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Risk Spillover Effect and Trading Strategy between Carbon Emission Allowance and Carbon-Neutral Index

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Abstract

An index based on the carbon-neutral concept stock pool is built, and GARCH-dynamic Copula-CoVaR is used to study the risk spillover effect between the carbon market and the carbon-neutral index. The results show as follows. 1) There is a bi-directional risk spillover between the national carbon emission allowance market and the carbon-neutral index, and the positive correlation is becoming increasingly significant. 2) The correlation between the local carbon market and the carbon-neutral index is weak, and there is an asymmetric risk spillover relationship between them: the former can have a one-way risk impact on the latter. 3) In general, the carbon-neutral index is a net risk receiver, and carbon-neutral concept enterprises face the risk of carbon emission allowance price fluctuation in the process of green transformation. In addition, drawing on the research ideas existed, appropriate "brown assets" and "green assets" in the carbon market and stock market are found, and trading strategies including hedging and pair trading are designed, providing new ideas for investors' asset allocation.

Keywords

Carbon Emission Allowance, Carbon-Neutral Index, GARCH-Dynamic Copula-CoVaR, Risk Spillover, Trading Strategy

1. Introduction

The carbon emission trading market is designed for reducing greenhouse gas emission, which can raise funds for achieving the "double carbon" goal and promoting regional low-carbon development. However, since carbon prices are affected by many factors in addition to their own supply and demand mechanisms (policies, extreme weather, etc.), carbon markets are more unstable than traditional stock markets and hide greater risks.

In recent years, studies have focused on spillover effects between carbon markets and financial markets. By using two novel nonlinear approaches, Jiang et al. (2022) examine the nonlinear dependence between carbon market and stock market in China under both normal and extreme market conditions. By employing Pattern Causality method, Sun et al. (2022) study the relationship between China carbon prices and four energy intensive stock indexes. Wang and Wang (2022) comprehensively analyzed the risk spillover between China's carbon market and stock sectors including electric power, materials, real estate, finance, traditional energy, and new energy. Oldfield et al. (2022) explored importance of communication among stakeholders in the voluntary carbon market. Brammer & Bennett (2022) suggested that land managers use the growing carbon credits for taking advantage of carbon markets. Yadav et al. (2022) concluded the short-run diversification opportunity among green bonds, energy stock, bitcoin, and the carbon market.

However, there is a category of enterprises that has the "carbon-neutral" characteristic but is rarely studied, which originally engaged in traditional high-carbon businesses but began to actively do green transformation after the "double carbon" goal was proposed. For example, Shenzhen Energy has invested billions of yuan to carry out energy-saving and emission reduction technical transformation for existing coal-fired units, and has completed the goal of ultra-low emission transformation, making an important contribution to improving the quality of the atmospheric environment; Huaneng Power International is the world's largest listed thermal power enterprise, but its proportion of new energy investment has increased rapidly in recent years, and the installed capacity growth rate is leading in the industry; Chenming Paper has cooperated with professional institutions to develop carbon sinks on the basis of its own forest land, giving full play to the advantages of the whole industrial chain and taking the road of circular economy. Compared with others, carbon-neutral concept stocks will be more significantly and directly affected by the carbon market. On the one hand, the rising price of carbon emission allowances will increase the environmental cost of enterprises, forcing them to carry out green transformation. On the other hand, the declining price of carbon emission allowances will weaken their motivation for green transformation.

In addition, many studies have focused on common trading strategies including stock hedging (Chang et al., 2022), commodity futures hedging (Conlon et al., 2016; Rout et al., 2021; Soni & Nandan, 2022), stocks pair trading (Cai, 2021; Bui & Ślepaczuk, 2022; Sohail et al., 2022), etc. However, few studies design trading strategies under the theme of "double carbon". With the deepening of the concept of carbon-neutral, the green transformation of brown assets has become a hot topic (Sun, 2021). Ma (2020) points out that the "carbon beta" can be obtained by regressing the returns of "brown assets" and "green assets", which can be further applied to investment strategies for risk hedging.

The marginal contributions and innovations of this paper lie in filling the research gaps in the above fields. Firstly, the risk spillover characteristics between carbon emission allowances and carbon-neutral concept stocks are studied, which is of great significance for enterprises to do risk management in the process of green transformation. Secondly, suitable "brown assets" and "green assets" in the carbon market and stock market are explored. Several trading strategies are designed, which will provide new ideas for investors' asset allocation.

2. Research Methods and Empirical Analysis

2.1. Sample Selection and Data Sources

1) Data range: October 2017 - October 2022 (last 5 years)

2) Data source: iFinD database

3) Carbon emission allowances: the closing price of the national carbon emission allowance (CEA); the average transaction price of Beijing carbon emission allowance (BJEA); the average transaction price of Shanghai carbon emission allowance (SHEA); the average transaction price of Guangdong carbon emission allowance (GDEA).

