Correlation Between Chinese Carbon Market and New Energy Market——Evidence Based on Wavelet Analysis and Granger Causality Tests

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Abstract. Based on the background of global energy conservation and emission reduction, this paper studies the correlation between Chinese carbon market and new energy market. Sample data are from August 2013 to January 2024. The empirical results of the morlet wavelet model and quantile Granger causality test show that the carbon market is ahead of the new energy market in the medium- and long-term dimensions, and that Guangdong carbon allowances and Beijing carbon allowances Granger affect the new energy market during bull and bear markets, respectively.And the impact of the carbon market on some segments of the new energy market has obvious similarities.The findings of this paper confirm that the carbon market contributes to the development of the new energy industry, which in turn has a positive significance for the transition to a green and low-carbon economy.

Keywords: Carbon Market, New Energy Markets, Morlet Wavelet Model, Quantile Granger Causality Test.

1. Introduction

Greenhouse gas-induced increases in extreme weather and food security concerns have substantially impacted human life [1-2]. In December 2015, as the first global agreement on emission reductions in the history of mankind to cover nearly 200 countries and territories, the Paris Agreement was formally concluded. Since then, countries have announced or formalized long-term net-zero GHG emission targets [3]. As the world's largest developing country, China has pioneered a dual-carbon policy, contributing Chinese solutions to global environmental governance. The carbon market has been adopted by many countries as an important economic tool to achieve energy saving and emission reduction targets. China has launched eight pilot carbon markets since 2013 and has built the world's largest carbon market. Meanwhile, as an important industrial means to reduce greenhouse gas emissions at source, the development of renewable energy has a positive significance in reducing carbon dioxide emissions and improving environmental quality [4]. Adams S et al (2019) analysed that the implementation of new energy policies has reduced carbon emissions [5]. Under the background of global emission reduction, the development of new energy industry has become a general trend. Research on the linkages between the carbon market and the new energy market is thus of great significance.

Previous studies by scholars have mainly focused on the impact of traditional energy markets on the carbon market, or the relationship between traditional and new energy sources. And most of them take the market as a whole as the research object, and there is little research literature based on the perspective of subdividing the new energy market and carbon market.

Based on this, this paper innovatively selects Chinese segmented carbon market and segmented new energy market. Using the morlet wavelet model applicable to the economic domain and the interquartile Granger causality test with higher confidence level, the article discusses in depth of the correlation between the two on different time scales and in different market conditions. The study finds that the carbon market leads new energy market in low and medium frequency bands. Guangdong Carbon Allowance and Beijing Carbon Allowance Granger influence the new energy market during bull and bear markets, respectively. And the carbon market has obvious similarities in the form of impacts on the new energy market segments CSI New Energy, Photovoltaic Industry and CS New Energy Vehicle.

The research contribution of this paper is threefold:

Firstly, the research perspective is novel and fills a gap in the relevant field. In this paper, Chinese segmented carbon market and segmented new energy market are innovatively selected as research objects. The study of inter-market relationships is not only refined, but also discussed based on the perspectives of different time scales and market performance conditions, which fills a research gap in the field.

Second, the empirical results of this paper show that Chinese carbon market is the Granger cause of the new energy market, providing an empirical basis for carbon markets to facilitate the green economy transition.

Thirdly, this paper points out that the carbon market is ahead of the new energy market at low to medium frequencies. Using this time lag, the above results can provide some reference for investors to adjust their investment portfolios, new energy listed companies to adjust their corporate strategies, and policy makers to regulate the strength of their policies. Ultimately promoting the development of new energy industries and the implementation of dual-carbon policies.

This paper is organized as follows. Chapter 2 reviews empirical studies of carbon and energy markets. Chapter 3 describes the models used in this paper. Chapter 4 presents the data. Chapter 5 describes the empirical results. Chapter 6 concludes and makes recommendations.

2. Literature review

Much of the previous literature has focused on traditional energy and carbon markets, with few articles describing the linkages between new energy markets and carbon markets. Studies have noted that traditional energy (crude oil, natural gas, etc.) markets have a significant impact on carbon markets [6-8]. Wang Z J et al. (2021) used structural equation modelling to study the impact of energy markets on the carbon market, noting that natural gas and Brent crude oil directly affect EU allowances (EUA) [9]. Kim H S et al. (2010) show that coal prices are a determinant of carbon allowances in the long run, while in the short run crude oil, natural gas, and coal prices all have a significant impact on the carbon market [10]. As for different carbon markets, scholarly studies have pointed to the country specificity of carbon market effects [11]. Sousa R et al. (2015) found a negative correlation between energy prices and carbon markets in the WCI while a positive correlation in the EU ETS and emphasized that this phenomenon may be related to different carbon market characteristics [12].

In summary, the volatility of conventional energy prices has a significant impact on the carbon market. There is also evidence of a positive relationship between new and conventional energy prices [13]. The lack of uniformity in previous studies on the relationship between different carbon and energy markets also suggests that different market systems, internal and external economic environments, and so on, can have different outcomes. Therefore, we propose Hypothesis 1 of this paper:

H1a: There is a causal relationship between Chinese carbon market and the new energy market.

H1b: The causal relationship between Chinese carbon market and the new energy market can be similar or different depending on the segment and market conditions.

