

Research on the Correlation Between China's Green Bond Market and Carbon Market

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Abstract: The issues of climate change have attracted much attention around the world. This study investigates the correlation between China's green bond market and carbon market using continuous and discrete wavelets. For the green bond index and carbon market transaction prices during 2014-2024, we find that the correlation and dependence between the green bond market and carbon market are strong, with the green bond market exhibiting a stronger correlation and dependence on the carbon market in the low-frequency region, and this strong correlation becomes more pronounced after 2020. Carbon market transaction prices have preceded changes in the green bond index, and the implementation of relevant policies or the occurrence of special events may strengthen the correlation between the two markets. These findings reflect the importance of developing green economy markets to facilitate the gradual transition to a sustainable economy.

Keywords: Green bond, Carbon market, Correlation, Wavelets, Wavelet coherence

1. Introduction

The convergence of environmental sustainability and financial innovation has established green finance as a critical enabler of energy conservation, emission mitigation, and optimized resource utilization. This dual role not only propels industrial modernization but also supports the advancement of high-quality economic development. As a cornerstone of green finance, China's green bond market has experienced rapid growth in recent years, aligning with national commitments to environmental targets. In parallel, China's pursuit of its "dual carbon" goals has led to the implementation of carbon trading pilot programs in seven regions, including Beijing, Shanghai, and Guangdong, since 2011. These initiatives have facilitated the creation of a hybrid carbon market system that combines project-specific mechanisms with quota-based trading. By embedding emission costs into corporate strategies and encouraging low-carbon innovation, these efforts not only lower compliance burdens but also provide empirical foundations for expanding nationwide carbon market frameworks.

Examining the interplay between China's green bond market and carbon trading mechanisms offers practical insights into accelerating low-carbon transitions. While prior research has focused on isolated analyses of green financial instruments, empirical investigations into their bidirectional relationships, particularly within China's dynamic policy environment, remain limited. This study addresses this gap by applying wavelet-based methodologies to analyze temporal and frequency-domain correlations, thereby uncovering nuanced interdependencies. Central research questions include: (1) What systematic linkages exist between China's green bond market and carbon markets?

(2) To what extent do carbon pricing dynamics precede shifts in green bond performance? (3) How do external policy interventions or macroeconomic shocks influence the strength and direction of these linkages?

By addressing these questions, this research advances academic understanding and informs policy frameworks, highlighting the synergistic potential of financial instruments and regulatory mechanisms in achieving sustainable development objectives?

2. Literature review

Existing scholarship has extensively examined the interplay between green financial instruments and environmental markets. [1] documented the superior performance of green bonds relative to conventional bonds, emphasizing their dual role in environmental and financial outcomes. [2] expanded this analysis by identifying weaker correlations between green bonds and equity or energy markets, contrasting their stronger alignment with traditional debt and monetary markets. Subsequent studies, such as [3], revealed short-term spillover effects between green bonds and broader financial markets, exacerbated by exogenous shocks like the COVID-19 pandemic. However, empirical investigations into the relationship between China's green bond market and its carbon trading mechanisms remain limited.

[4] and [5] posited that green bonds could accelerate low-carbon innovation, while carbon pricing mechanisms influence corporate emission reduction strategies. [6] employed nonlinear autoregressive distributed lag models to identify asymmetric interactions between carbon markets and energy-intensive sectors, highlighting the necessity of complementary green financing to address pricing challenges [7]. Research [8] further contributed to this discourse by emphasizing the role of market efficiency in cost internalization, a principle applicable to both carbon and green bond markets. Recent work [9] demonstrated that policy-related uncertainty amplifies interdependencies between these markets, whereas transient shocks weaken them. These findings collectively underscore a shared objective of emission reduction while highlighting divergent temporal cost structures: green bonds prioritize immediate decarbonization through future liabilities, whereas carbon markets impose present costs to incentivize long-term sustainability [10].

[11] further explored the sensitivity of green bond and carbon market linkages to economic policy uncertainty, reinforcing the need for multidimensional analyses. Despite these contributions, prior studies predominantly examine carbon markets in isolation or their interactions with equities [12], leaving the green bond-carbon market nexus underexplored. Additionally, temporal and frequency domain dynamics in the Chinese context remain overlooked. This study addresses these gaps by integrating wavelet methodologies, offering a comprehensive perspective on market interdependencies and advancing empirical insights into China's low-carbon transition.