4) Carbon-neutral index: Following the idea of Sun (2022), a carbon-neutral index is built. Taking the carbon-neutral concept stocks in iFinD as the research object, after excluding ST shares and stocks with empty data, 50 stocks with the highest average market capitalization in the past two years are selected to construct the index weighted by their market capitalization.

2.2. Descriptive Statistics

The yield series for each of the above assets are calculated. The results of stationarity test and ARCH test are reported, as shown in the following Table 1. The AR order is determined by the AIC criterion and *** stands for significance at 1% level. All yield series are stable and have an ARCH effect.

2.3. GARCH-Dynamic Copula-CoVaR Modeling

GARCH family models can well fit the significant summit and fat tailed skewed characters of price series, so they are widely used in the study of risk spillovers between markets. However, they can only determine whether the spillover effect exists but cannot specifically characterize the direction and size of the spill, so the models need to be optimized. 1) Considering the possible time-varying nonlinear correlation between the carbon market and other markets, dynamic Copula can

Table 1. Descriptive statistical results.

Series	CEA	BJEA	SHEA	GDEA	Carbon-Neutral Index
ADF	−18.864***	−30.150***	−35.723***	−49.657***	−35.038***
AR order	6	6	5	5	8
ARCH	34.696***	24.164***	32.679***	194.555***	11.901***

be used to depict the nonlinear and asymmetric dependence structure between different markets at different times. 2) Since Value at Risk (VaR) only measures the extreme risk of a single market and ignores the connections between markets, the Conditional Value at Risk (CoVaR) can be used to measure the risk spillover effect between markets. 3) With reference to the research of Zhou and Han (2017), three models (GARCH, dynamic Copula and CoVaR) are combined. The modeling process is summarized as follows.

Firstly, consider an AR (m) model, where residual $\varepsilon_t = \sigma_t z_t$ and z follows standard normal distribution. If σ_t^2 satisfies the following equation, then the residual obeys the GARCH (p, q) process.

$$\begin{cases} y_t = \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \cdots + \alpha_m y_{t-m} + \varepsilon_t \\ \sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \cdots + \alpha_q \varepsilon_{t-q}^2 + \beta_1 \sigma_{t-1}^2 + \cdots + \beta_p \sigma_{t-p}^2 \end{cases}$$

Secondly, the dependent structure between the two fitted sequences is depicted by the Copula function. Different from the static Copula function, the dynamic Copula changes the correlation coefficient with time.

Finally, the extreme loss can be calculated after obtaining the residual fitting sequence and the time-varying correlation coefficient. Let q represent the level of significance, then the $CoVaR$ of j represents the VaR of j in an extreme case (when the loss reaches VaR). Further, $\Delta CoVaR$ of j can be determined.

$$\begin{cases} \Delta CoVaR_{q,t}^{j|i} = CoVaR_{q,t}^{j|X^i = VaR_q^i} - CoVaR_{q,t}^{j|X^i = VaR_{norm}^i} \\ \Delta CoVaR_{q,t}^{i|j} = CoVaR_{q,t}^{j|X^j = VaR_q^j} - CoVaR_{q,t}^{j|X^j = VaR_{norm}^j} \end{cases}$$

Empirical results based on the modeling process are summarized as follows.

Firstly, Table 1 shows that all the series have an ARCH effect, so the GARCH (1, 1) model with partial-t distribution can be used to fit the residual series.

Secondly, the dependent structure between the fitted sequences is depicted by the dynamic Copula function to obtain the time-varying correlation coefficient. The t-distribution is selected as the fitted distribution. As shown in Figure 1, the correlation between national carbon emission allowances (CEA) and the carbon-neutral index is overall unstable and has become increasingly positive in recent years. However, the correlations between local carbon emission allowances (BJEA, SHEA, GDEA) and the carbon-neutral index are small but remain stable and positive. There are two reasonable explanations for the above phenomenon. 1) Compared with regional carbon markets, the national carbon market was established later, so there are many uncertainties and fluctuations in development; 2) The carbon-neutral enterprises are distributed throughout the country, so the correlation between the index and the national carbon market is strong, but the correlation with the regional market is not obvious.