In addition, some scholars have also pointed out in their studies of carbon and energy markets that there is a lead-lag relationship between price movements in the markets. Dawar I et al. (2021) state that the lagged effect of WTI crude oil on new energy stocks is generally significant [14]. Yin J et al. (2023) proposed for Chinese carbon and energy markets that the critical time lag of the market is 50 [15]. And the positive correlation between them is enhanced when the time delay is considered. In summary, rising prices in the carbon market may lead to an increase in the cost of carbon emissions for companies and an increase in the demand for new energy sources, which in turn will increase the intrinsic value of new energy companies. Therefore, we propose Hypothesis 2 of this paper:

H2: There is a lead-lag relationship between Chinese carbon market and the new energy market.

3. Methodology

3.1. Wavelet model

Wavelet models can respond to the dynamic correlation information of data at different time scales, which can be used to study the co-movement and causality of data. Models include haar wavelet, morlet wavelet, Mexican hat wavelet, etc. The morlet wavelet is a symmetric non-orthogonal wavelet, a wavelet model commonly used in economics, and can be represented as:

$$\Omega(t) = e^{i\omega_0 t} e^{-\frac{t^2}{2}} \tag{1}$$

The continuous wavelet transform operations on the data are given by:

$$Q_x(\sigma) = \int_{-\infty}^{+\infty} x(t)|\sigma|^{-\frac{1}{2}}\Omega^*(\frac{t}{\sigma}) \tag{2}$$

Where $x(t)$ is the square integrable function, σ denotes the telescopic scale, $\Omega^*(\frac{t}{\sigma})$ denotes the complex conjugate of $\Omega(\frac{t}{\sigma})$.

Wavelet coherence is used to analyse the characteristics of two columns of time series data in the time and frequency domains. Referring to the method of Liu X et al. (2023) [16], the cross-wavelet power spectra of $x(t)$ and $y(t)$ are defined using the results $Q_n^x(\sigma)$ and $Q_n^y(\sigma)$ of the successive wavelet transforms of two columns of time series $x(t)$ and $y(t)$:

$$Q_n^{xy}(\sigma) = Q_n^x(\sigma)Q_n^{y*}(\sigma) \tag{3}$$

* Denotes complex covariance. The cross-wavelet power spectrum responds to the covariance between two time series on different scales, with larger values indicating that the two series are more significantly correlated.

Referring to the paper by Farid S et al. (2023) [17], the wavelet coherence coefficients are defined as:

$$R_n^2(\sigma) = \frac{|(\sigma^{-1}Q_n^{XY}(\sigma))|^2}{(\sigma^{-1}|Q_n^X(\sigma)|^2)(\sigma^{-1}|Q_n^Y(\sigma)|^2)} \tag{4}$$

Where σ is the time and scale smoothing operator. $0 \leq R_n^2(\sigma) \leq 1$. A larger $R_n^2(\sigma)$ indicates a stronger correlation between the two columns of the time series. However, further investigation is required to determine whether the correlation is positive or negative, necessitating an analysis of wavelet coherence phase differences:

$$\phi_{xy}(\sigma) = \tan^{-1}(\frac{\theta(\sigma^{-1}Q_n^{XY}(\sigma))}{\delta(\sigma^{-1}Q_n^{XY}(\sigma))}) \tag{5}$$

Where θ and δ denote the imaginary and real parts of the cross-wavelet transform term, respectively. An arrow towards the right (→) in the wavelet coherence diagram indicates a positive correlation between the two columns of data and towards the left (←) indicates a negative correlation. An arrow pointing upwards (↑) indicates that the former is 90°behind the latter and pointing downwards (↓) indicates that the former sequence overshoots the change by 90°, i.e., data 1 is ahead of data 2.

3.2. Quantile Granger causality test

We refer to Chuang C C et al. (2009) and Troster V et al. (2018) for the quantile Granger causality test model [18-19]. Denote the two smooth columns of time series data in the set Γ as $\{(X_t, Y_t)\}_{t\in\Gamma}$, implicit variable $Y_t \in \mathbb{R}$. The explanatory variable $C_t \equiv (C_t^{Y\prime}, C_t^{X\prime})' \in \mathbb{R}^k$, where $C_t^Y := (Y_{t-1}, Y_{t-2}, \ldots, Y_{t-p})' \in \mathbb{R}^m$, $C_t^X := (Y_{t-1}, Y_{t-2}, \ldots, Y_{t-p})' \in \mathbb{R}^n$, and $k = m + n$. $F_Y(y|C_t^Y, C_t^X)$ and

$F_Y(y|C_t^Y)$ are the conditional distribution functions under the given conditions (C_t^Y, C_t^X) and C_t^Y respectively. The quantile $\omega \in \mathbb{D}$ and $\mathbb{D} \subset (0,1)$. Define $U_\omega^{Y,X}(\cdot\,|C_t^Y, C_t^X)$ and $U_\omega^Y(\cdot\,|C_t^Y)$ to be the ω quantiles of $F_Y(\cdot\,|C_t^Y, C_t^X)$ and $F_Y(\cdot\,|C_t^Y)$ respectively. The null hypothesis of the quantile Granger causality test indicates that sequence X_t does not affect Y_t, denoted as:

$$H_0:\quad U_\omega^{Y,X}(Y_t|C_t^Y, C_t^X) = U_\omega^Y(Y_t|C_t^Y) \qquad \omega \in \mathbb{D} \tag{6}$$

and:

$$\Pr\{Y_t \le U_\omega^Y(Y_t|C_t^Y)|C_t^Y\} = \omega \qquad \omega \in \mathbb{D} \tag{7}$$

$$\Pr\{Y_t \le U_\omega^{Y,X}(Y_t|C_t^Y, C_t^X)|C_t^Y, C_t^X\} = \omega \qquad \omega \in \mathbb{D} \tag{8}$$

