al., 2003; Baumöhl and Shahzad, 2019; Naeem et al., 2020; Arif et al., 2021). This possible heterogeneity under different market circumstances motivates the dependence analysis across various quantile levels.

Moreover, differing risk perception, objectives, preferences and trading strategies of economic agents with heterogeneous investment horizons can lead to different patterns of dependence between assets in the short-, medium- and long-term. For example, active investors with shorter horizons (i.e., day traders) are more interested in high frequency dynamics among markets. In contrast, investors with longer horizons and more passive investment strategies (i.e., insurance companies) are more concerned about low frequency dynamics. As a result, the dynamics of interdependence between green and conventional asset classes may differ depending on the investment horizon considered. In short, the application of the Quantile Cross-spectral method is driven by the asymmetric nature of the dependence structure both across frequencies and quantile levels.

The Quantile Coherency approach offers several advantages over traditional methods used in the extant literature. First, classical, covariance-based approaches only consider averaged information, thus ignoring the fact that the dependence between two variables can vary across different parts of the joint distribution. However, the Quantile Coherency characterizes the dependence structure not only in the middle, but also in the upper and lower tails of the joint distribution of both variables, thus providing a more effective measure of the real dependence between variables. Second, the Quantile Coherency captures the general dependence in the frequency domain, allowing to uncover a frequency-dependent dependence structure that remains hidden when classical measures based on linear correlation and time series analysis are used. There are some frequency-domain methods, such as wavelet analysis, that have been utilized in some recent papers to explore the relationship between green financial instruments and traditional asset classes at different frequencies (i.e., Reboredo et al., 2020; Ferrer et al., 2021a; Nguyen et al., 2021). However, wavelet techniques fail to capture the dependence between variables under extreme bearish or bullish market conditions. For its part, the cross-quantilogram method of Han et al. (2016) examines the dependence under various market circumstances, but it does not take into account the heterogeneity in terms of investment horizons of agents that interact in financial markets. In short, by combining the analysis of dependence at various quantiles and across frequencies, the Quantile Coherency is able to describe simultaneously the pattern of interdependence during relatively normal, bearish and bullish market conditions as well as in the short-, medium- and long-run. Additionally, as noted by Baruník and Kley (2019), the Quantile Coherency is robust to several common violations of traditional assumptions found in financial data, such as outliers, heavy tails and normality of the distribution.

Despite the rapidly growing body of literature on the relationship between green financial instruments and conventional asset classes, to the best of our knowledge, no previous study has applied the Quantile Coherency methodology in this field. Our work further contributes to the green investment literature by considering a very recent dataset of both green bonds and green equities that includes the sub-period associated with the COVID-19 pandemic.

Our empirical results indicate that green bonds are most closely connected to Treasury and investment-grade corporate bonds, while clean energy stocks are particularly linked to general stocks and high-yield corporate bonds regardless of the investment horizon and market circumstance. In contrast, the association between green bonds and renewable energy stocks is quite limited, except under extreme bearish market circumstances in the medium- and long-term. The dependence between the two green investments and the crude oil market is weak, especially in the case of green bonds. Interestingly, there seems to be a significant linkage between green bonds and gold irrespective of the time horizon and market circumstances. In general, the pattern of dependence tends to be stronger under extreme bearish market conditions, i.e., in the lower tail quantiles.

The rest of the paper proceeds as follows. Section 2 contains a review of the most relevant related literature and Section 3 formally presents the quantile coherency method to be applied in the empirical analysis. Section 4 describes the financial dataset used, while Section 5 discusses the most significant empirical results and robustness analysis. Finally, Section 6 provides some concluding remarks.

2. Literature review

Given that green bonds became increasingly popular only since the publication of the Green Bond Principles in 2014, the academic research on this environmentally friendly financial instrument is still not very large. However, this literature has experienced a boom in the last few years due to rising investor demand motivated by concerns about global warming and climate change.

Seminal studies in the green bond field focused on green bond pricing, with the primary aim of determining whether investors are paying a green bond premium, the so-called "Greenium", characterized by higher bond prices and lower yields than non-green equivalents. However, no clear consensus has been reached on this issue so far. Most of the literature (Preclaw and Bakshi, 2015; Ehlers and Packer, 2017; Kapraun and Scheins, 2019; Baker et al., 2018; Zerbib, 2019) finds that investors are willing to accept a moderate Greenium in exchange for the environmental benefits of green bonds. Accordingly, green bonds may represent a cheaper source of financing for debt issuers compared to conventional bonds with similar features. On the contrary, according to Karpf and Mandel (2017) and Bachelet et al. (2019), green bonds have even higher yields than ordinary bonds with similar characteristics in terms of maturity, issuer and credit rating. Additionally, other studies do not find a significant pricing differential between green bonds and their non-green counterparts (Hachenberg and Schiereck, 2018; Larcker and Watts, 2020; Tang and Zhang, 2020; Flammer, 2021). In this regard, being aware of the general ambiguity on this issue, MacAskill et al. (2021) have recently undertaken a systematic literature review on the existence of the green bond premium. They estimate that the average Greenium accepted by investors in exchange for pro-environmental credentials ranges from -1 to -9 bp in the secondary market. Given the large differences in the primary market, with Greenium spreads ranging from -85 to +213bp in the literature, these authors highlight the need for further investigation on the green bond premium in this market. Likewise, Larcker and Watts (2020) review this strand of literature and conclude that the mixed evidence from previous studies can be due to misspecifications of the methodological design that produce biased estimates.

There are also a number of works that investigate the effects of the issuance of green bonds for the issuing company and shareholders. In this sense, Labelle et al. (2020) show that the market reacts negatively to the announcement of new corporate green bond issues, with cumulative abnormal returns between -0.5% and -0.2% depending on the asset pricing model used, as a result of the uncertainty perceived by investors regarding whether the potential new business model would be as profitable in the future. In contrast, Flammer (2021) reports that green bond issuers experience long-term enhancements in financial performance, translated into increases in both return on assets (ROA) and return on equity (ROE) measures, as well as CO2 emissions' reductions and environmental rating improvements, but only if green bonds are certified by independent third parties. In the same vein, Tang and Zhang (2020) show the improvement of short-run firm value, institutional ownership and stock liquidity after green bond issuance announcements, thus benefiting shareholders of issuing firms.

Another well-established line of research more closely linked to this paper explores co-movement and network connectedness between green bonds and various conventional asset classes. Within this segment of the literature, most studies have used pure time domain methods. For example, Broadstock and Cheng (2019) apply the dynamic conditional correlation (DCC) model to examine the correlation pattern between green and black bond markets. They find a positive correlation since the beginning of the strong expansion of the green bond market in 2014 and show that such correlation depends on certain macroeconomic factors, such as market volatility, policy uncertainty, energy prices, economic activity and news-based sentiment towards green bonds. Employing copula functions to study co-movement of green bonds and financial markets, Reboredo (2018) finds that the green bond market is highly integrated with the corporate and Treasury bond markets under all market circumstances, in contrast to the weak ties found between the green bond and the stock and traditional energy markets. Based on a structural VAR model and spillover measures, Reboredo and Ugolini (2020) confirm these results and observe a weak association between green and high-yield bonds. The DCC analysis carried out by Kocaarslan (2021) further supports the close connection between green and conventional bonds and the limited link between green bonds and energy commodity and stock markets. Pham and Nguyen (2021) show through a Markov switching model that green bonds are weakly connected with uncertainty in non-crisis periods, thus becoming a good hedging instrument only in low-uncertainty market states. Lastly, given its common green nature, Liu et al. (2021) examine the dependence structure between green bonds and several clean energy sectors using a time-varying copula approach. Their findings indicate a positive time-varying average and tail dependence between both green investments, as well as spillover effects from one market to the other, which suggests that both green markets generally boom and bust together.

Another segment of literature investigates frequency domain connectedness across the green bond market and several conventional markets. Using the connectedness framework developed by Diebold and Yilmaz (2014), Reboredo et al. (2020) demonstrate that green bonds exhibit a strong price dependence with Treasury and investment-grade corporate bonds both in the short- and long-run. However, the transmission of price shocks between green bonds and high-yield corporate bonds and general and energy stocks is negligible in both the short- and long-run, implying that green bonds can serve as useful tools for portfolio hedging and risk diversification in these cases. Furthermore, based on the frequency connectedness method introduced by Baruník and Křehlík (2018), Ferrer et al. (2021b) also detect close ties between green bonds and Treasury and investment-grade corporate bonds in the short-run and a weaker but still positive relationship in the long-run. Likewise, Naeem et al. (2021a) study the impact of COVID-19 on the frequency connectedness between green bonds and the global stock, bond, oil, USD, gold and Bitcoin markets. They show that the relationship between green and conventional bonds is strengthened during this period, especially in the short run. In contrast, the connection between green bonds and Bitcoin continues to be quite weak.

The unprecedented growth of the renewable energy sector in the past decade driven by more environmentally conscious investors, consumers and governments has been accompanied by a substantial increase of the literature on the relationship between clean energy stocks and other asset classes, including crude oil, and a number of major conventional assets, such as general stocks, technology stocks, bonds, currencies, gold, and several measures of uncertainty such as oil price volatility and the VIX index. The bulk of these studies have employed VAR models (Henriques and Sadorsky, 2008; Kumar et al., 2012; Managi and Okimoto, 2013; Sun et al., 2019), cointegration and Granger causality (Bondia et al., 2016; Lundgren et al., 2018, Kocaarslan and Soytas, 2019), multivariate GARCH models (Huang et al., 2011; Sadorsky, 2012; Broadstock et al., 2012; Ahmad, 2017; Ahmad et al., 2018; Abdallah and Ghorbela, 2018, Dutta et al., 2018), time-varying multi-factor asset pricing models (Inchauspe et al., 2015), copula functions (Reboredo, 2015; Reboredo and Ugolini, 2018; Mejdoub and Ghorbel, 2018; Bouri et al., 2019; Tiwari et al., 2021), wavelet analysis (Reboredo et al., 2017; Maghyereh et al., 2019; Nasreen et al., 2020; Jiang et al., 2020), return and volatility spillovers (Wen et al., 2014; Ahmad, 2017; Xia at al., 2019; Ghaemi Asl et al., 2021), and time and frequency connectedness methods (Ferrer et al., 2018; Lundgren et al., 2018; Naeem et al., 2020). Overall, the results of these studies agree on the fact that the performance of technology stocks has a stronger influence on the clean energy equity market than crude oil. This suggests that investors tend to perceive renewable energy and high-technology stocks as similar asset classes mainly due to the fact that technology firms are major suppliers of inputs to clean energy companies. Moreover, many of these works reveal that the renewable energy equity sector and the crude oil market have exhibited a quite decoupled behavior over the last years, since clean energy stocks are mostly demanded by investors concerned with ESG criteria and climate change.

