A Study on the Correlation between Carbon Prices and Energy Companies' Stock Prices Based on the Copula Model

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Abstract. Since the 21st century, global carbon emissions have been positively correlated with economic development. Research has shifted to exploring the relationship between carbon prices and energy companies' stock prices. This is crucial for carbon asset management and market performance, especially in China, where the carbon trading market is still in its infancy. This study constructs a theoretical framework linking carbon prices, corporate value, and stock prices. Empirical analysis using the ARIMA(1,0,1)-GARCH(1,1)-t model and the Gumbel Copula function reveals that both carbon prices and energy stock prices exhibit leptokurtosis and volatility clustering, with Hubei carbon prices showing higher volatility. Traditional energy companies' stock prices show low correlation with carbon prices, while new energy companies' stock prices are positively correlated, particularly in the upper tail. Tail correlations between carbon prices and energy stock prices are weak, indicating low market linkage effects. The study recommends government support for the new energy industry, promotion of low-carbon technologies, and a green economic transformation. New energy companies should leverage carbon assets to enhance profits, while traditional energy companies should upgrade their low-carbon technologies and improve energy efficiency.

Keywords: Copula model, Carbon emission price, Energy companies, Correlation.

1 Introduction

Since the 21st century, global carbon dioxide (CO_2) emissions have been highly correlated with economic development. With economic growth, both total CO_2 emissions and per capita emissions have increased significantly, leading to a series of secondary natural disasters. To address climate change, countries have introduced CO_2 emission rights into the carbon trading market through the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, and have continuously revised and strengthened the carbon trading system. Since July 2021, China has

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launched the National Carbon Emission Trading Market, covering several high-emission industries. However, the current carbon prices are relatively low and exhibit abnormal volatility, which urgently requires further research and solutions.

Carbon emission trading is closely related to energy companies, as changes in carbon prices directly affect their production costs and business decisions. Energy-intensive companies are particularly vulnerable to carbon price fluctuations, and market investors also need to make investment decisions based on carbon price information to reduce risks. This paper examines the impact of carbon prices on the stock prices of traditional and new energy companies from the perspective of the carbon market, analyzes the transmission pathways, and aims to provide references for governments and enterprises. Theoretically, this study fills the gap in research on the correlation between carbon prices and energy companies' stock prices in China and uses the Copula function model to make up for the shortcomings of traditional models in analyzing carbon price volatility. In reality, studying the relationship between carbon prices and energy companies' stock prices helps to improve China's carbon trading system and assists enterprises in better controlling carbon costs and optimizing investment decisions during the economic transformation period.

2 Literature Review

The growth of the carbon trading market has spurred research on carbon pricing and its impact on energy company stocks. However, empirical studies on this dynamic relationship are still limited, especially in China.

2.1 Research on the Pricing Mechanism of Carbon Emission Rights

Zhu et al. [1] improved the carbon pricing model using dynamic factors and scarcity corrections, better capturing China's market volatility and regional price gaps. The MAC curve and shadow pricing, as used by Montgomery [2] , are essential for initial pricing. The World Bank [3] advises customizing shadow pricing to regional contexts in developing countries to link carbon prices with abatement costs.

2.2 Research on the Influencing Factors of Carbon Emission Rights Prices

Carbon prices are influenced by macroeconomic conditions, energy prices, policy design, information disclosure, and extreme weather events. Bataller et al [4]. found that the EUA futures prices are significantly influenced by economic conditions and policies. Bai et al. [5] found that energy prices, macroeconomics, and policies drive China's carbon price volatility. Wang et al. [6] confirmed these factors using a graph-structured Lasso model, with trading activity also playing a key role..