Define the schematic function ζ(a≤b), so:

$$\Pr\{Y_t \le U_\omega(Y_t|C_t)|C_t\} = E\{\zeta[Y_t \le U_\omega(Y_t|C_t)]|C_t\} \tag{9}$$

The null hypothesis can thus be transformed:

$$E\{\zeta[Y_t \le U_\omega^{Y,X}(Y_t|C_t^Y, C_t^X)]|C_t^Y, C_t^X\} = E\{\zeta[Y_t \le U_\omega^Y(Y_t|C_t^Y)]|C_t^Y, C_t^X\} \qquad \omega \in \mathbb{D} \tag{10}$$

The left-hand side of the equal sign in the above equation is the ω-quantile of $F_Y(\cdot\,|C_t^Y, C_t^X)$. Parametric models were selected to estimate the ω quartile of $F_Y(\cdot\,|C_t)$. family $\mathscr{B} \subset \mathcal{M}$, $\mathcal{M} = \{m(\cdot, \delta(\omega))|\delta(\cdot): \omega \longmapsto \delta(\omega) \in \Theta \subset \mathbb{R}^p, \omega \in D \subset [0,1]\}$. As a result, the parametric model $m(C_t^Y, \delta_0(\omega))$ can accurately represent the quantile $U_\omega(\cdot\,|C_t)$. Therefore, the original hypothesis, equation 5, is converted into the original and alternative hypotheses:

$$H_0:\quad E\{\zeta[Y_t \le m(C_t^Y, \delta_0(\omega))]|C_t^Y, C_t^X\} = \omega \qquad \omega \in \mathbb{D} \tag{11}$$

$$H_1:\quad E\{\zeta[Y_t \le m(C_t^Y, \delta_0(\omega))]|C_t^Y, C_t^X\} \ne \omega \qquad \omega \in \mathbb{D} \tag{12}$$

At the ω locus, rejection of H_0 suggests that X_t is the Granger cause of Y_t.

4. Data

This paper analyses the average price of carbon emissions trading in China and the closing price of the new energy market. Data between August 2013 and January 2024 were selected as samples, including (1) Guangdong Carbon Emission Allowance (GDEA); (2) Beijing Carbon Emission Allowance (BEA); (3) CSI New Energy (ZZXN); (4) Photovoltaic Industry (GFCY); (5) Wind Power Industry (FDCY); (6) CS New Energy Vehicle (CSXNC); (7) New Energy Battery (XNDC). Sample data from Wind database and Oriental Wealth Choice data.

Table 1 shows the results of the descriptive analysis of the seven columns of sample data. The median and mean of the seven columns of data show that the daily returns of both the carbon and new energy markets are close to zero, with the carbon market having a larger standard deviation and more dramatic fluctuations, and the new energy market having relatively smaller fluctuations. For the skewness value test, the skewness of carbon markets and new energy batteries is greater than 0, and the probability distribution plot is right-skewed; the rest of the data are left-skewed. In the kurtosis test, the kurtosis of all seven samples of data is not equal to 3, indicating that the data do not conform to a normal distribution. The kurtosis value of Guangdong's carbon credit allowances is much larger than 3, indicating a fat-tailed distribution. In addition, the K-S test p-values for all seven columns of the data sample are much less than 0, rejecting the original hypothesis that the sample data follow a normal distribution.

Table.1. Descriptive statistics of carbon markets and new energy yields

		GDEA	BEA	ZZXN	GFCY	FDCY	CSXNC	XNDC
Maximum		6.445	0.599	0.084	0.092	0.093	0.082	0.094
Lower quartile		0.029	0.032	0.011	0.011	0.011	0.011	0.011
median		0.000	0.001	0.001	0.001	0.001	0.001	-0.002
upper quartile		-0.028	-0.022	-0.010	-0.010	-0.010	-0.011	-0.013
Minimum		-0.909	-0.254	-0.092	-0.094	-0.096	-0.093	-0.076
Mean		0.016	0.004	0.000	0.001	0.000	0.001	0.000
Std. Dev.		0.234	0.087	0.020	0.020	0.021	0.021	0.022
Skewness		12.714	0.243	-0.359	-0.294	-0.306	-0.172	0.371
Kurtosis		289.714	2.773	2.721	2.534	2.931	1.910	1.067
K-S test	D-value	0.282	0.138	0.064	0.063	0.071	0.053	0.064
	P-value	0.000***	9.4e-76***	2.3e-27***	2.3e-26***	3.2e-29***	4.8e-18***	8.9e-9***

Notes: *, **, *** indicate significant at 10%, 5%, 1% level respectively

Figure 1 illustrates the trend of selected carbon market and new energy indices for the period from August 2013 to January 2024. The new energy market saw a rise of about 65 per cent in the first half of 2015, possibly influenced by the huge 60 per cent rise created by the Shanghai Securities Composite Index during the same period. Between 2020 and 2023, the new energy market has seen three significant rises of 104.92 per cent, 46.87 per cent and 64.96 per cent, respectively. However, during the same period, the Shanghai Composite index rose by only 13.87 per cent, 3.72 per cent and 2.47 per cent, respectively. Preliminary speculation that the Shanghai Composite index is not a determinant of changes in new energy indices. In addition, Figure 1 shows that the carbon market and the new energy market are not completely synchronised, and the volatility of the carbon market is slightly greater than that of the new energy market, which is consistent with the conclusions in the descriptive analysis above.