3. Methodology and data

3.1. Methodology

Drawing on [13], this study employs continuous wavelet transforms (CWT) and cross-wavelet analysis to decompose the localized variance and covariance structures of the time series. Wavelet coherence and phase difference metrics are further utilized to quantify synchronized movements between the green bond index and carbon market prices across time-frequency domains. And a detailed analysis of wavelet methods can be found in [14]. Discrete wavelet transforms (DWT) supplement this approach by isolating linear and nonlinear causal relationships over multiscale horizons.

A wavelet function, derived from a mother wavelet, is defined as:

$$\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}} \psi\left(\frac{t-\tau}{s}\right) \quad (1)$$

Where τ and s denote translation and scale parameters, respectively. The Morlet wavelet, a Gaussian-modulated sinusoid, is selected for its optimal time-frequency resolution, with $w_0 = 6$ to balance localization precision:

$$\psi(t) = \pi^{-\frac{1}{4}} e^{iw_0 t} e^{-\frac{t^2}{2}} \quad (2)$$

The continuous wavelet which transforms $W_x(s)$ for a time series $x(t)$ is expressed as:

$$W_x(s) = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{s}} \psi^*\left(\frac{t}{s}\right) \quad (3)$$

Where the $*$ signifies the complex conjugate. Cross-wavelet power $W_n^{XY}(s)$, derived from $W_n^X(s)$ and $W_n^Y(s)$, captures joint variance contributions:

$$W_n^{XY}(s) = W_n^X(s) W_n^{Y*}(s) \quad (4)$$

In addition, the covariance between two sequences with time and frequency can be measured by wavelet coherence [15]. The formula for calculating the coherence coefficient of squared wavelets is as follows:

$$R_n^2(s) = \frac{\left| (s^{-1} W_n^{XY}(s)) \right|^2}{(s^{-1} |W_n^X(s)|^2) (s^{-1} |W_n^Y(s)|^2)} \quad (5)$$

Where s is the smoothing operator for time and scale. $R^2(s)$ is similar to the correlation coefficient. If $R^2(s)$ close to 0 indicate a weak dependence between the two series, and close to 1 indicates a strong dependence.

This paper also uses wavelet coherent phase difference to capture the negative correlation, positive correlation and lead-lag relationship between two time series in time-frequency space:

$$\varphi_{xy}(s) = \tan^{-1} \left(\frac{\Im(s^{-1} W_n^{XY}(s))}{\Re(s^{-1} W_n^{XY}(s))} \right) \quad (6)$$

Where $\Im$ and $\Re$ are the imaginary part and the real part of the smoothing power spectrum. The phase relationship between two time series is indicated by arrows in coherent phase. When the arrows point to the upper right or lower left, the second sequence is ahead of the first sequence. When the arrows point to the lower right or upper left, the first sequence is ahead of the second sequence.

For DWT, the time series $y(t)$ is decomposed into approximation S_j and detail D_j components:

$$y(t) = S_J(t) + \sum_{j=1}^J D_j(t) \quad (7)$$

Where $J = 8$ capturing multiscale dynamics from intraday ($D_1: 2 \text{ days}$) to annual ($D_8: 256 \text{ days}$) cycles.

3.2. Data

This paper focuses on five carbon markets: Beijing, Shanghai, Guangdong, Shenzhen, and Hubei. The study utilizes daily transaction prices from April 2014 to April 2024 as the research dataset. Data is sourced from the CSMAR database. During the same period, the study employs the China Bond-China Green Bond Index to represent the financial performance of the China's green bond market. Data is also obtained from the Wind database. After excluding missing values, 795 sets of valid data remain. Table 1 presents the descriptive statistics for main study variables. Figure 1 depicts the fluctuations in daily transaction prices of the carbon markets and the green bond index during the sample period¹.

Table 1: The descriptive statistics for main study variables.