2.3 Research on the Influencing Factors of Carbon Emission Rights Prices

The relationship between carbon prices and the stock prices of energy companies can be categorized into three types:

Positive Correlation. Da Silva et al. [7] found that a 1% increase in carbon prices leads to a 0.0087% increase in electricity companies' stock prices. Wang Xu et al. [8] used Copula-GARCH and DCC-GARCH models to show a positive correlation between the carbon and new energy markets. He Yuliang [9] verified the positive correlation between China's carbon prices and the stock prices of new energy companies through the construction of a time-varying t-Copula-GARCH model.

Negative Correlation. Hengge et al. [10] showed that higher carbon prices in the EU ETS significantly reduce stock returns for high-emission firms. Similarly, Jiménez-Rodríguez [11] found a negative correlation between EU carbon allowance prices and high-carbon firms' stock market indices. These findings suggest that rising carbon prices increase operating costs for high-carbon companies, negatively impacting their stock prices.

Complex Temporal Dynamics. Zeng Qing [12] used a cointegration vector error correction model (VECM) to study the impact of carbon prices on the stock prices of traditional and new energy companies, finding that the relationship shifts from negative to positive over time. Bu Wenke [13] used a VAR model to show that carbon prices have a short-term negative correlation with the stock prices of traditional energy companies but a long-term positive correlation. For new energy companies, the impact is mainly positive.

3 Theoretical Analysis

3.1 Transmission Pathways between Carbon Emission Prices and Traditional Energy Companies' Stock Prices

Analysis from the Perspective of Corporate Value. Stock prices reflect changes in corporate value, closely tied to operating profits and investment decisions. Rising carbon prices increase costs for traditional energy companies, reducing profits and stock prices. Conversely, companies with surplus quotas can sell them to boost value and stock prices. Higher carbon prices also prompt investments in low-carbon technologies, which enhance corporate credibility and support stock prices in the long run (see Fig. 1).

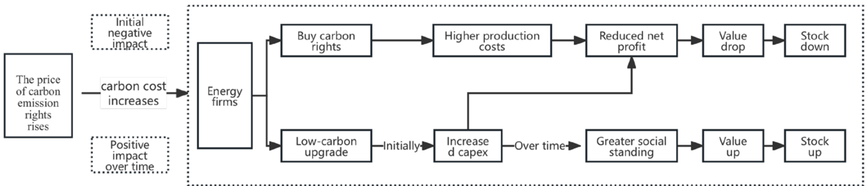

Fig. 1. The transmission pathway of carbon emission prices to traditional energy companies from the perspective of value.

From the perspective of supply and demand. The price of carbon emission rights impacts the supply of traditional energy products. Without carbon trading, market equilibrium is reached at point E (supply curve S intersects demand curve D). With carbon trading, costs rise as firms buy carbon quotas, shifting the supply curve left to S'. If demand is constant, the new equilibrium at E' results in a higher price. This price increase reflects carbon reduction costs. However, regulated energy prices prevent high-carbon firms from passing these costs to consumers, leading to lower profits and stock prices (see Fig. 2).

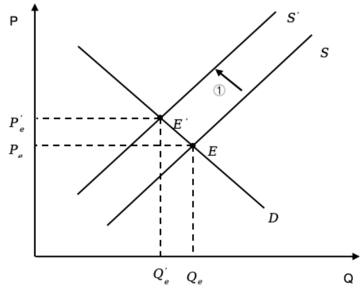

Fig. 2. The transmission pathway of carbon emission prices to traditional energy companies from the perspective of supply and demand.

3.2 The Transmission Pathways between Carbon Emission Prices and Renewable Energy Companies' Stock Prices

Analysis from the Perspective of Corporate Value. When carbon emission prices rise, renewable energy companies can earn additional income by selling surplus carbon quotas, thereby enhancing corporate value and stock prices. Additionally, these companies can provide low-carbon and energy-saving technology services to traditional energy firms. As demand for low-carbon technologies increases, the operating performance and stock prices of renewable energy companies are expected to rise (see Fig. 3).