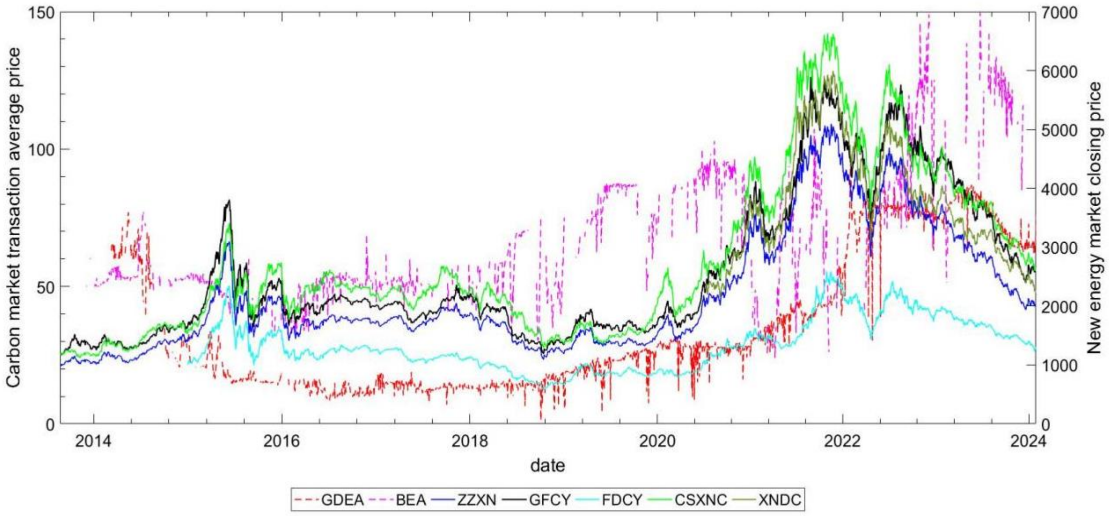


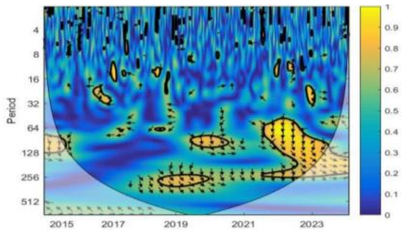
Figure 1. Carbon Market and New Energy Market Trends

5. Empirical results

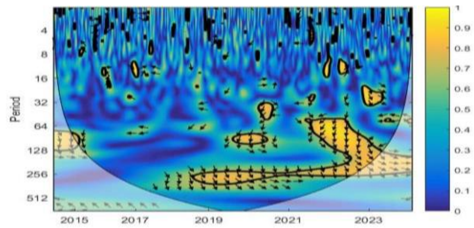
5.1. Wavelet coherence analysis

Figures 2 and 3 represent the wavelet coherence of Guangdong Carbon Emission Allowance and New Energy Index, and Beijing Carbon Emission Allowance and New Energy Index, respectively. The horizontal axis represents time in years. The vertical axis represents frequency, with the time scale covering a period from 1 day (high frequency) to 512 days (low frequency). The warm areas in the figure indicate that the two columns of time series data are highly correlated. The thin black solid lines at the edges indicate the Cone Of Influence region, within which the results of the wavelet analysis are relatively plausible as they are not significantly affected by data boundary effects. And the area enclosed by the thick solid line within the cone indicates that it passes the red noise test at a confidence level of 95%, indicating that the two columns of data are significantly correlated. An arrow pointing to the right (→) indicates that the two columns of time series are positively correlated; an arrow pointing down (↓) indicates that the second column of data (new energy market) is lagging behind the first column of data (carbon market) by 90°, i.e., the carbon market is ahead of the new energy market.

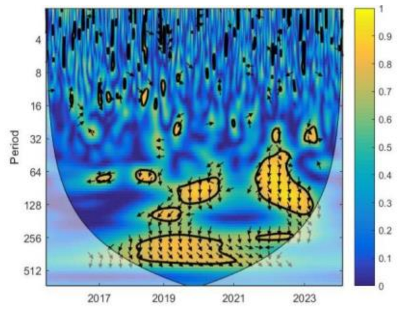
It can be clearly seen from Figure 2 that there is an extremely obvious correlation between Guangdong Carbon Emission Allowance and the new energy market at low and medium frequencies. For example, from February 2018 to January 2021, Guangdong Carbon Emission Allowance leads the Wind Power Industry in the bands 64 to 128 and 256 to 472, and this also occurs in the period from May 2021 to March 2023 in the bands 42 to 172. The arrows of Guangdong Carbon Emission Allowance and New Energy Battery are mostly pointing downwards at low and medium frequencies during the period from June 2021 to April 2023, suggesting that Guangdong Carbon Emission Allowance is significantly ahead of the new energy market. In addition, Guangdong Carbon Emission Allowance shows a similar form of correlation with CSI New Energy, Photovoltaic Industry, and CS New Energy Vehicle: the degree of correlation is insignificant until 2019, while it shows a relatively high correlation in the low and medium frequency bands (48-256 days) in the end of 2021 to the beginning of 2023. Overall, Guangdong Carbon Emission Allowance leads the new energy market in the low and medium frequency bands, and the former has a similar impact on CSI New Energy, Photovoltaic Industry, and CS New Energy Vehicle, with differences in the impact on the rest of the market.