Moreover, in order to gain a more complete picture of the dependence pattern between assets, several recent papers have investigated the relationship between green investments and other assets across different market circumstances. For example, Naeem et al. (2021b), Arif et al. (2021) and Pham (2021) have examined the dependence structure between green bonds and a number of traditional asset classes using the cross-quantilogram technique developed by Han et al. (2016). More precisely, Naeem et al. (2021b) documents the asymmetric but, in general, low correlation between green bonds and three groups of commodities (energy, metals and agriculture). Their results suggest that green bonds are an effective instrument for diversification and hedging matters in a commodity portfolio, especially against natural gas's fluctuations. Arif et al. (2021) confirm these results and, additionally, show that green bonds could serve as hedging instruments for currency investments and diversifier assets for equity investors under all market conditions. Moreover, they test the safe-haven potential of green bonds during the COVID-19 crisis and, given its resilience during the period, conclude that governments could use this sustainable asset as part of recovery funds. Pham (2021) specifically focuses on the interdependence between green bonds and green equity and, in line with Liu et al. (2021), finds that, after controlling for general conditions in the stock, bond and energy markets, this dependence is relatively weak under normal market conditions, but is moderately strengthened during extreme market conditions. In the same vein, Uddin et al. (2019) and Yahya (2020) explore the cross-quantile dependence between clean energy stocks and a set of conventional asset classes. Particularly, Uddin et al. (2019) studies the asymmetric dependence structure between renewable energy stocks and regular stocks, oil, gold and exchange rates. They find that the positive dependence between renewable energy equities and oil and the aggregate stock market dissipates in longer lags except under bearish market conditions, that is, when both asset returns are in the lower quantiles. Likewise, they show that the positive dependence between renewable energy stocks and exchange rates and gold only holds during extreme market conditions. Yahya (2020) investigates the asymmetric relationship between various clean energy stock indices and non-ferrous metals indices and determines that the dependence strengthens during turmoil periods (lower quantiles) but weakens over periods of economic prosperity (top quantiles), thus confirming the safe-haven role of non-ferrous metals. Alternative quantile-based methods used in the green market literature are found in Dawar et al. (2021) and Saeed et al. (2021). Specifically, Dawar et al. (2021) run a quantile regression analysis and provide evidence on strong effects of oil returns on clean energy stock returns during bearish periods, in contrast to insignificant connections during bullish episodes, while Saeed et al. (2021) use a quantile VAR model and quantile measures of spillovers and find stronger levels of connectedness between green securities and dirty energy investments in the left and right tails that at the mean.

Likewise, other papers have focused on the causality in quantiles between green investments and conventional assets. For instance, Lee et al. (2021) explore causality relationships among green bonds, oil and geopolitical risk in the U.S. and find evidence of bi-directional causality from oil to green bonds only at the lower tail of the conditional distribution, which implies that diversification benefits of green bonds against crude oil investments would only be feasible under bullish market conditions. In the same way, Shao et al. (2021) shows that the Oil Volatility Index (OVX) has a causal effect on Chinese clean energy metal stocks especially for low quantiles of the distribution, which corroborates once more the idea of stronger relationship of green markets and crude oil under bearish market states.

A third segment of the literature analyzes the relationship between green investments, represented by both green bonds and clean energy stocks, and a number of traditional asset classes. From this perspective, Boyer de la Giroday and Stenvall (2019) analyze cross-quantile dependence of such green securities and corporate bonds, stocks and crude oil. They find that green bonds are tail-dependent and closely connected to the corporate bond market, especially in the short-term, while the renewable energy market is highly dependent on the general stock market. Besides, they find that the clean energy stock market is influenced by oil returns of similar quantiles but that this relationship does not hold in the opposite direction, which suggests that clean energy substitutes crude oil when oil prices increase but oil does not generally substitute renewable energy sources, and corroborates the idea that each energy source satisfies a different segment of the overall energy demand. In turn, Ferrer et al. (2021a) employ a combination of wavelet methods and network analysis and also detect a strong connection between green investments with their respective non-green counterparts (i.e., clean energy stocks with general stocks, as well as green bonds with Treasury and investment-grade corporate bonds) irrespective of the time horizon. The directional spillover analysis in the time and frequency domains of Pham (2021) supports these findings. Furthermore, the evidence provided by Nguyen et al. (2021), who apply a rolling window wavelet correlation approach to measure the dynamic features of correlation across asset pairs over time and different frequencies, is totally in line with the previous findings.

There are also a few recent papers that compare the hedging and safe haven properties of green bonds and clean energy equities. For example, Huynh et al. (2020) analyzed green bonds from a portfolio diversification perspective and conclude that, although they may have some potential safe haven properties, portfolio risks in terms of large joint losses prevail especially during market turmoil periods. On the other hand, Saeed et al. (2020) explore the hedging potential of green bonds and clean energy stocks against traditional energy assets, such as crude oil or dirty energy stocks. They find that clean energy stocks tend to be a more effective hedge than green bonds, especially for crude oil. In a similar vein, Kuang (2021) examines risk reduction abilities of clean energy assets for traditional equites and conclude that, while green bonds are a safe haven for international equity indices, clean energy stocks generally increase the portfolio downside risk.

This study extends previous research by applying the novel quantile coherency methodology proposed by Baruník and Kley (2019) to measure the dependence structure between green financial investments, represented by green bonds and green stocks, and a group of major conventional assets at different frequencies and quantile levels of the joint distribution of returns simultaneously. Unlike other quantile-based methods, such as the quantile cointegration of Xiao (2009), the quantile-on-quantile approach of Sim and Zhou (2015), the causality-in-quantiles test of Balcilar et al. (2016) and the cross-quantilogram technique of Han et al. (2016), which analyze relationships between different quantiles of two variables exclusively in the time domain, the Quantile Coherency examines the pattern of dependence in the frequency domain and under different market conditions simultaneously, thus providing a more complete picture of the dependence than the aforementioned approaches. The Quantile Coherency method has been already applied in various financial applications. For example, Baumöhl (2019), Maghyreh and Abdoh (2020), and Jiang et al. (2021) have utilized this approach to explore the interdependence between cryptocurrencies and various market indices, including stock, commodity and bond indices, while Baumöhl and Shahzad (2019) examined the tail dependence network of international stock markets. However, as far as we as we know, this is the first time the Quantile Coherency method is employed in the area of green financial assets.

3. Empirical methodology

This paper employs the novel Quantile Coherency, also known as Quantile Cross-spectral, methodology proposed by Barunik and Kley (2019) to quantify the extent of dependence between green financial instruments and conventional asset classes over different frequencies and across various quantile levels simultaneously.

The dynamic dependence between any two stationary processes, represented by $X = \{x_t\}$ and $Y = \{y_t\}$, respectively, with $t \in Z$, can be measured through the following relationship[1]:

$$\mathfrak{R}^{X,Y}(\omega;\ \tau_1,\tau_2) = \frac{f^{X,Y}(\omega;\tau_1,\tau_2)}{(f^{X,X}(\omega;\tau_1,\tau_1)f^{Y,Y}(\omega;\tau_2,\tau_2))^{1/2}} \tag{1}$$

where $-\pi < \omega < \pi$, $\omega \in \mathbb{R}$ and $\tau \in [0,1]$. ω and τ represent the values of the frequency and quantile, respectively. $\mathfrak{R}^{X,Y}(\omega;\ \tau_1,\tau_2)$ is the quantile coherency kernel, and $f^{X,Y}(\omega;\ \tau_1,\tau_2)$, $f^{X,X}(\omega;\ \tau_1,\tau_2)$ and $f^{Y,Y}(\omega;\ \tau_1,\tau_2)$ denote the quantile cross-spectral and

[1] The description of the methodology and the notation used in this section follow closely the works of Baruník and Kley (2019), Maghyreh and Abdoh (2020) and Jiang et. al (2021).

quantile spectral densities of processes *X* and *Y*, respectively. These quantile cross-spectral densities are derived from the Fourier transform of a matrix of quantile cross-covariance kernels:

$$\Gamma_k\,(\tau_1, \tau_2) := (\gamma_k^{X,Y}(\tau_1, \tau_2)) \tag{2}$$

where the cross-covariance function of processes X and Y is given by:

$$\gamma_k^{X,Y}(\tau_1, \tau_2) = \mathrm{Cov}\,(I\{X_{t+k} \leq q_x(\tau_1)\}, I\{Y_t \leq q_y(\tau_2)\}) \tag{3}$$

where $k \in \mathbb{Z}$, and I{A} is the usual indicator function of event A. Regarding the covariance function in Eq. (3), it should be pointed out that $q_x(\tau)$ and $q_y(\tau)$ refer to corresponding quantile functions, where $q_x(\tau) = F_x^{-1}(\tau) := inf\{q \in \mathbb{R} : \tau \leq F_x(q)\}$ and $q_y(\tau) = F_y^{-1}(\tau) := inf\{q \in \mathbb{R} : \tau \leq F_y(q)\}$, being $F_x(q)$ and $F_y(q)$ the marginal distribution functions of X and Y processes.

In addition to providing information about cross-section dependence when choosing $X \neq Y$, varying the value of *k* gives information about serial dependence. This way, we can obtain the following so-called matrix of quantile cross-spectral density kernels in the frequency domain:

$$f(\omega;\, \tau_1, \tau_2) := (f^{X,Y}(\omega;\, \tau_1, \tau_2)) \tag{4}$$

where:

$$f^{X,Y}(\omega;\, \tau_1, \tau_2) := (2\pi)^{-1} \sum_{k=-\infty}^{\infty} \gamma_k^{X,Y}(\tau_1, \tau_2) e^{-ik\omega} \tag{5}$$

$f^{X,Y}(\omega;\, \tau_1, \tau_2)$ in Eq. (4) is a complex value, which consists of a real part and an imaginary part, as follows:

$$f^{X,Y}(\omega;\, \tau_1, \tau_2) = (2\pi)^{-1} \sum_{k=-\infty}^{\infty} cos\,(\omega k)\gamma_k^{X,Y}(\tau_1, \tau_2) - \mathrm{i}\,(2\pi)^{-1} sin\,(\omega k)\gamma_k^{X,Y}(\tau_1, \tau_2) \tag{6}$$

The real part can be attributed to the cospectrum of the processes ($I\{X_t \leq q_x(\tau_1)\}$) and ($I\{Y_t \leq q_Y(\tau_2)\}$), and shows the frequency dynamics in quantiles of the joint distribution of returns under study. In turn, the imaginary part represents the quadrature spectrum and is aimed at removing all sources of noise coherence caused by instantaneous volatility. Following Barunik and Kley (2019), Maghyreh and Abdoh (2020), Jiang et al. (2021), among others, we will focus on the real part of the quantile coherency estimates. Furthermore, also in line with Barunik and Kley (2019), we use the Epanechnikov kernel and a bandwidth of $b_n = 0.5n^{1/4}$ for the computation of the density kernel estimates, where *n* is the number of observations of each process.