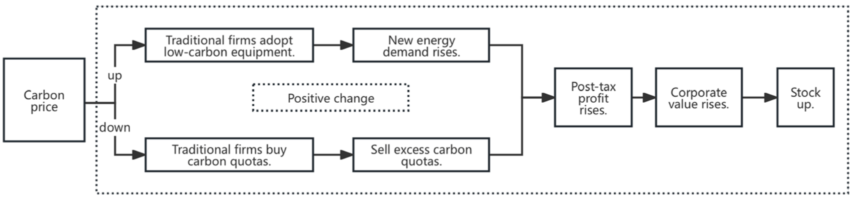

Fig. 3. The transmission pathway of carbon emission prices to renewable energy companies from the perspective of value.

Analysis from a supply and demand perspective. Renewable energy companies reach market equilibrium at the intersection of supply and demand curves without carbon trading. As low-carbon initiatives advance, increased demand for renewable products shifts the demand curve rightward, raising prices and boosting corporate performance and stock prices. Regulatory constraints cause low-carbon firms to reduce supply, shifting the supply curve leftward and further increasing prices. Additionally, traditional energy firms facing high carbon reduction costs may purchase carbon quotas, also driving up renewable energy companies' stock prices (see Fig. 4).

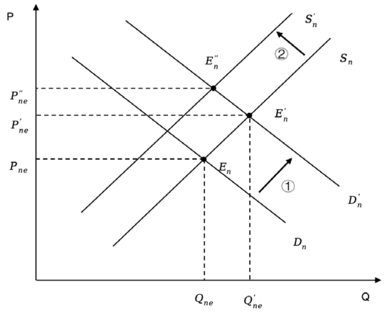

Fig. 4. The transmission pathway of carbon emission prices to renewable energy companies from the perspective of supply and demand.

4 Empirical Analysis

4.1 Variable Selection and Data Sources

Explanatory Variable. Hubei's carbon market, launched in 2014, was China's first to include foreign participation. By 2022, it handled 44.6% of the national trading volume (375 million tons) and 46.9% of the transaction value (CNY 9.071 billion), involving 339 enterprises in 16 energy-intensive industries. Since July 2021, China has operated a national carbon market with trading in Shanghai and settlement in Wuhan, primarily on quota trading (CEA) with CCER as an addition. This study focuses on Hubei due to national market imperfections.

Dependent Variable. Given China's coal-dominated energy structure, firms are divided into traditional and renewable energy companies. The Wind Energy Index and CSI China New Energy Index are used as proxies. Daily returns were calculated using closing prices from April 28, 2014, to March 2, 2024, excluding non-trading data. Data are from the Wind Database (see Table 1).

Table 1. Model Variables and Descriptions

Variable Name	Definition	Symbol
Traditional Energy Company Stock Price	Wind Energy Index	EI
New Energy Company Stock Price	CSI China New Energy Index	NEI

4.2 Unit Root Test and ARCH Effect Test

In empirical research, financial time series data are often non-stationary, and direct regression analysis in the presence of unit roots can lead to spurious results. Therefore, unit root tests are necessary before regression modeling. This study uses the ADF test to assess stationarity. The results show (see Table 2) that, at the 1% significance level, the daily logarithmic returns of the energy and new energy indices and carbon prices are all stationary, with no unit root issues.

Table 2. Unit Root Test

Variable	EI	NEI	HB
Dickey-Fuller Statistic	-13.826	-12.529	-14.386
p-value	0.01	0.01	0.01

The returns of the energy and new energy indices show weak autocorrelation, while Hubei carbon prices exhibit strong autocorrelation. The Ljung-Box test confirms significant autocorrelation in all three return series. Table 3 shows the ARCH-LM test results, with p-values below 0.05 at the 1% confidence level, indicating ARCH effects. These series are thus stationary and suitable for GARCH modeling.