Variable	Obs	Mean	Median	Variance	skewness	kurtosis
Beijing	794	0.0366	0.0007	0.239	17.174	371.15
Shanghai	794	0.0039	0	0.007	6.865	128.10
Guangdong	794	0.0029	0	0.006	2.511	29.460
Shenzhen	794	0.0502	0	0.246	8.621	101.52
Hubei	794	0.0014	0	0.002	1.646	17.377
greenbond	794	0.0007	0.0002	9.63e-06	6.507	78.112

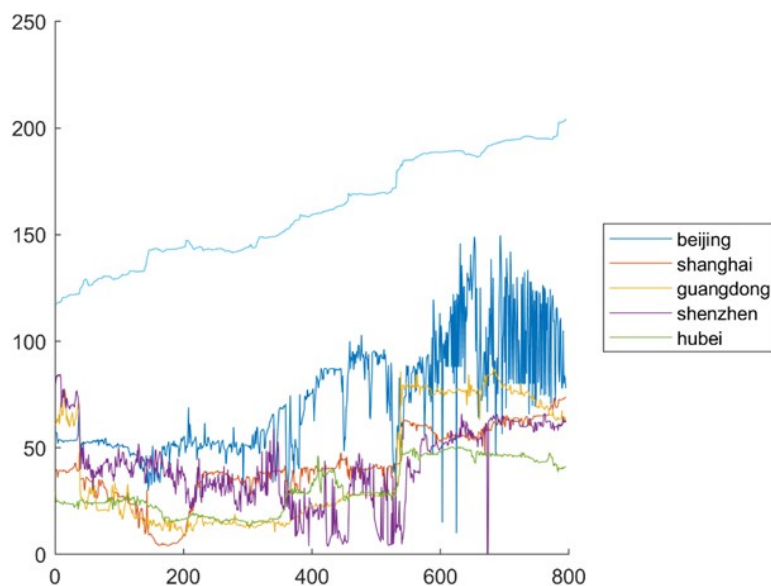


Figure 1: 795 sets of C China's Carbon Market Transaction Prices and Green Bond Index.

Table 2 shows the results of the correlation between the yield series of carbon market transaction prices of five carbon markets and the green bond index². Table 3 shows Augmented Dickey-Fuller

¹ The carbon market transaction prices of the carbon markets in Beijing, Guangdong and Shenzhen fluctuated violently in the sample period, especially the Beijing carbon market, indicating that the yield series of the domestic carbon market has the characteristics of fluctuation and aggregation; at the same time, the carbon market transaction prices of the five carbon markets have obvious upward trends after 2020.

² The correlation coefficient between the yield of the green bond index and the yield of the carbon market in Shanghai, Guangdong, Shenzhen and Hubei is positive, showing a positive correlation characteristic; while the correlation coefficient between the yield of the green bond index and the yield of the carbon market in Beijing is -0.0255, which shows a weak correlation.

test (with a lag order of 20) on the yield series of carbon market transaction prices and green bond index in the sample period, and the yield series of the two kinds of indicators show remarkable stability. Therefore, the time series data in this paper meets the research needs.

Table 2: Correlation between the Yield Series of China's Carbon Market Transaction Prices and Green Bond Index.

Variable	Beijing	Shanghai	Guangdong	Shenzhen	Hubei	greenbond
Beijing	1.0000					
Shanghai	-0.0211	1.0000				
Guangdong	0.0071	0.065*	1.0000			
Shenzhen	-0.0127	0.0217	0.0137	1.0000		
Hubei	0.0018	-0.0543	0.128***	-0.0437	1.0000	
greenbond	-0.0254	0.135***	0.079**	0.0391	0.082**	1.0000

Table 3: Augmented Dickey-Fuller Test Results of the Yield Series of China's Carbon Market Transaction Prices and Green Bond Index.

Variable	Test-Statistic Z(t)	Dickey-Fuller critical value			Obs
		1%	5%	10%	
Beijing	-5.844	-3.430	-2.860	-2.570	773
Shanghai	-5.106	-3.430	-2.860	-2.570	773
Guangdong	-6.051	-3.430	-2.860	-2.570	773
Shenzhen	-3.962	-3.430	-2.860	-2.570	773
Hubei	-5.588	-3.430	-2.860	-2.570	773
greenbond	-5.915	-3.430	-2.860	-2.570	773

4. Empirical results and discussion

Building on the continuous wavelet analysis, the empirical findings presented in Figure 2 are derived. Figure 2 delineates the estimated wavelet coherence and phase difference between the carbon market transaction price and the green bond index across five carbon markets, highlighting varying dependencies at different frequencies and over time. The vertical axis in Figure 2 represents frequency, ranging from scale 1 (one day) to scale 256 (approximately one market year); the horizontal axis represents time, spanning the sample period from April 8, 2014, to April 19, 2024. The results are represented by solid lines. Wavelet coherence analysis involves identifying regions, depicted in warmer colors, and those with lower dependency in cooler colors.