As detailed by Barunik and Kley (2019), the Quantile Coherency is non-parametrically estimated via the use of a smoothed version of quantile rank-based copula cross-periodograms (CCR-periodograms), which can be thought of as the discrete Fourier transform of the estimated cross-covariance function of two signals (Todd and Cruz, 1996). The CCR-periodograms are widely used in the field of signal processing to reflect common power across two distinct signals. Accordingly, Barunik and Kley (2019) apply this methodology in the area of finance since it can be used to identify the common dominant cyclical behavior (or frequencies) of two wide-sense stationary time series, i.e., returns of two assets. Previously, Kley et al. (2016) showed that the original CCR-periodograms failed to estimate $f^{X,Y}(\omega;\ \tau_1,\tau_2)$ consistently, but that consistency can be achieved by smoothing such CCR-periodograms across frequencies. Thus, the following matrix of smoothed CCR-periodograms is used:

$$\hat{G}_{n,R}(\omega;\ \tau_1,\tau_2) := \hat{G}_{n,R}^{X,Y}(\omega;\ \tau_1,\tau_2) \tag{7}$$

where:

$$\hat{G}_{n,R}^{X,Y}(\omega;\ \tau_1,\tau_2) := \frac{2\pi}{n}\sum_{s=1}^{n-1} W_n(\omega\ -\frac{2\pi s}{n}) I_{n,R}^{X,Y}(\frac{2\pi s}{n},\tau_1,\tau_2) \tag{8}$$

where $I_{n,R}^{X,Y}$ stands for the matrix of CCR-periodograms and W_n is a sequence of weight functions. Then, the estimator used for the Quantile Coherency analysis can be denoted by:

$$\hat{\mathfrak{R}}_{n,R}^{X,Y}(\omega;\ \tau_1,\ \tau_2) := \frac{\hat{G}_{n,R}^{X,Y}(\omega;\tau_1,\tau_2)}{\left(\hat{G}_{n,R}^{X,X}(\omega;\tau_1,\tau_2)\hat{G}_{n,R}^{Y,Y}(\omega;\tau_1,\tau_2)\right)^{1/2}} \tag{9}$$

In line with the usual practice in this literature, in this paper we specifically focus on the dependence structure under relatively stable and extreme market conditions. Accordingly, the Quantile Coherency is only estimated in the quantiles 0.5, 0.05 and 0.95, which represent the median, left tail and right tail, respectively, of the joint distribution, and all their combinations (i.e., 0.5|0.5, 0.05|0.05, 0.95|0.95, 0.5|0.95, etc.). Furthermore, similarly to previous studies that apply this approach, three different frequencies are considered: short-term (represented by 2 days), medium-term (22 trading days, that is, one business month) and long-term (250 trading days, that is, one business year). These frequencies correspond to ω ∈ 2π{1/2,1/22,1/250}. The empirical analysis is performed with R software using the *quantspec* package developed by Kley (2016) to estimate Quantile Coherency matrices.

It is worth highlighting that common volatility may be a possible source of dependence. In fact, in the multivariate setting, Barigozzi et al. (2014) demonstrate that common volatility factors in the stock market manage to capture the overall level of risk in the global equity market and, thus, conclude that common volatility constitutes a very important risk factor. Therefore, as Barunik and Kley (2019) suggest, in order to account for time-varying volatility processes that can create peaks in quantile spectral densities (Li, 2014), we consider standardized returns, calculated as the difference between the returns and their conditional mean, and divided by their conditional volatility. This adjustment will prevent strong volatility processes from overshadowing the study of possible common factors in the joint distribution of returns across frequencies, which can result in spurious dependence. Following the common practice in the literature on volatility modelling and as proposed by Barunik and Kley (2019), return volatility estimates of each series are calculated by means of GARCH (1,1) models. Moreover, after careful consideration of the autocorrelation functions, ARMA (1,1) models are chosen to estimate the conditional mean of return series. In addition, normal distribution functions have been assumed to specify the conditional density for the innovations of the volatility processes[2].

4. Data description

The dataset used in this paper comprises daily closing prices of green bonds and clean energy stock indices, as well as a number of conventional asset classes that represent some of the most traditional investment alternatives. Our sampling period spans from August 4, 2014 to March 26, 2021, including a total of 1723 daily observations. The starting date of the sample is determined by the availability of the green bond market data. All data are gathered from Bloomberg. Global indices that reflect the performance of each market worldwide are used in this study. All price indices are quoted in US dollars. The variables employed are described below.

Parallel to the extraordinary growth of the green bond universe since 2014, various green bond indices, such as the Barclays MSCI Green Bond Index, the S&P Dow Jones Green Bond Index, the Bank of America Merrill Lynch Green Bond Index and the Solactive Green Bond Index, have been created. As expected, all these green bond indices exhibit a near-one Pearson correlation coefficient (Reboredo, 2018). The S&P Dow Jones Green Bond Index (SPGBI) is utilized in this paper to track the price performance of the global green bond market. This index was launched in July 2014 and is a multi-currency benchmark, but calculated in US dollars, that includes green-labelled bonds according to CBI criteria issued by multilateral, government and corporate issuers from any country. The SPGBI constitutes a market-value weighted index which is rebalanced on a monthly basis, and only includes investment-grade rated bonds with a maturity greater than or equal to one month from the rebalancing period. It should be noted that the SPGBI has been used in many studies in the green bond field (e.g., Boyer de la Girovay and Stenvall, 2019; Naeem et al., 2021b; Arif et al., 2021; Ferrer et al., 2021a; Pham, 2021), although most of these works show that empirical findings are robust to any particular green bond index employed.

The green equity market is proxied by the S&P Global Clean Energy Index (SPGCE), which measures the stock performance of corporations from both developed and emerging countries that are involved in the production of clean energy or provision of clean energy technology and equipment. The S&P Global Clean Energy Index used in

[2] T-student distribution functions have been alternatively used for the conditional density of innovations and the results of the Quantile Coherency approach are virtually unaltered.

this paper captures the performance of the 30 global leading clean energy-related stocks. However, since April 19, 2021 this index has broaden to include up to 100 eligible stocks in order to better reflect the clean energy industry as investor attention has substantially increased over the past few years.

As for the conventional asset classes, different types of fixed-income securities, including Treasury bonds, investment-grade and high-yield corporate bonds, general stocks, crude oil and gold are considered. The choice of various categories of ordinary bonds has its origin in the fact that green bonds are a special type of fixed-income security. Similarly, given that clean energy stocks represent a segment of the of the overall stock market, it seems also appropriate to analyze the dependence between general stocks and alternative energy stocks. Moreover, the inclusion of crude oil in the analysis is motivated by the idea that the behavior of green financial instruments can be influenced by the development of energy prices, particularly crude oil. For instance, lower oil prices reduce incentives to use renewable energy alternatives and can affect adversely the economic viability of many eco-friendly projects mostly funded by green bonds and green equities. In addition, studying the link between green financial assets and gold can be of particular interest for investors in order to determine whether green bonds and/or stocks exhibit certain safe-haven properties similar to gold, especially in times of market turbulence.

More specifically, the Bloomberg Barclays Global Treasury Total Return Index Value Unhedged is employed as a proxy for the global Treasury market. This index tracks fixed-rate, local currency government debt of investment grade countries, including both emerging and developed markets. It currently contains issues from 37 countries. For its part, the Bloomberg Barclays Global Aggregate Corporate Total Return Index Unhedged is employed to represent the investment-grade, fixed-rate corporate debt market. This multi-currency benchmark includes high credit quality bonds from developed and emerging market issuers within the industrial, utility and financial sectors. Likewise, the high-yield corporate debt market is represented by the Bloomberg Barclays Global High-Yield Total Return Index Unhedged, which is a multi-currency benchmark that accounts for the price performance of this market as reflected by the union of the US High-Yield, the Pan-European High-Yield, and Emerging Markets Hard Currency High Yield Indices.

Furthermore, the MSCI All Country World Index (MSCI ACWI) is used to measure the global equity market performance, including the full-opportunity set of large- and mid-cap stocks across 23 developed and 27 emerging markets. As of November 2020, it included more than 3,000 constituents across 11 different sectors, covering approximately the 85% of the free float adjusted market capitalization in each market. Although numerous works in this field have employed the MSCI World Index (i.e., Reboredo and Ugolini, 2020; Pham, 2021), which only covers stock price performance from 23 developed countries, we have decided to use the MSCI ACWI Index in this study for several reasons. Firstly, emerging market green bond issuance has grown extraordinarily during the last five years and, according to the World Bank Group member

International Finance Corporation (IFC), the 2023 figure is expected to exceed the $100bn mark of annual issuance, which is more than double the $40bn 2020 figure. Secondly, the green stock market of emerging countries is also expected to continue its current upward trend; in fact, according to IFC, climate-smart investment opportunities are predicted to amount up to $23tn in emerging markets. And lastly, the remaining bond and stock market indices considered also include both developed and emerging country issuers. In any case, the MSCI All Country World Index and the MSCI World Index have a near-one Pearson correlation coefficient, so the results should not be practically affected by the particular general stock market index utilized.

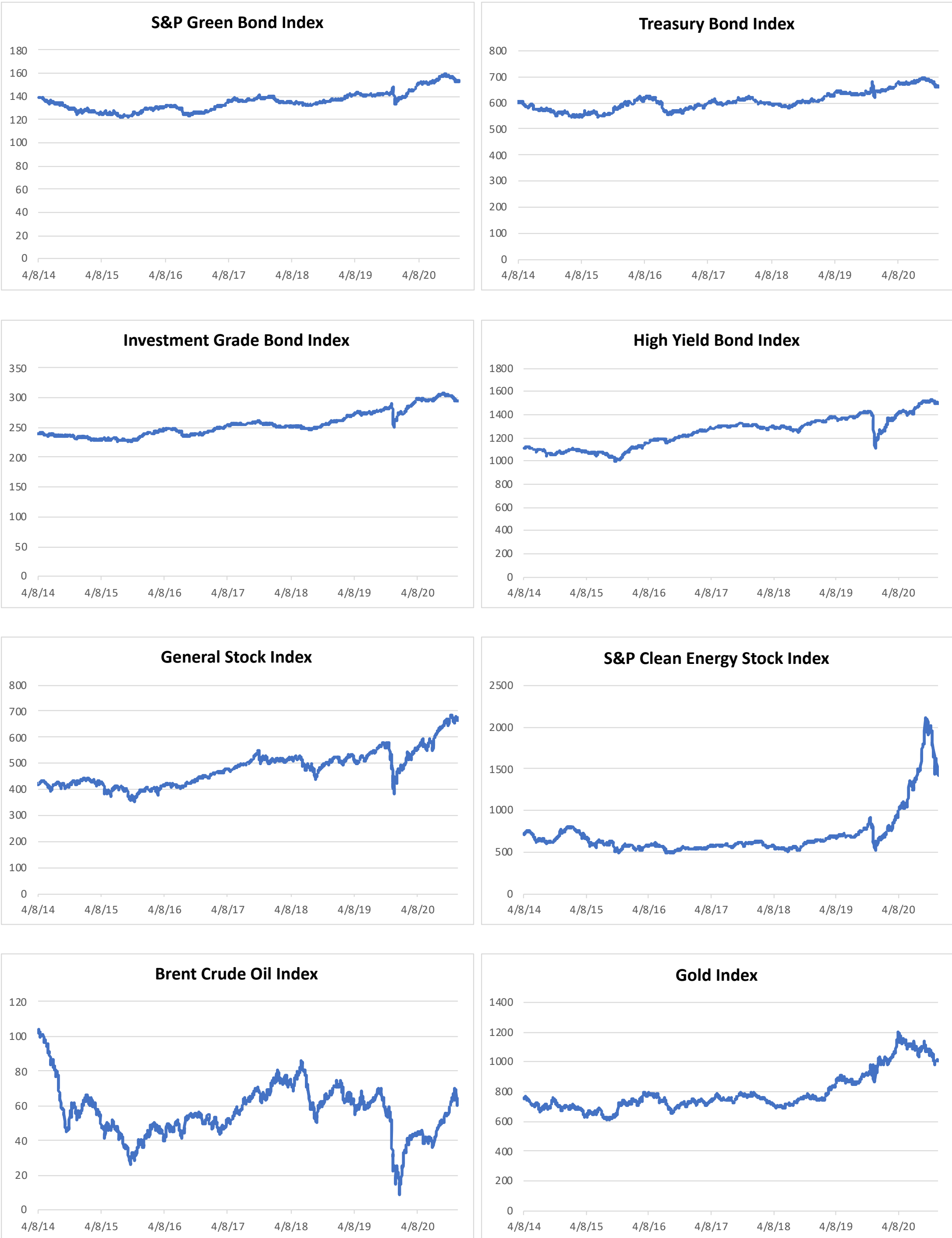
In addition, the Brent Spot Price (FOB), which is nowadays the leading global benchmark for African, European, and Middle Eastern crude oil, is used to describe the dynamics of the international oil market.