Finally, a series of extreme value can be calculated. Figure 2 shows the ΔCoVaR between markets. It can be seen that there is an equivalent two-way risk spillover between the national carbon market and the carbon-neutral index, while

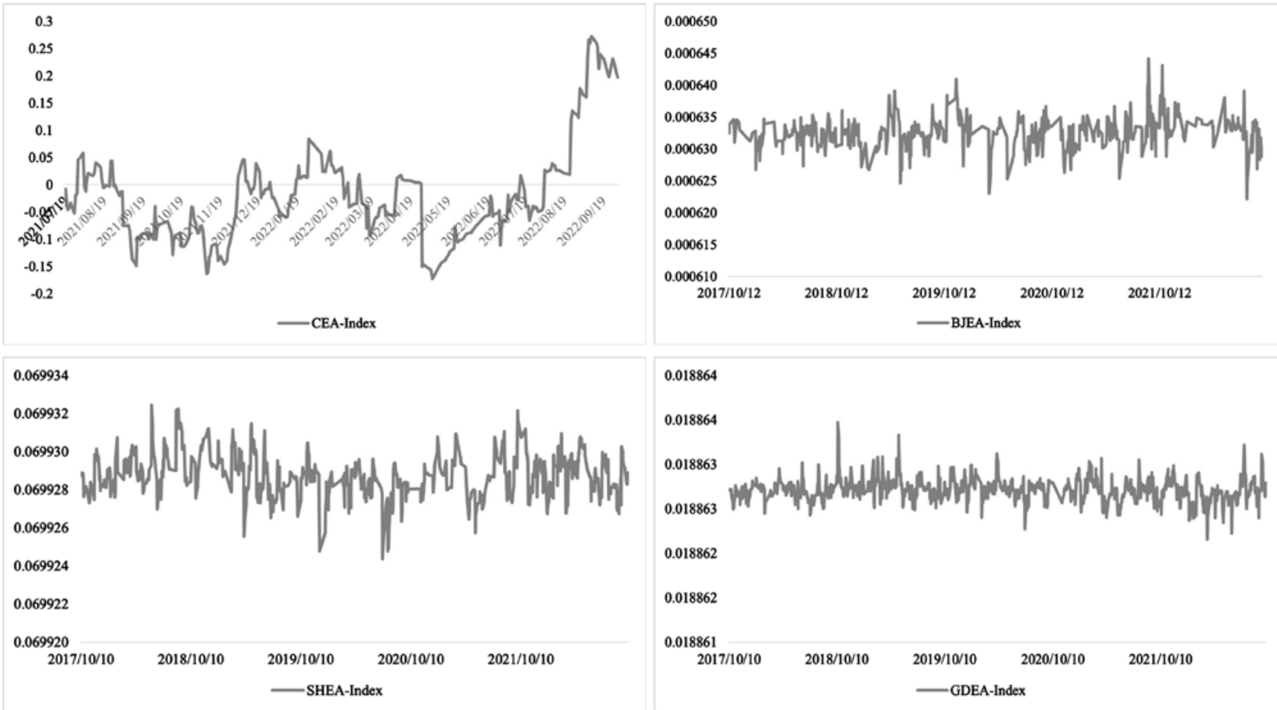

Figure 1. Time-varying Copula correlation coefficients (CEA, BJEA, SHEA, GDEA).