Upon examining the visual representation, it is evident that the coherence between the carbon market transaction price and the green bond index is weaker at higher frequencies, a pattern that persists throughout the sample period. However, at lower frequencies, the dependency of the carbon market transaction price to the green bond index escalates, particularly post-COVID-19 pandemic (2020 and beyond), culminating in a heightened dependency level focused on lower frequencies (32-128 days) from 2020 to early 2023, with the Beijing carbon market being an exception. Subsequent to 2023, both the short-term and long-term dependencies within the Shanghai and Shenzhen carbon markets dissipated.

In the case of Shenzhen's carbon market, Figure 2 indicates that around 2021, there is a strong correlation between the carbon market transaction price and the green bond index, particularly at lower frequencies, contrasting with a weaker dependence prior to this period. Data from Guangdong and Hubei's carbon markets indicate that post-2019, there was a robust dependence between the

carbon market transaction price and the green bond index across intermediate and low frequencies, in contrast to a weaker dependence observed before 2019. Overall, Figure 2 demonstrates that the dependence between the carbon market transaction price and the green bond index fluctuates dynamically over time and frequency. By early 2024, the low-frequency dependence remains robust while high-frequency dependence is subdued; in the initial years of the sample, this pattern was characterized by weak dependence across both short and long terms. Furthermore, the phase indicated by the arrows in Figure 2 predominantly points to the right across most time and frequency intervals, suggesting a positive local correlation and indicating that the carbon market transaction price does not precede the issuance of green bonds. During the latter half of 2020 to 2022, however, the phase of the Shenzhen carbon market shifted, offering tentative evidence that the carbon market transaction price may precede the green bond index. For the lower frequency band within the 2020-2024 timeframe (128-256 days), the phase of all market combinations except Hubei points to the bottom right or top left, suggesting that the carbon market transaction price leads the green bond issuance.