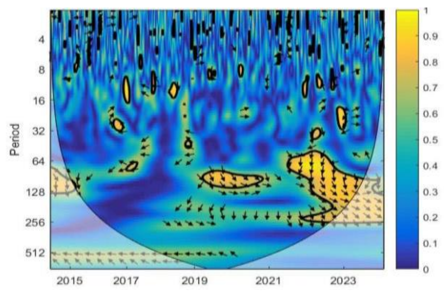
GDEA-ZZXN



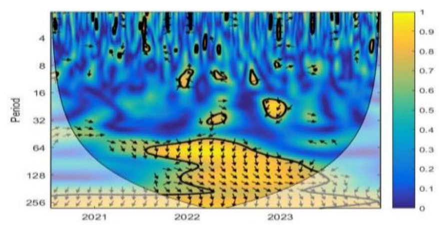
GDEA-GFCY



GDEA-FDCY



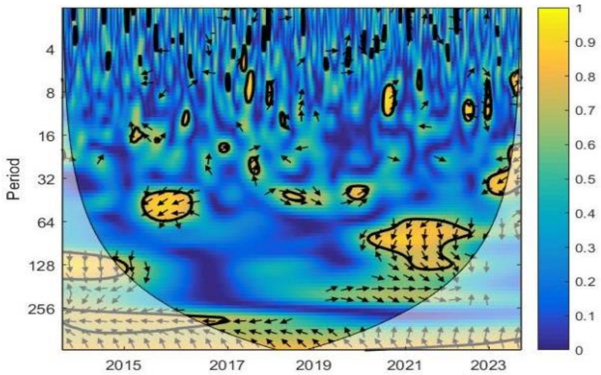
GDEA-CSXNC



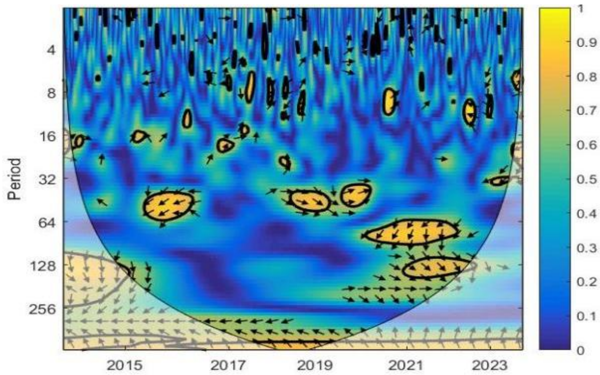
GDEA-XNDC

Figure 2. Wavelet Coherence of Guangdong Carbon Emission Allowance and New Energy Indices

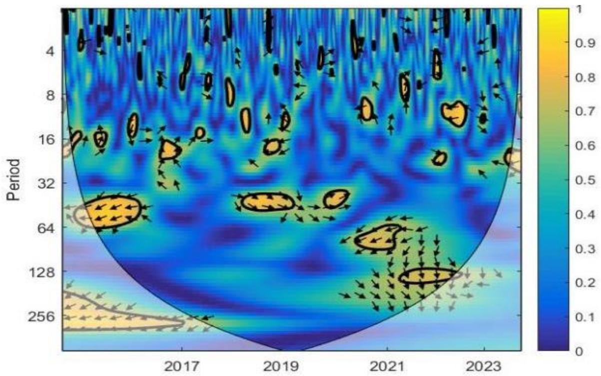
Figure 3 shows the wavelet coherence relationship between Beijing Carbon Emission Allowance and the new energy index, the correlation between the two is weak in the high-frequency part, but this correlation is significantly stronger in the middle and low frequency bands. The black solid line in the high frequency part of the correlation graph between Beijing Carbon Emission Allowance and CSI New Energy is extremely small, indicating a weak correlation between the two. In the low-frequency segment, such as the 42-64 days from February 2015 to March 2016 and the 64-160 days from January 2020 to May 2022, the arrows are mostly pointing downwards, confirming the fact that Beijing Carbon Emission Allowance is ahead of the new energy market. Similarly, in the correlation between Beijing Carbon Emission Allowance and Photovoltaic Industry, Wind Power Industry and New Energy Battery, the arrows in the prominent black solid line area are mostly pointing downwards, further confirming that Beijing Carbon Emission Allowance is ahead of the new energy market. Only the correlation between Beijing Carbon Emission Allowance and CS New Energy Vehicle near 256 days (low frequency band) is anomalous. Overall, Beijing Carbon Emission Allowance is ahead of the new energy market in the low and medium frequency bands, and the former has a more similar impact on CSI New Energy, Photovoltaic Industry, and CS New Energy Vehicle.