Table 3. ARCH Effect Test

Variable	EI	NEI	HB
t-statistic	167.7978	208.1788	491.8874
p-value	0	0	0

4.3 Establishing the ARIMA-GARCH-t Distribution Mode

By conducting descriptive statistics and the Jarque-Bera (J-B) test on the three datasets, it was determined that the daily logarithmic returns of the energy index, new energy index, and carbon emission prices all exhibit characteristics of leptokurtosis and heavy tails. Therefore, a t-distribution was selected for the GARCH modeling. Based on this, ARIMA(1,0,1)-GARCH(1,1)-t models were established for each dataset. The estimation results indicate that the daily logarithmic return series for the Wind Energy Index, CSI New Energy Index, and Hubei carbon emission prices are significantly different from zero, and their sums are close to 1, suggesting that the volatility of the three return series exhibits clustering and persistence. Additionally, the degrees of freedom for the return series of the energy index, new energy index, and carbon emission prices are relatively low, ranging between 3 and 5. Parameter estimation based on the ARIMA(1,0,1)-GARCH(1,1)-t model allows us to deduce the marginal distribution of the return series.

4.4 Optimal Copula Function Selection and Correlation Coefficient Analysis

Using standardized residuals from the ARIMA(1,0,1)-GARCH(1,1)-t model, a Copula function model was developed via probability integral transformation. Both elliptical and Archimedean family models were considered, with the optimal Copula function identified by the minimum Euclidean distance. Table 4 indicates that the original series do not follow a normal distribution, and their marginal t-distributions have significantly different degrees of freedom. The Gumbel Copula model fits best, effectively capturing the thick-tail characteristics in the upper tail.

Table 4. Parameter Estimation Results of Various Copula Function Models

Parameter		Elliptical Family			Archimedean Family		
		Gaussian	Student-t	Clayton	Gumbel	Frank	SJC
EI	Parameter Estimates	-0.03	-0.03 30	0	1	-0.25	1 0
	Log-Likelihood Value	1	0.49	-0.01	0	1.99	0
	AIC	0	3.02	2.01	2	-1.97	4
NEI	Parameter Estimates	-0.02	-0.02 30	0	1	-0.12	1.01 0
	Log-Likelihood Value	0.29	0.99	-0.01	0.02	0.48	0.08
	AIC	1.43	2.01	2.01	1.96	1.03	3.84

The calculation of tail correlation coefficients indicates that the tail correlation coefficient between the energy index and carbon prices is 0, suggesting that the probability of simultaneous sharp declines or surges in carbon emission prices and the energy index is zero, implying no significant correlation between the two. In contrast, the tail correlation coefficient between the new energy index and carbon prices is 0.01, higher than that of the energy index, indicating that when carbon prices soar, the new energy index is likely to rise in tandem.

5 Conclusions and Policy Recommendations

5.1 Conclusions

This study analyzed the transmission pathways of the correlation between carbon prices and the stock prices of traditional and new energy companies from the perspectives of supply and demand and corporate value. A GARCH-Copula model was established, yielding the following conclusions: China's carbon prices show weak correlation with the stock prices of both traditional and new energy companies. While new energy companies exhibit a positive response to carbon price changes, traditional energy companies are largely unaffected. This indicates that China's carbon market plays a role in stimulating the development of new energy companies. Traditional energy companies, influenced by factors such as energy structure adjustments, are less affected by carbon price volatility. Therefore, China should actively promote a unified national carbon market system and improve mechanisms to reasonably set carbon prices. By creating a healthy carbon trading market, it can drive the development of both traditional and new energy companies.

5.2 Policy Recommendations

Based on empirical results and the context of carbon peaking and neutrality, the following recommendations are proposed:

Government. Promote low-carbon technologies, support the new energy sector, and assist high-carbon companies in transitioning to a green economy.

Traditional Energy Companies. Adopt low-carbon technologies to reduce emissions and costs, and manage carbon assets to support sustainable development.

New Energy Companies. Utilize carbon assets and leverage positive correlations with carbon prices to enhance growth potential and stock values.

Investors. Focus on multi-asset allocation, track new energy trends, and monitor carbon prices to seize market opportunities and achieve better returns.

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