Finally, the performance of the global gold market is tracked by the S&P GSCI Gold Spot Price Index.

Figure 2 displays the evolution over time of prices of green bonds and clean energy stocks as well as the group of conventional asset classes. At first sight, green bonds behave very similarly to Treasury bonds, investment grade and high yield corporate bonds. On the contrary, the performance of the green equity market during the full sample period is not very similar to that of the general stock market. Besides, there seems to be no close connection between green bond and green equity markets. Likewise, the crude oil market behavior appears to be quite independent from that of the remaining markets under scrutiny. Interestingly, the general market downturn during the period March-April 2020 period caused by the outbreak of the COVID-19 pandemic is quite visible in all cases, with the only exception of gold. The singular behavior of gold can be attributed to its safe-haven nature, which is manifested especially during periods of economic and financial uncertainty, such as the COVID-19 crisis.

Following the usual practice in financial applications to achieve stationarity of the data, returns are calculated as the first difference of the log price indices. Table 1 present the main descriptive statistics of the time series under study. As can be seen, all series have near-zero average daily returns, the Brent crude oil being the only one with a negative mean value during the entire sample period. Standard deviation values are substantially higher than mean returns in all cases, suggesting relatively high volatility in all asset classes and possible outliers in the data. As expected, the standard deviation of green bonds is similar to that of the other types of bonds. Moreover, general and clean energy stocks have a notably higher volatility than fixed-income securities, reflecting the riskier nature of equities. Interestingly, the Brent crude oil exhibits the largest standard deviation, which can be attributed to the enormous variability of crude oil prices since the mid-2000s.

Figure 2. Time series plot of green and conventional asset class price indices



Source: Own elaboration

Except from gold returns, all series display a certain negative skewness, which is rather common in the case of financial returns and suggests a greater probability of negative returns compared to normal distributions. All series are clearly leptokurtic, with a larger number of observations close to the mean and fatter tails than normally distributed series. Thus, it is not surprising that the Jarque-Bera (JB) test statistics overwhelmingly reject the null hypothesis of normality in all cases at the 1% level. This departure from normality supports the usefulness of the Quantile Coherency methodology, as the dependence structure can vary across different parts of the joint return distribution when the normality assumption is not met.

Finally, the values of the statistics of the standard Augmented Dickey-Fuller (ADF) test, which tests the null hypothesis that a unit root is present in a time series, indicate that all individual series are stationary processes at the 1% significance level. The results of the Kwiatkowski-Phillips-Schmidt-Shin stationarity (KPSS) stationarity test confirm this evidence, failing to reject the null hypothesis that a time series is stationary around a deterministic trend in all eight cases at the 5% level.

Table 1. Descriptive statistics of the data

	Mean	Std	Skn	Kurt	JB	ADF	KPSS
SPGBI	0.000054	0.0031	-0.5552	9.0763	2,738.7***	-12.453***	0.337
TREASURY	0.000054	0.0036	-0.1956	6.7259	1,007.1***	-12.724***	0.145
INV. GRADE	0.000119	0.0029	-2.0028	25.5127	37,517.6***	-12.115***	0.129
HIGH-YIELD	0.000174	0.0034	-2.5812	42.4036	113,317.8***	-10.636***	0.067
MSCI ACWI	0.000271	0.0092	-1.5265	25.9347	38,410.4***	-11.789***	0.108
SPGCE	0.000414	0.0145	-0.8127	15.2511	10,958.9***	-10.613***	0.473**
BRENT	-0.000282	0.0343	-2.9300	96.1213	624,653.3***	-11.877***	0.131
GOLD	0.000172	0.0092	0.0377	7.8416	1,682.3***	-11.805***	0.155

*Note: This table shows the main descriptive statistics of each individual return series. Std, Skn and Kurt denote standard deviation, skewness and kurtosis, respectively. In turn, JB stands for the value of the statistic of the Jarque-Bera test for normality. In addition, ADF refers to the unit root Augmented Dickey-Fuller test, while KPSS is the Kwiatkowski-Phillips-Schmidt-Shin test for stationarity. As usual, *** and ** indicate statistical significance at the 1% and 5% levels, respectively.*

Table 2 reports the Pearson correlation coefficients between the returns of each pair of assets over the entire sample period. A very high positive correlation is found between green bond and Treasury bond returns (0.86), and also between green bond and investment-grade corporate bond returns (0.84) This suggests a remarkable association between green bonds and ordinary high credit-quality bonds. A positive but weaker linear relationship is found for green and high-yield corporate bond returns (0.47), and an even lower linear link is shown with the general stock market (0.14). For its part, the global clean energy sector seems to be mostly connected with the overall equity market (0.76) and, to a lesser extent, the high-yield corporate bond market (0.56). In this sense, it is also interesting to highlight the quite significant correlation between high-yield bond returns and general stock returns. However, despite the common climate-friendly nature of green bonds and renewable energy stocks, their correlation is rather low (0.16). Furthermore, an almost negligible positive correlation (0.02) is observed between the green bond and the crude oil markets. Although the linkage between the clean energy and the crude oil market is considerably higher (0.29), it is still much lower in comparison with the connection it has with other asset classes, such as the general stock market. Lastly, it is surprising the quite strong connection between green bonds and gold (0.45), while the correlation between green stocks and gold is considerably low (0.08). The high pairwise linear correlations here presented indicate the possible existence of a rich dependence pattern between green investments and traditional asset classes, which suggests the appropriateness of applying the Quantile Coherency approach to conduct a more in-depth analysis of the dependence structure at various time horizons and under different market conditions.

Table 2. Pearson correlation matrix

	SPGBI	TREASURY	INV. GRADE	HIGH-YIELD	MSCI ACWI	SPGCE	BRENT	GOLD
SPGBI	1.0000							
TREASURY	0.8637	1.0000						
INV. GRADE	0.8413	0.7968	1.0000					
HIGH-YIELD	0.4678	0.2116	0.5183	1.0000				
MSCI ACWI	0.1357	-0.083	0.1160	0.6581	1.0000			
SPGCE	0.1621	-0.016	0.1615	0.5600	0.7550	1.0000		
BRENT	0.0155	-0.0741	0.0022	0.2991	0.3338	0.2872	1.0000	
GOLD	0.4549	0.5077	0.4153	0.1116	0.0355	0.0798	0.0703	1.0000

Note: This table shows the values of the Pearson linear correlation coefficient between all pairs of variables over the full sample period.

5. Empirical results

In this section, we first show the empirical results of the dependence structure between green financial instruments and conventional asset classes over different quantile levels and frequencies based on the Quantile Coherency analysis for the whole sample period. Then, we check the robustness of the full sample results by examining the Quantile Coherency in the COVID-19 sub-period, which is associated with a considerable increase of market stress and financial uncertainty.

The findings of the Quantile Coherency analysis are presented through symmetric Quantile Coherency matrices at three quantile levels, i.e., 0.05, 0.50 and 0.95, which are indicative of the left tail, middle and right tail of the joint distribution of each pair of variables, respectively, as well as all their combinations. Each of the three sub-matrices located in the main diagonal of the Quantile Coherency matrix represent the dependence between two assets when both of their returns are situated in the same quantile level, that is, they are in the same market state (relatively stable, extreme bearish or extreme bullish). As indicated earlier, three different frequencies are taken into consideration: short-term (two trading days), medium-term (one business month) and long-term (one business year).[3]

The sign of the Quantile Coherency estimate indicates the sign of the dependence between the two variables considered. Since Quantile Coherency matrices are symmetric, we only show statistically significant coherencies (at the 5% level) in the area above the diagonal. All non-significant values are set to zero. Thus, the Quantile Coherency captures the pattern of dependence across various frequencies and under different market circumstances, providing a far richer picture than that obtained from pure frequency-domain or quantile-based methods.

5.1. Full sample analysis

The Quantile Coherency matrix depicted in Figure 3 shows the dependence structure between green financial assets and conventional asset classes in the very short-term (two days). As can be seen, the strongest positive dependence is found between green bonds and Treasury bonds, and between green bonds and corporate investment-grade bonds, irrespective of the quantile levels considered, i.e., under relatively stable and extreme bearish and bullish conditions in the two markets under consideration. There is also a significant positive dependence between green bonds and high-yield corporate bonds, although this association is substantially weaker than in the case of Treasury and high-credit quality corporate bonds, regardless of the market circumstances. Interestingly, there are no large differences in the level of dependence in these cases across different market conditions, although the dependence seems to be slightly high in the middle of the distribution. However, there is a weak dependence between the green bond and the general equity markets in the short run, particularly in the middle of the joint distribution of returns.

On the other hand, the connection between the green bond and the crude oil markets in the short-term appears to be so weak that quantile coherencies become statistically non-significant across the three market states considered. Furthermore, contrary to what one could think a priori due to its common green nature, no significant dependence is found between green bonds and clean energy stocks in the short-term irrespective of market circumstances.

[3] Several alternative frequencies, such as a week or two weeks, have been used to describe the short-term and the results of the Quantile Coherency approach are virtually unaltered.