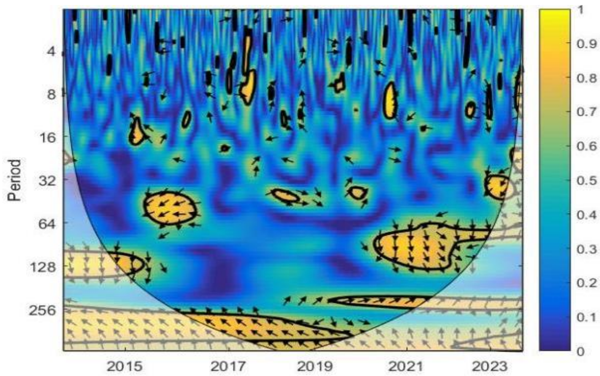
BEA-ZZXN



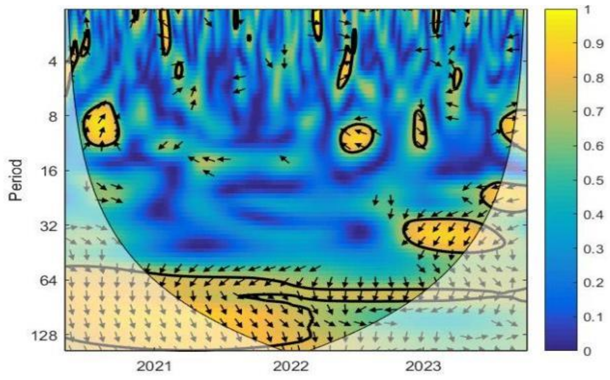
BEA-GFCY



BEA-FDCY



BEA-CSXNC



BEA-XNDC

Figure 3. Wavelet Coherence of Beijing Carbon Emission Allowance and New Energy Indices

Summarising Figures 2 and 3 one can draw consistent conclusions. The carbon market exhibits no significant relationship with the new energy market in the high-frequency domain, yet demonstrates a stable correlation in the middle and low frequency ranges. This observation suggests that the carbon market precedes the new energy market, aligning with the hypothesis stated in this paper, H2. And the carbon market has some similarity in the form of impact on CSI New Energy, Photovoltaic Industry and CS New Energy Vehicle, and there are differences in the impact on the rest of the market. The above results confirm that the development of carbon markets has far-reaching implications for the realisation of a dual-carbon policy. The rise in carbon market price will promote the development of new energy industry in the medium and long term scales, and push the country to build a green, low-carbon and recycling development economic system.

5.2. Granger causal analysis

Table 2 demonstrates the results of the ADF, where the null hypothesis of the existence of a unit root is rejected at the 1% significance level for both carbon and new energy market return series ($H_0: \delta = 0$), indicating that the data are smooth and can be used for Granger causality analysis.

Table.2. Raw data smoothness test

	GDEA	BEA	ZZXN	GFCY	FDCY	CSXNC	XNDC
t-Statistic	-56.21	-20.50	-48.46	-48.85	-45.24	-47.47	-27.73
Prob.*	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***

Notes: *, **, *** indicate significant at 10%, 5%, 1% level respectively

Figure 4 shows the results of the quantile Granger causality test between Guangdong's carbon emission allowances and the five new energy markets respectively. The images are divided into five groups, and the left image of each group represents the impact of Guangdong's carbon emission allowances on the new energy market, with the original hypothesis being "the carbon market does not affect the new energy market". The right one represents the impact of the new energy market on Guangdong's carbon emission allowances, with the original assumption that "the new energy market does not affect the carbon market". The horizontal axis represents the quantile δ. Different sizes of δ represent the height of the market price, which can be roughly categorized into bear market ($0.1 \leq \delta \leq 0.35$), normal market ($0.35 < \delta < 0.65$), bull market ($0.65 \leq \delta \leq 0.9$). The vertical axis represents the t-statistic for the nonlinear Granger causality test. The curve above the red line indicates that it passes the Granger causality test at the 5% significance level.

From the relationship between Guangdong Carbon Emission Allowance and the new energy market, it can be seen that during the bull market, Guangdong Carbon Emission Allowance is the Granger cause for CSI New Energy, Photovoltaic Industry and CS New Energy Vehicle. When the market is in the normal price, it has a significant impact on Photovoltaic Industry, Wind Power Industry and CS New Energy Vehicle. during the bear market, it has an impact on the New Energy Battery only, and this impact fades away with the rise of the market. In contrast, the new energy market has a weak impact on Guangdong Carbon Emission Allowance, with only Wind Power Industry and New Energy Battery being the Granger cause of the carbon market under a few quartiles. Overall, in most cases, Guangdong Carbon Emission Allowance is the cause of Granger in the new energy market, and the effect is mainly manifested in the bull market. However, the impact of the new energy market on Guangdong Carbon Emission Allowance is extremely weak.