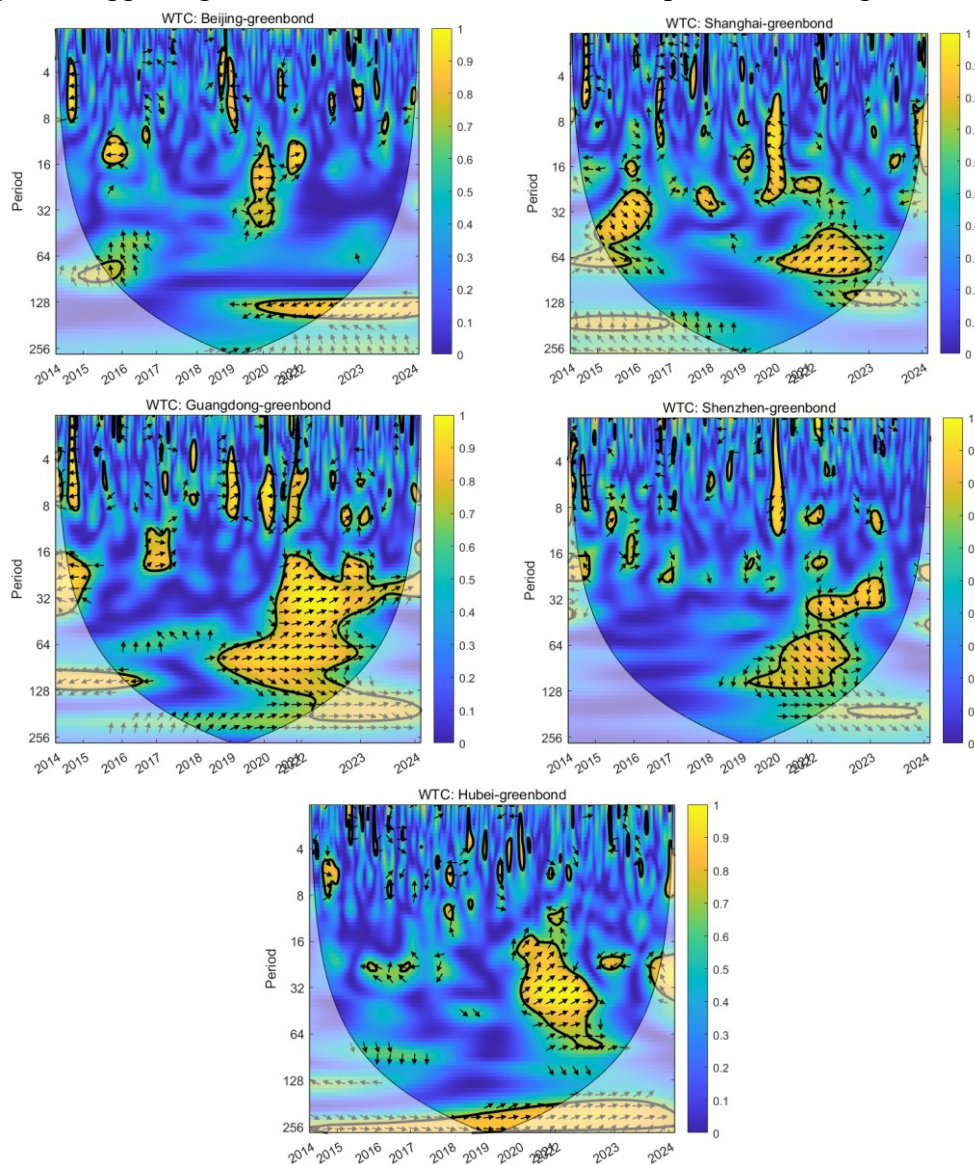


Figure 2: Wavelet Coherence of Carbon Market Transaction Price and Green Bond Index.

The empirical analysis indicates that from 2020 onward, the carbon market transaction price and the green bond index series of China's five carbon pilot trading markets have demonstrated strong dependence and correlation, particularly in low-frequency regions. In light of the numerous uncertainties arising from events such as the COVID-19 pandemic, understanding the correlation between both markets is significant [16]. This aligns with the necessity for a transition to green and low-carbon development amid heightened economic pressures following the onset of the COVID-19 pandemic in 2020. [10] have emphasized the role of the green bond market as a safe asset in the context of rising uncertainty. As a cost-effective financing mechanism, green bonds influence the transaction price of carbon emission rights by incentivizing enterprises to pursue green and low-carbon transformations. In addition, most of the phase arrows point to the right, indicating that the series of carbon market transaction prices and the green bond index exhibit a local positive correlation. At the same time, the phase of the four carbon markets in Beijing, Shanghai, Guangdong, and Shenzhen all points to the lower right or upper left, suggesting that the carbon market transaction price precedes changes in the green bond index.

5. Conclusions and implication

5.1. Conclusions

This paper analyzes the correlation between the green bond market and the carbon market through empirical research from the time and frequency domain perspective. The findings reveal a strong correlation between the green bond and carbon markets; second, post-2020, the low-frequency dependence and correlation are more pronounced; third, the correlation exhibits temporal variations, with the carbon market transaction price leading changes in the green bond index; fourth, policy implementations and special events can intensify the correlation between the markets due to their time-varying interdependencies; fifth, the 2020-2024 period shows increased dependence and interconnectivity between the green bond and carbon markets compared to 2014-2019.

5.2. Implications

Based on the above conclusions, this paper proposes the following policy implications: First, for enterprises with emission reduction obligations, since the construction of the green bond market and the carbon trading market has a common purpose, enterprises can obtain strong financial support through green bonds, and finance their own low-carbon transformation through green financial market, so as to achieve the purpose of reducing greenhouse gas emissions. Second, for policy makers, we must first consider the relevance and differences between the green bond market and the carbon trading market, give full play to the advantages of different markets, realize the complementary advantages of the two markets. Additionally, establishing risk early warning mechanisms is crucial for the stable and sustainable operation of both markets, ensuring enduring momentum for green and low-carbon development.

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