Surprisingly, we observe a significant association between green bonds and the gold market when markets are under extreme bearish and relatively stable market conditions, although the degree of connection is lower than with fixed-income instruments. This relationship decreases when both markets are under extreme bullish market conditions, becoming insignificant.

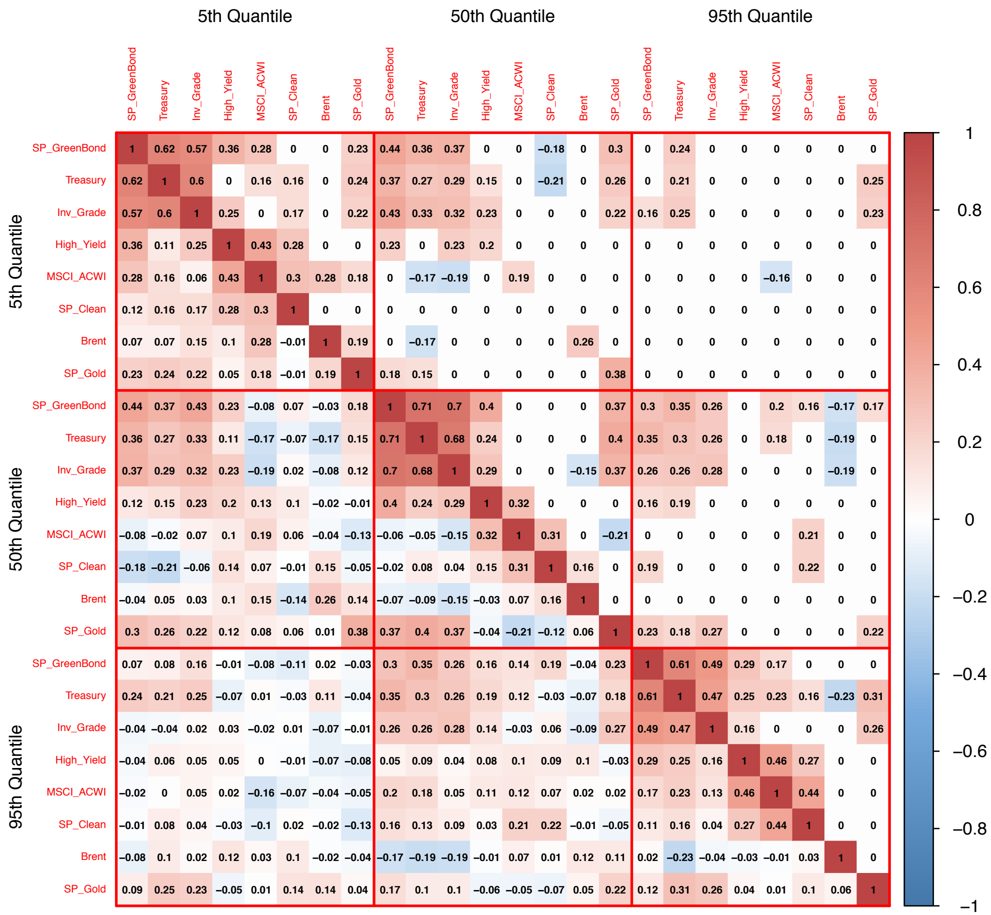
As for the dependence dynamics of the clean energy equity sector in the short-term, as might be expected, there is a significant association between renewable energy and general stocks irrespective of the market state. A remarkable positive relationship is also observed between alternative energy stocks and high-yield corporate bonds. Additionally, there seems to be a slight positive dependence between clean energy stocks and Treasury and investment-grade bonds, especially under bearish market conditions, but this linkage is much weaker.

Similarly to the green bond market, there appears to be no significant dependence between green stocks and crude oil in the short-term, excepting under relatively stable market circumstances. Likewise, the dependence between green stocks and the gold market in the short-term remains non-significant under the three market states.

Figure 4 depicts the dependence pattern between green financial instruments and conventional asset classes in the medium-term (1 month). Overall, the dependence structure in the medium-term is very similar to that observed in the very short-term. The dynamics of the green bond market is again most closely tied to movements in the Treasury and investment grade corporate bond markets and, to a lesser extent, to high-yield bonds. In fact, the level of dependence between green bonds and conventional bonds is very similar to that found in the very short-term for the three market states. Except for the median quantile, the already weak connection between the green bond and the general equity market appears to decrease under extreme market conditions. Interestingly, in the medium run, the dependence between the green bond and the gold market is quite solid under all market circumstances, which suggests that their connection tends to strengthen in longer investment horizons.

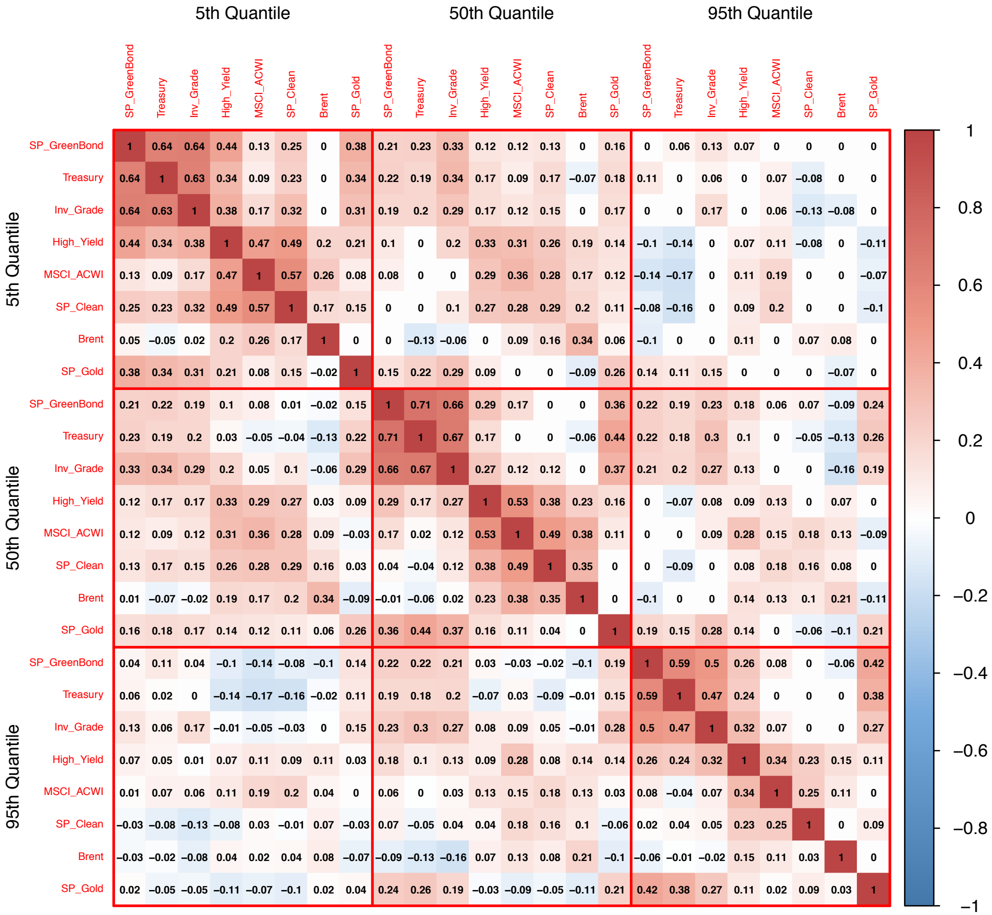
Once more, the connection between the green bond and the crude oil market appears to be negligible regardless of the market state, with the sole exception of a modest significative negative dependence under extreme bullish conditions. Similarly, the association between the green bonds and clean energy stocks is only significant during extreme bearish circumstances.

Figure 3. Short-term Quantile Coherency matrix (full sample)



Note: This matrix displays the estimates of the Quantile Coherency between green bonds and clean energy stocks and a set of major conventional asset classes in the short-term (2 days) for the entire sample period. All non-significant values at the 5% level above the main diagonal are set to zero. A color code is used where dark red and blue grids denote high positive and negative values of the Quantile Coherency, respectively.

Figure 4. Medium-term Quantile Coherency matrix (full sample)



Note: This matrix displays the estimates of the Quantile Coherency between green bonds and clean energy stocks and a set of major conventional asset classes in the medium-term (22 days) for the entire sample period. All non-significant values at the 5% level above the main diagonal are set to zero. A color code is used where dark red and blue grids denote high positive and negative values of the Quantile Coherency, respectively.

For their part, clean energy equities are mostly connected to general stocks under all market circumstances in the first place, and to high-yield corporate bonds in the second place. In a similar manner to short-term results shown in Figure 2, it is also remarkable the fact that when paired returns are located in the lower tail of the joint distribution, clean energy stocks seem to be also connected, although to a lesser extent, to the other three fixed income instruments under consideration (investment-grade corporate, green, and Treasury bonds) in the medium-run.

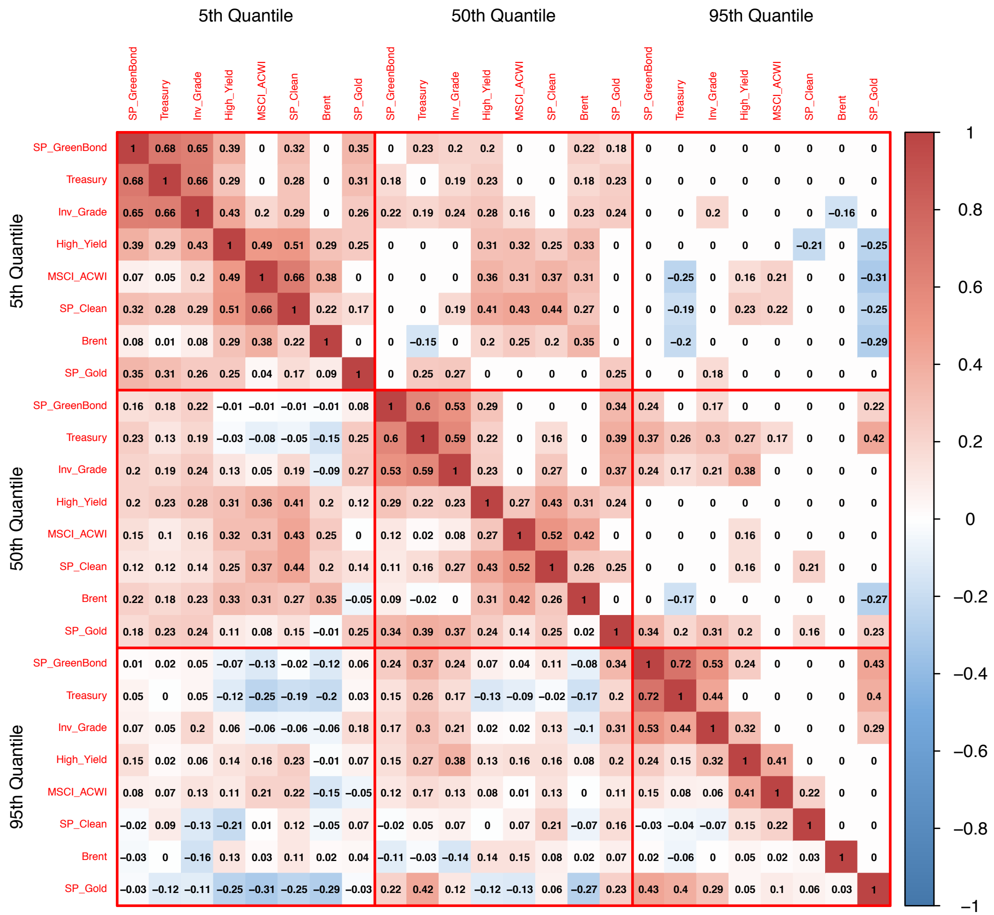
Nonetheless, contrary to the evidence in the short-term, the association between the clean energy equity sector and the crude oil market is significantly positive, although moderate, under extreme bearish and relatively stable market states, while it becomes negligible when both markets are booming. The connection between the renewable energy stock sector and the gold market in the medium-term is positive, but weak, mainly during extreme bearish market conditions.