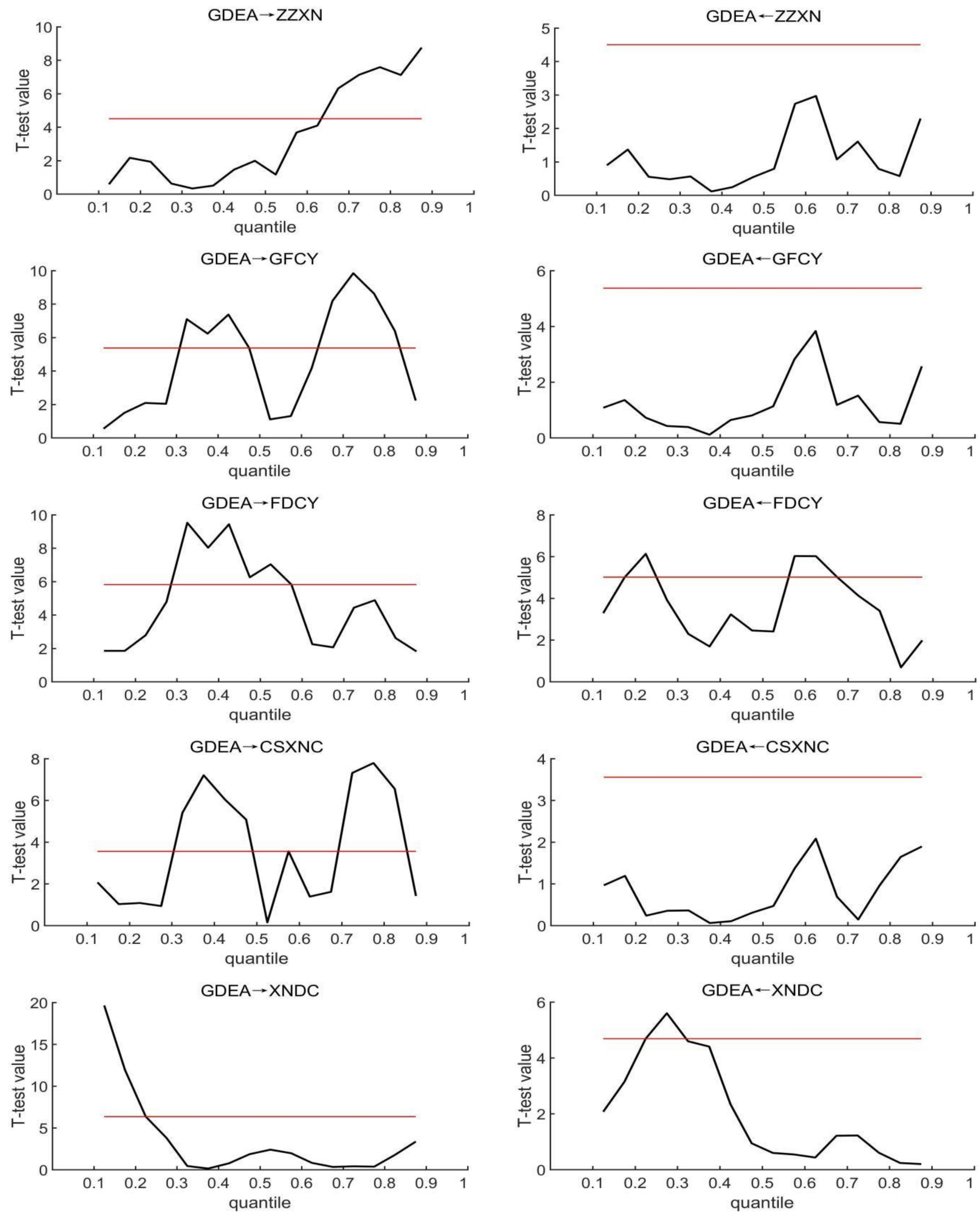


Figure 4. Granger Causality Test of Guangdong Carbon Emission Allowance and New Energy Markets

Figure 5 shows the results of the quantile Granger causality test between Beijing Carbon Emission Allowance and each of the five new energy markets. When the market is in the lower to normal price range, Beijing Carbon Emission Allowance is the Granger cause of CSI New Energy, Photovoltaic Industry, Wind Power Industry, and CS New Energy Vehicle, and this effect is significant and covers a wide range of market conditions. However, as the market strengthens, all of these causal relationships fade away. When Markets Are Bullish, Beijing Carbon Emission Allowance Is Only Granger Reason for New Energy Battery. In contrast, there is no evidence that the new energy market has an impact on Beijing Carbon Emission Allowance. Overall, in the vast majority of cases, Beijing Carbon Emission Allowance is the Granger cause of the new energy market, and this effect is more significant and covers a wider price range than Guangdong Carbon Emission Allowance. However, in contrast to Guangdong Carbon Emission Allowance, Beijing Carbon Emission Allowance has a significant impact on the new energy market mainly during bearish times.

In summary, the nonlinear Granger causality test unveils that, in most instances, the carbon market acts as the Granger cause of the new energy market, rather than vice versa. This corroborates the wavelet model's assertion that the carbon market assumes a leading role in shaping the dynamics of the new energy market. Additionally, the results indicate that Guangdong Carbon Emission Allowance and Beijing Carbon Emission Allowance exert significant influences on the new energy market during bull and bear markets, respectively. Moreover, the impact of the carbon market on the CSI New Energy, Photovoltaic Industry, and CS New Energy Vehicle exhibits a degree of similarity. These findings are consistent with the hypotheses H1a and H1b proposed in this paper. The results further confirm that the carbon market promotes the development of the new energy industry. It promotes the smooth transformation of the traditional energy-led economy to a new energy-led economy. And ultimately realise the transformation and upgrading of the rough type to the green and low-carbon economic model.