Lastly, the estimates of the Quantile Coherency matrix corresponding to the long-term (1 year) are displayed in Figure 5. In general, the dependence structure shows a similar picture to that observed in the short- and medium-term. The strongest dependence is found again between green bonds and Treasury and investment-grade corporate bonds irrespective of the market circumstances, followed by a notably weaker dependence between green and high-yield corporate bonds. Contrarily, the association between green bonds and general equities is significant in the long-term only during extreme bearish conditions in both markets. Once more, the dependence between the green bond and the crude oil market is negligible in the three quantile combinations under consideration. Similarly to the results found in the medium-term, the association between green bonds and clean energy stocks is significant in the long-term only during extreme bearish conditions in both markets. Furthermore, a moderate significant positive dependence is detected between the green fixed-income and gold markets in the long-term.

On the other hand, clean energy stocks are again mostly connected to general stocks and, to a lesser extent, to high-yield corporate bonds, especially when markets are under extreme bearish or relatively stable conditions. A more moderate positive association is found in the long-term between renewable energy equities and Treasury and investment-grade corporate bonds, particularly under extreme bearish or stable market conditions. The degree of connection between clean energy stocks and crude oil is moderately positive and significant under extreme bearish and relatively stable market circumstances, and very similar to the one found in the medium-term. Finally, the dependence between renewable energy stocks and gold is moderately positive under extreme and relatively stable market states, although its values are considerably lower than in the case of green bonds.

Overall, our results reveal that the dependence structure between green investments and conventional asset classes varies across different quantiles. In general, the

Figure 5. Long-term Quantile Coherency matrix (full sample)



Note: This matrix displays the estimates of the Quantile Coherency between green bonds and clean energy stocks and a set of major conventional asset classes in the long-term (250 days) for the full sample period. All non-significant values at the 5% level above the main diagonal are set to zero. A color code is used where dark red and blue grids denote high positive and negative values of the Quantile Coherency, respectively.

dependence tends to be stronger under extreme bearish market conditions (quantile 0.05) than during relatively stable (quantile 0.5) and extreme bullish market states (quantile 0.95), especially when considering the association between clean energy stocks and traditional assets. This finding is consistent with the idea that returns of different markets are more interconnected during episodes of significant market downturns than in periods of sharp market upturns (Baruník and Kley, 2019), most likely as a result of financial risk contagion between markets or asset classes. However, it is worth noting that the dependence between green bonds and Treasury and investment-grade corporate bonds seems to be slightly stronger during relatively stable market conditions than during extreme bearish circumstances in the short- and medium-run.

There is not a significant difference across frequencies in terms of the level of dependence between green financial instruments and conventional asset classes in the cases where the connection is stronger. For example, the association between green bonds and Treasury and investment grade and high-yield corporate bonds is quite pronounced in the short-, medium- and long-term. Nevertheless, the dependence between renewable energy stocks and general stocks and high-yield corporate bonds varies in a greater extent across frequencies, although it remains quite high for the three investment horizons. For other combinations of assets, such as green bonds and clean energy stocks or crude oil and clean energy stocks, the level of dependence is particularly weak at the shorter horizon, indicating that these markets have a clear tendency to follow a marked idiosyncratic behavior in the very short-term.

Our empirical evidence clearly shows that the dependence structure between green bonds and Treasury and investment-grade corporate bond markets is strong in the short, medium- and long-term irrespective of market circumstances. This finding is totally consistent with the evidence provided by Reboredo et al. (2020), Ferrer et al (2021a) and Pham (2021). for various investment horizons. Likewise, Reboredo (2018), Reboredo and Ugolini (2020), Nguyen et al. (2021) and Ferrer et al. (2021b) also confirm the strong co-movement between the green bond and the Treasury and corporate bond markets, although they do not consider the dependence across different time scales or market conditions. This close linkage can be attributed to the fact that green bonds share many similarities with regular high-credit quality bonds in terms of issuers, credit rating, currency, maturity, coupon rates, etc. In fact, a large fraction of green bonds is issued by governments, supranational entities and corporations, who also issue most of the ordinary fixed-income securities and who set yields for green bonds taking Treasury or corporate bond yields as a reference. In other words, although green bonds differ from conventional bonds in terms of the use of their proceeds, allowing investors to integrate climate risk in their portfolios, green bonds exhibit a similar risk-return profile to that of Treasury and investment-grade corporate bonds. This means that green bonds offer little diversification benefits to investors in Treasury and high-credit quality corporate bonds, rather they can act as substitutes for traditional fixed-income securities in investors' portfolios.

High-yield corporate bonds are considered riskier than Treasury and investment-grade corporate bonds, being closer to general stocks in terms of risk profile, most likely due to the substantial exposure to default risk that high-yield bonds and stocks have in common. This fact could explain the lower connection between green bonds and high-yield corporate bonds irrespective of market circumstances and investment horizons, in comparison with the two previous types of bonds. Likewise, the modest degree of linkage between green bonds and general stocks regardless of the investment horizon and market conditions is most probably due to the fact that green bonds share more common characteristics with other fixed-income instruments than with equity investments, especially in terms of their long-term low risk profile, which would explain that the connection between both markets decreases in longer investment horizons. This evidence is in accordance with Reboredo (2018) and Reboredo and Ugolini (2020), who also report a time-varying but always weak connection between the green bond and the overall equity markets. Our results suggest that green bonds could serve as diversifiers for general stocks, especially in the long-term.

Interestingly, a quite solid linkage between gold and green bonds is observed at all time horizons and regardless of market circumstances, with the sole exception of the extreme bullish market state in the short-term. This indicates that green bonds seem to share some hedging and safe-haven capabilities with gold, which may be particularly useful in times of market turmoil. This evidence is in agreement with that of Ferrer et al. (2021a), who show that gold and green bonds can be included in the same category of assets for all time horizons.

In contrast, despite the substitutive character between renewable energy and crude oil, the insignificant dependence between the green bond market and the crude oil market irrespective of the time horizon and market circumstances indicates that the dynamics of crude oil prices has not played a leading role in the vertiginous growth of the global green bond market in the last few years. Therefore, the expansion of green bonds may be more likely explained by alternative factors such as rising environmental awareness among investors and policy makers, the attractiveness of green bonds in terms of market performance, and the growing issuers and investors' confidence in green bonds as a result of the improved transparency and market integrity. In the light of this evidence, it can be said that green bonds can act as a good diversifier against traditional crude oil investments. This finding is consistent with the decoupling of crude oil prices from the green bond market suggested by Ferrer et al. (2021a) and Ferrer et al. (2021b).

As mentioned above, green bonds and renewable energy stocks exhibit a moderate positive dependence in the medium- and long-term, but only under extreme bearish market conditions, when returns of both green financial instruments are falling at the same time. This result is in line with the evidence provided by Ferrer et al. (2021a), who show that green bonds and green stocks are not closely tied for any investment horizon. Moreover, our findings are in accordance with those of Pham (2021), who suggests that the connection between these two green financial instruments is not sizeable under relatively normal market circumstances but increases greatly during extreme market conditions. Therefore, the low level of general dependence found between green bonds and renewable energy equities implies that, despite the green nature they share, these two green investments cannot be regarded as a separate *green* asset class. In fact, in the very short-term green bonds and clean energy stocks show a completely independent behavior irrespective of market conditions. An interesting implication of this result is that green bonds and clean energy stocks can act as effective diversifiers for each other, particularly in the very short-term, but also in the medium- and long-term, excepting during episodes of sharp market downturns.

The remarkable association between alternative energy stocks and general stocks regardless of the time horizon and market conditions is not surprising at all, taking into account that clean energy equities represent an increasingly important part of the overall equity market. Moreover, the significant link between renewable energy stocks and high-yield corporate bonds can be explained by the similar risk-return profile of both assets. In fact, high-yield bond investments have historically offered similar returns to equities, especially in the long-term, due to the combination of enhanced yield and their potential for capital appreciation (although less than stocks). Accordingly, high-yield bonds seem to be more similar to stocks than to Treasury and investment-grade corporate bonds. Therefore, according to the results obtained, diversifying benefits of clean energy stocks against portfolios primarily composed of general stocks and/or high-yield corporate bonds are quite limited regardless of the investment horizon and market conditions. Once more, these findings are consistent with the evidence reported in Ferrer et al. (2021a), who find that green stocks, general stocks and high-yield bonds belong to the same wavelet coherence-based network for all time horizons.

The Quantile Coherency estimates of the dependence between renewable energy stocks and crude oil indicate a moderate positive association, particularly in the medium- and long-term and under relatively stable and bearish market states. A possible explanation for this result is that medium-term and long-term investors are more concerned about the development of crude oil prices, mainly when markets are not performing at their best. Rising crude oil prices during extended periods of time lead to an increase in demand for alternative energy sources, thus strengthening the positive relationship between the crude oil and clean energy stock returns. Furthermore, growing crude oil prices are typically associated with increased global aggregate demand, which has also a positive effect on renewable energy stock prices. Consequently, alternative energy stocks can act as significant diversifiers against crude oil investments especially in the very short-term. In any case, it is important to highlight that the connection between both markets is still weak compared to the dependence of clean energy equities with other assets, which confirms that crude oil price dynamics is not a key driver of the behavior of renewable energy stock prices. Thus, the equity market performance of clean energy companies is likely to be more related to other factors, such as the overall stock market performance, the business cycle or the increasing global awareness of climate-change issues. Together with the negligible dependence between the green bond and the crude oil market, this weak connection suggests that crude oil and green energy are used to satisfy different parts of the global energy demand and do not generally act as substitute investments. Particularly, green instruments attract a special type of investor profile driven, at least partly, by non-pecuniary interests related to pro-environmental preferences and climate change awareness.