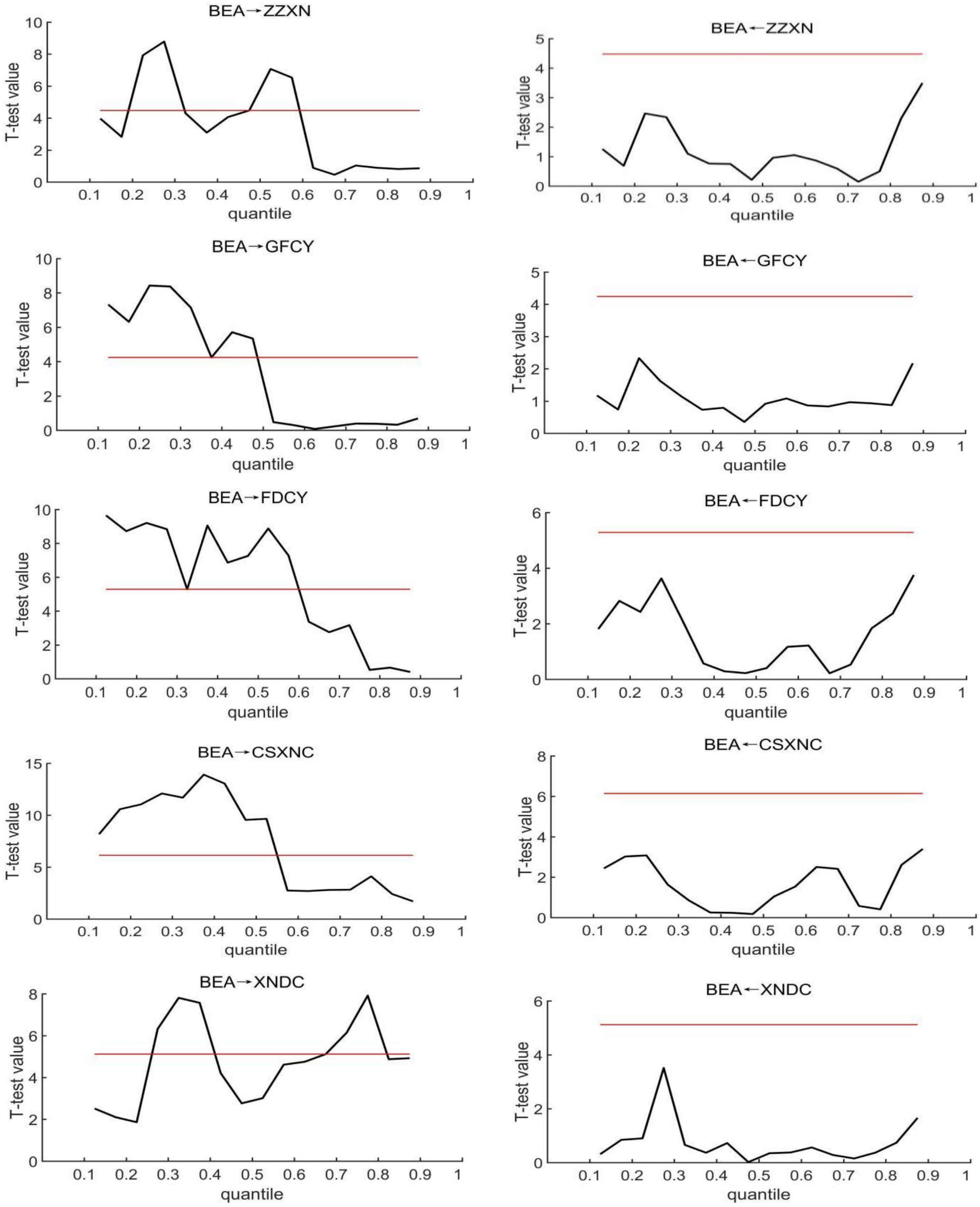


Figure 5. Granger Causality Test of Beijing Carbon Emission Allowance and New Energy Markets

6. Conclusions

This paper conducts morlet wavelet analysis and Granger causality test on China's carbon market and new energy market. It confirms that there is no significant relationship between the two in the short term, but there is a stable correlation in the medium- and long-term time scales, which is manifested by the fact that the carbon market is ahead of the new energy market. Considering market conditions, while both Guangdong Carbon Emission Allowance and Beijing Carbon Emission Allowance are the Granger cause of the new energy market (not vice versa), Guangdong Carbon Emission Allowance tends to have an impact when the market is stronger, and Beijing Carbon Emission Allowance tends to have an impact when the market is weaker. The findings provide a degree of insight for investors, listed companies, and policymakers:

For medium- to long-term investors, they can take advantage of the pioneering nature of the carbon market relative to the new energy market to adjust their investment strategies, avoid risks and enhance returns.

For new energy listed companies, they can refer to the transmission effect of the carbon market on the new energy market to adjust the company strategies. If a prolonged downturn in the carbon market is observed, they need to be wary of the adverse effects of a decline in one's own secondary market share price, such as loss of company value, deterioration of reputation, and difficulty in raising secondary finance. Companies can take advantage of the time lag between the impact of the carbon market and the new energy market to make timely strategic adjustments to maintain share price stability.

For policymakers, the carbon market's role in facilitating the new energy market can be used to promote the green transformation of the economy. Policymakers need to increase their efforts to maintain the stability of new energy markets when a downturn in carbon markets is observed, while such policy efforts can be reduced when carbon markets are stronger. This can promote the upgrading of industrial structure and accelerate the construction of a green and low-carbon economic system.

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