Lastly, clean energy stocks appear to be weakly connected with gold, particularly at longer investment horizons. This result suggests that renewable energy stocks share less safe haven features with gold than green bonds, probably because of the riskier profile of clean energy stocks given their equity nature.

For the rest of the quantile combinations, the evidence suggested by our results is rather mixed. In general, we find similar results in terms of a moderate connection between green bonds and Treasury and investment-grade corporate bonds, and an association between clean energy stocks and general equity and high-yield corporate bonds when returns are located in different quantiles. However, it is remarkable that the connection between assets tends to weaken or even become non-significant in the majority of the cases, especially for opposite quantile combinations in the short-term (as seen in Figure 2, which shows a considerable number of white grids above the diagonal). Specifically, along with the results of Pham (2021), we find that when the green bond and the green stock market returns are in opposite quantiles, i.e., 0.05|0.95 or 0.95|0.05, respectively, the Quantile Coherency analysis suggests insignificant or considerably low degrees of connectedness between these markets regardless of the time horizon considered. This means that, in general, both markets boom and crash together, so good (bad) news in one market are seen as good (bad) news impacting the other market.

5.2. COVID-19 sub-period analysis

Next, we check the robustness of the results of the full sample period by performing the Quantile Coherency analysis for the sub-period associated with the COVID-19 crisis, which runs from January 2, 2020 to the end of the sample (March 26, 2021). Due to the limited length of the COVID-19 sub-period, we define the long-term in this case as 6 months (125 days). We keep the very short- and medium-term as 2 trading days and 1 month (22 days), respectively.

Figures 6, 7 and 8 display the results of the dependence dynamics between green assets and the set of conventional asset classes for the short-, medium- and long-term, respectively. The limited number of available observations included in the COVID-19 sample period may justify the fact that we obtain a considerable number of non-significant Quantile Coherency values, in comparison with the entire sample analysis. Thus, especially long-term results should be interpreted with caution.

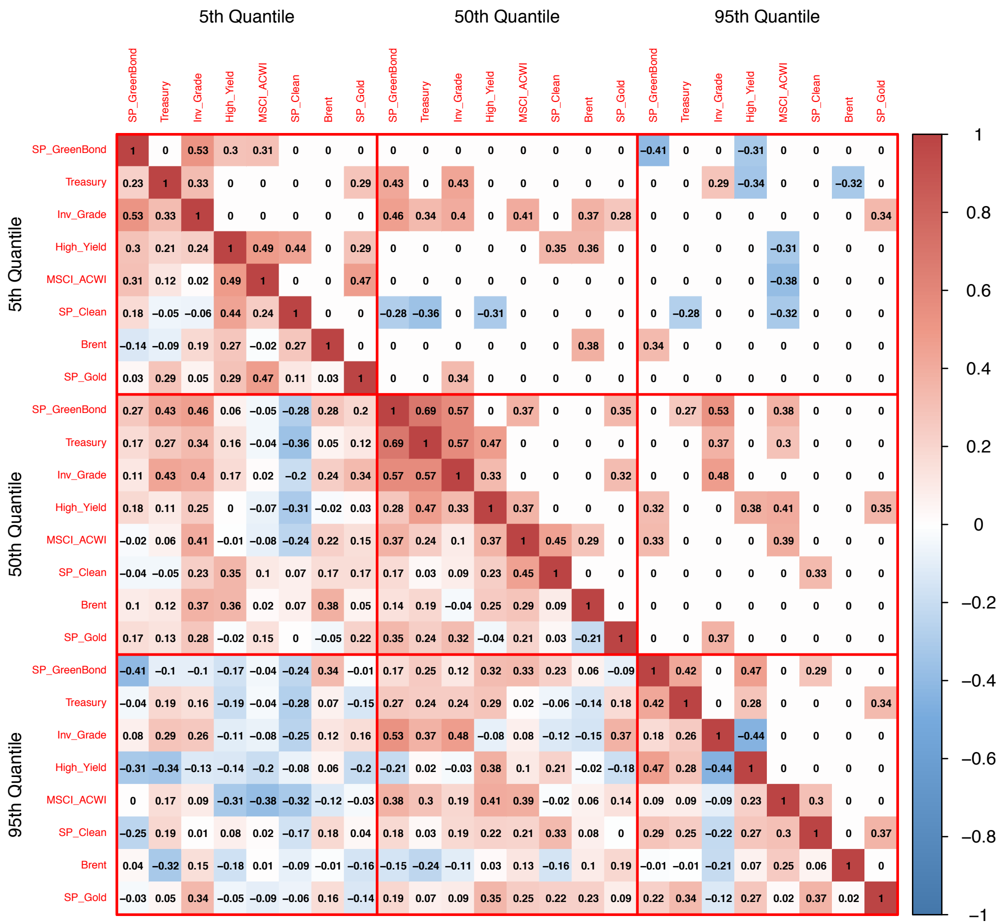
Overall, the results for the COVID-19 sub-period are largely consistent with those of the full sample analysis in terms of the strongest and weakest connections between green investments and conventional asset classes irrespective of the time horizon and market conditions. Again, green bonds exhibit a close association with high credit-quality bonds, while clean energy equities are mostly linked to general equities and high-yield corporate bonds. Moreover, there appears to be only a limited dependence between green investments and the crude oil market. In general, the most pronounced connections between green financial instruments and traditional asset classes are detected in the medium- and long-term under extreme bearish market conditions, supporting the view of increased market interdependence in turbulent times, such as the COVID-19 crisis. These findings are in line with the evidence reported by Pham (2021), who suggests that the increasing uncertainty during the COVID-19 pandemic led to more persistent responses of investors to shocks, thereby increasing the connectedness at intermediate and longer frequencies.

Particularly, we can highlight the significant strengthening of the dependence between green bonds and clean energy stocks in the medium- and long-term under extreme bearish market circumstances, as against the full-sample results. This result is consistent with the idea that investors with longer horizons assume that the two green investments are affected by the same risk factors when the whole financial system is in a situation of maximum uncertainty. Thus, in such cases, investors might regard green bonds and green stocks as more similar asset classes. In this sense, our sub-period results are in line with the evidence of Ferrer et al. (2021a), who only find that green stocks and green bonds are in the same asset class in the long-term during the COVID-19 crisis. This finding is also in agreement with that of Pham (2021), who shows that both green markets bust together, thus significantly increasing their interdependence under extreme bearish market conditions during turmoil periods.

In the same vein, the linkages between green bonds and the general equity market, and between green equities and investment-grade bonds and, in a lower extent, Treasury bonds, notably increase in the COVID-19 sub-period. This can be attributed to the fact that green investments represent a subset of the overall financial market, so their interconnection with other assets rises during financial crises. This greater connectedness during the COVID-19 pandemic is fully consistent with the results of Naeem et al. (2021a) and the overall financial contagion literature theory.

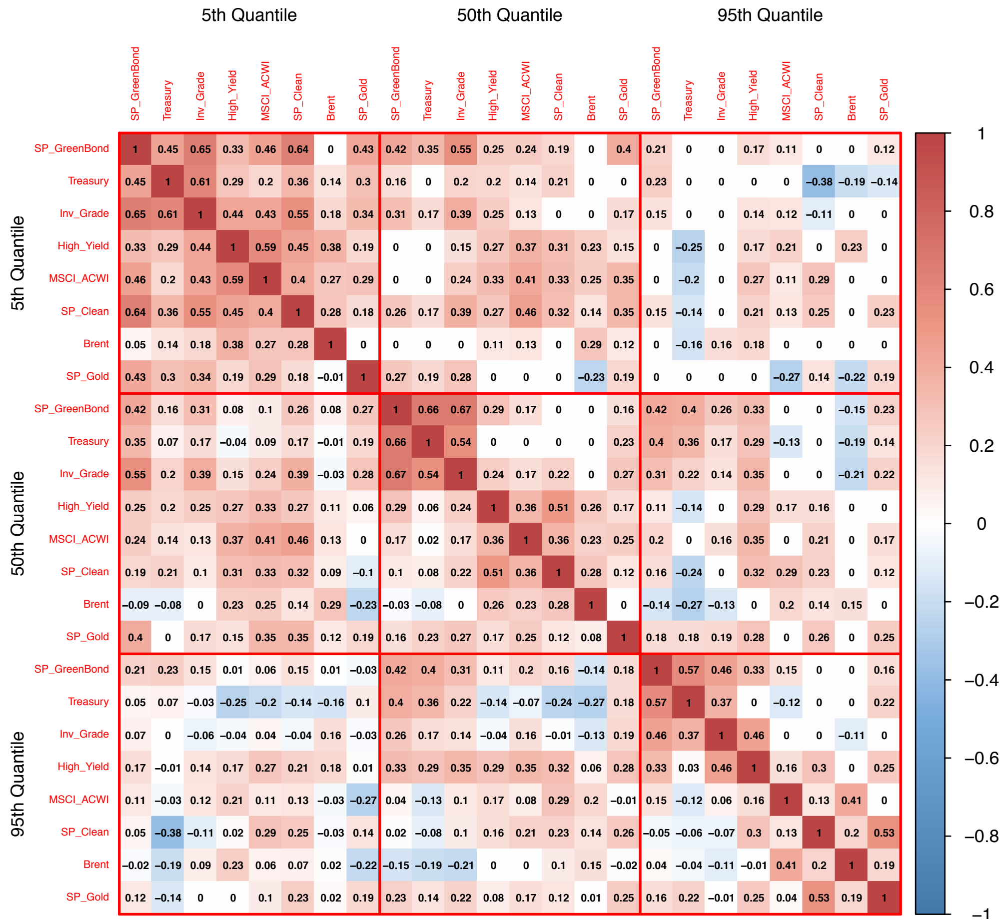
Our COVID-19 subperiod results confirm the insignificant dependence between green bonds and crude oil regardless of the horizon and market state, indicating that the price dynamics of the crude oil energy market has a very limited capacity to affect the green fixed-income market even during turbulent times. Moreover, the fact that the connection between clean energy equities and crude oil considerably increases in the medium- and long-term under extreme bearish market conditions as compared to our full-sample results supports the idea that investors in clean energy stocks are more concerned about more permanent changes in oil prices that could affect the value of their portfolios, mainly during episodes of sharp market downturns.

Figure 6. Short-term Quantile Coherency matrix (COVID-19 sub-period)



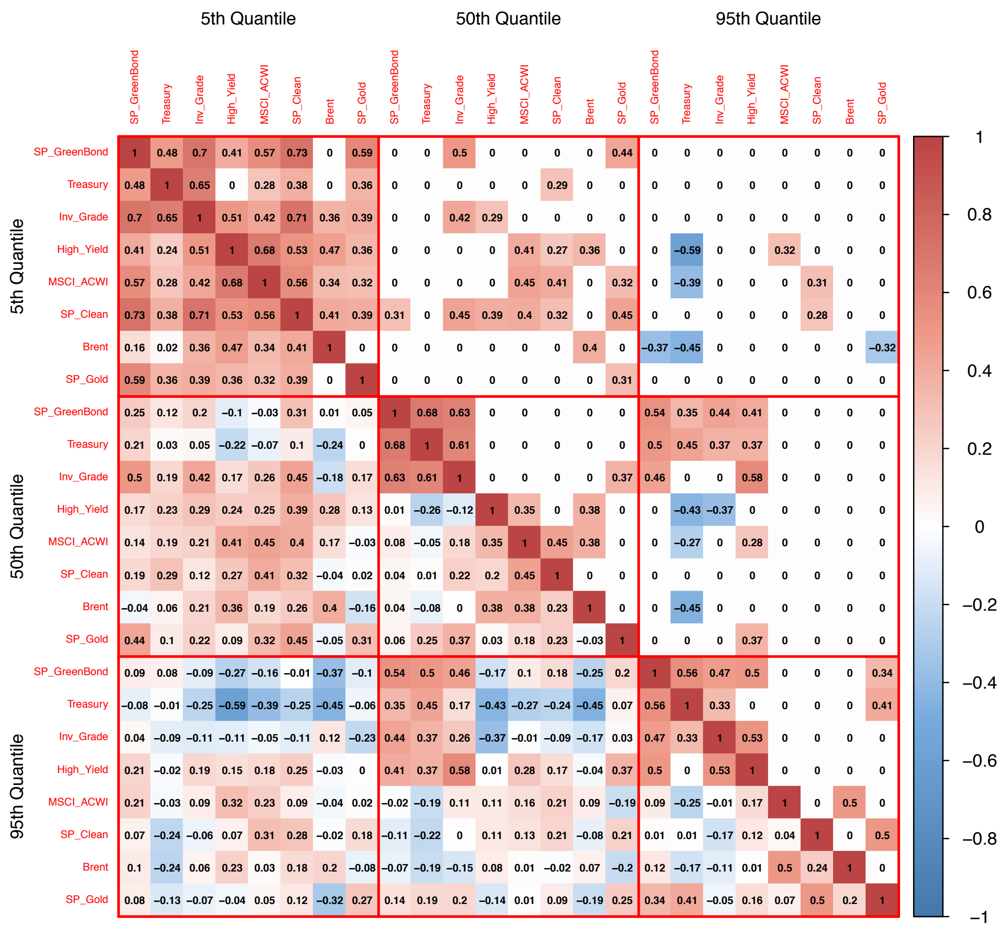
Note: This matrix displays the estimates of the Quantile Coherency between green bonds and clean energy stocks and a set of major conventional asset classes in the short-term (2 days) for the COVID-19 sub-period. All non-significant values at the 5% level above the main diagonal are set to zero. A color code is used where dark red and blue grids denote high positive and negative values of the Quantile Coherency, respectively.

Figure 7. Medium-term Quantile Coherency matrix (COVID-19 sub-period)



Note: This matrix displays the estimates of the Quantile Coherency between green bonds and clean energy stocks and a set of major conventional asset classes in the medium-term (22 days) for the COVID-19 sub-period. All non-significant values at the 5% level above the main diagonal are set to zero. A color code is used where dark red and blue grids denote high positive and negative values of the Quantile Coherency, respectively.

Figure 8. Long-term Quantile Coherency matrix (COVID-19 sub-period)



Note: This matrix displays the estimates of the Quantile Coherency between green bonds and clean energy stocks and a set of major conventional asset classes in the long-term (125 days) for the COVID-19 sub-period. All non-significant values at the 5% level above the main diagonal are set to zero. A color code is used where dark red and blue grids denote high positive and negative values of the Quantile Coherency, respectively.

Finally, our sub-period results confirm the existence of a solid link between green bonds and gold, especially under extreme bearish market conditions in the medium- and long-term, as compared to the full-sample analysis. This corroborates the idea that green assets may have some safe-haven properties against traditional assets in times of financial uncertainty and stress, as also suggested by Arif et al. (2021).

6. Conclusions

The increasing environmental awareness caused by the acceleration of climate change over the last decade has underlined the urgent need of a transition towards a low-carbon economy. An immense amount of capital has to be mobilized to finance the massive environmental-friendly projects required for that transition and green financial instruments should play a crucial role in this process. In this context, the present paper examines the pattern of dependence between green investments, represented by green bonds and clean energy stocks, and a set of major conventional assets, including Treasury bonds, investment grade and high-yield corporate bonds, general stocks, crude oil and gold, over diverse investment horizons (very short-, medium- and long-term) and under different market conditions (relatively stable and extreme bearish and bullish states) simultaneously. With this purpose, the Quantile Coherency approach recently developed by Baruník and Kley (2019) is applied.

Overall, our empirical results show that the dependence pattern between green financial instruments and traditional asset classes tends to be stronger in lower tail quantiles for the majority of the cases both in the full-sample and the pandemic sub-period analyses, most likely as a result of financial contagion and increased market interconnectedness during episodes of significant market downturns, such as the COVID-19 sub-period. A strong level of dependence is detected between green bonds and government and investment-grade corporate bonds irrespective of the investment horizon and specific market circumstances. This finding can be attributed to the large common ground between green bonds and regular fixed-income instruments in terms of credit quality, issuers, maturity, coupon rates and currency, which makes them assets with a very similar risk-return profile. Analogously, as might be expected, a close tie is identified between clean energy stocks and general stocks regardless of the time horizon and market state. The high dependence can be explained by the fact that renewable energy equities constitute an increasingly important part of the overall equity market. There is also a significant positive relationship between clean energy stocks and high-yield corporate bonds at longer horizons, confirming that high-yield bonds share great similarities with stocks in the long-term due to their common high exposure to default risk. At the same time, a modest link is found between green bonds and general stocks for any horizon and market situation, due presumably to the lower risk profile of green fixed-income securities compared to stocks. Likewise, the association between renewable energy stocks and Treasury and investment-grade corporate bonds is weak under any circumstance for the same reason.

Despite the environmental-friendly nature shared by green bonds and clean energy stocks, the empirical results illustrate a quite low level of dependence between both green investments, with the only exception of the medium- and long-term under extreme bearish market conditions. In the light of this evidence, it is quite clear that green bonds and renewable energy stocks cannot be labelled as a separate *green* asset class. Instead, investors are more likely to regard green bonds as a type of fixed-income instrument and clean energy stocks as a category of equity, which supports the idea that, in terms of asset classification, the intrinsic character of both green investments is more relevant than their green nature.

Our findings also reveal a negligible connection between green bonds and crude oil regardless of the time horizon and market circumstances, even during the COVID-19 sub-period. This implies that the rapid expansion of the green bond market since the mid-2010s has been virtually unaffected by the dynamics of crude oil prices. However, a more significant positive association is observed between renewable energy stocks and crude oil, particularly in the medium- and long-term and under relatively stable market states. In any case, the lack of a close linkage between green financial instruments and crude oil appears to indicate that the development of crude oil prices has not played a leading role in the boom of green bonds and renewable energy stocks over the past decade, but the blossoming of green finance can be more related to increased environmental awareness within society.

Lastly, it is also worth mentioning the solid linkage detected between green bonds and gold irrespective of the time horizon and market circumstances, suggesting that green bonds seem to exhibit some hedging and safe-haven properties similar to gold, which may be particularly useful in times of market turmoil. The COVID-19 sub-period analysis further corroborates this idea. On the contrary, the riskier profile of clean energy equities justifies their weaker connection with gold which, once again, supports the view that green bonds and green equities represent different asset classes. In general, our results are broadly consistent with the empirical evidence previously provided by Reboredo (2018), Reboredo et al. (2020), Reboredo and Ugolini (2020), Ferrer et al. (2018), Nguyen et al. (2021), Ferrer et al. (2021a) and Ferrer et al. (2021b) using a number of different empirical approaches. Therefore, the pattern of dependence found between green financial instruments and conventional asset classes is robust to the methodology applied.

The empirical evidence regarding the dependence between green financial instruments and conventional asset classes can have several interesting implications for green investors in terms of portfolio design and risk management. Specifically, green bonds allow investors with pro-environmental preferences and low-risk profile to safeguard their commitment in the fight against climate change without having to sacrifice a significant part of returns produced by ordinary high-credit quality bonds. Furthermore, investors should be aware that green bonds offer very little diversification and hedging benefits to portfolios primarily made up of Treasury and investment-grade corporate bonds. Likewise, clean energy stocks give investors the possibility to achieve enhanced returns typically associated with riskier assets like stocks, while contributing to *greening* the economy. Once more, investors should bear in mind that the diversification and hedging benefits of renewable energy equities against general equities and high-yield bonds are quite limited. However, green bonds constitute an effective hedging risk tool over different investment horizons and under various market conditions for portfolios comprised of assets such as crude oil-related assets, clean energy equities, and/or general stocks. In the same vein, renewable energy stocks can provide a good hedge against Treasury bonds, investment-grade corporate bonds and crude oil-related investments. Furthermore, investors can also benefit from the fact that holding green asset positions boosts their portfolio's ESG scores, which is nowadays of major relevance given the increased climate risk awareness in society. In addition, given the weak relationship found between green bonds and clean energy stocks, investors could further increase their portfolio's ESG ratings by combining both green investments, while preserving the diversification benefits that their different intrinsic nature offers.

Finally, our evidence also has useful implications for policy makers concerned about the expansion of a robust and transparent sustainable financial system that helps achieve the environmental goals of governments. Policy makers should be aware that green financial markets are exposed to the same risk factors than their non-green equivalents. Therefore, they must continue implementing policies aimed at promoting the development and improvement of the efficiency of green markets, thus reducing their vulnerability during episodes of financial turmoil. In this way, increased confidence of investors and issuers in such green financial markets will contribute to mobilize the vast amount of funds required for the transition towards a more sustainable economy. The lack of a strong dependence between green financial assets and crude oil is positive from the perspective of policy makers as it implies a lower susceptibility of the green financial system to crude oil price shocks. Likewise, the weak link between green bonds and clean energy equities also lessens the level of fragility of the green financial sector to external shocks. Additionally, the high dependence between green bonds and high-credit quality bonds, alongside the safe haven features that green bonds seem to share with gold in times of heightened uncertainty, support the suitability of green bonds as low-risk instruments to be used in public COVID-19 recovery funds, while attaining governments' climate-change goals.

Although we have used global indices and revealed noteworthy findings in the present paper, it is worth noting that the alternative energy industry is very broad and is composed of various sectors depending on the particular source of energy. Moreover, the results could differ depending on the particular geographic market considered. Therefore, future research could address these limitations expanding the Quantile

Coherency analysis by considering different types of green stocks or using regional market indices. Furthermore, given the interesting empirical evidence obtained in related literature including other variables, another possibility would be to expand the analysis by adding other asset classes, such as technology stocks, various commodities or uncertainty-related variables. Alternative pathways of research could be to further explore the association between green and conventional assets from a multivariate perspective, so as to overcome the limitation of pairwise analysis that the Quantile Coherency approach faces, or to investigate dynamic causality between green and traditional assets in the frequency domain.

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