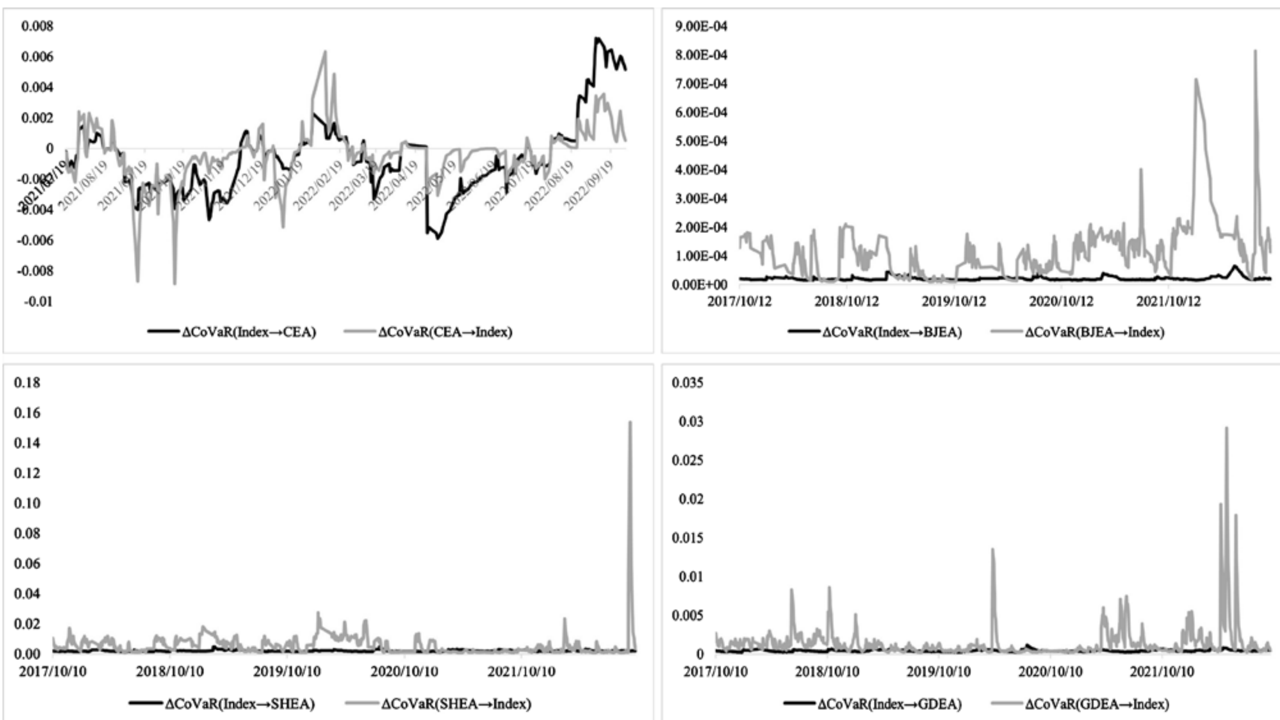

Figure 2. ΔCoVaR (CEA, BJEA, SHEA, GDEA).

the risk contagion between the local carbon market and the carbon-neutral index is asymmetric (mostly the one-way impact of the former on the latter), and the average value of this shock is small (due to the weak correlation between the two series).

The above results show that the positive correlation between the carbon market and the carbon-neutral index is becoming increasingly significant on a national scale, and the two markets can influence each other and spill over risks. From a local perspective, although the correlation between the carbon market and the stock market is weak, the former can have a one-way risk impact on the latter. Therefore, in general, the carbon-neutral index is the net risk-receiver, indicating that carbon-neutral concept enterprises face the risk of fluctuations in carbon emission allowances in the process of green transformation, which puts forward requirements for risk management.

2.4. Trading Strategy Designs

2.4.1. Trading Objects

There are two ways for choosing ideal "brown asset" and "green asset".

Firstly, from the research results of spillover effect, the carbon emission allowances fluctuate greatly and spill over risks to the carbon-neutral index. Active carbon trading indicates that enterprises are engaging in high-carbon activities. Therefore, carbon emission allowances can be regarded as brown assets and carbon-neutral index as green assets.

Secondly, the enterprises in the carbon-neutral index can be divided into the "low-carbon" group (clean energy, carbon reduction technology, finance, etc.) and the "high-carbon" group (thermal power, construction, chemistry, etc.) according to the relative intensity of carbon emissions of their production activities. The former can be regarded as green assets and the latter as brown assets.

Since most investors in the market are not qualified to trade carbon emission allowances, considering the universality of trading strategies, this paper only designs trading strategies for the second type of asset portfolio.

2.4.2. "Carbon Beta" and Hedging

Based on the idea proposed by Ma (2020), the yield series of brown assets and green assets are regressed, and the regression coefficient is called "carbon β", which can be used to quantify the hedging ratio. The overall and annual regression results are shown in **Table 2**. The data shows that most of the coefficients are significant, and the positive correlation between the two portfolios is strong, which can obtain a better hedging effect.

2.4.3. "Futures" Hedging

At present, domestic carbon futures market and green derivatives market are underdeveloped. However, since most of the high-carbon enterprises (brown assets) lie in midstream or upstream industries and are greatly affected by the price fluctuations of raw materials, they have the characteristics of commodity

Table 2. Regression results of carbon β over the past years.

Time	2018	2019	2020	2021up to now	Last 5 years
Carbon β	0.8945***	0.6271***	0.6496***	0.7107***	0.6996***

futures. Considering that the transformation cost and uncertainty of brown assets are higher than that of green assets, the subsequent value decline of brown assets is more likely, a simulated short hedging strategy can be adopted: assuming that the market allows short selling, the hedging can be completed by buying green assets (spot) and short selling brown assets (futures) at present and doing the reverse operation at maturity.

Set the hedge ratio as h, the green asset (spot) as s and the brown asset (futures) as f. If there is no margin in short selling and the hedging goal is to achieve the minimum variance, the optimal hedging ratio can be calculated by this formula.

$$h^* = \rho_{sf} \frac{\sigma_s}{\sigma_f}$$

However, in reality, most hedging operations require margin γ, and preventing extreme risk tends to be the most important target. Therefore, it is necessary to calculate the real optimal hedging ratio with the goal of minimizing extreme risk (VaR).

1) Return of the hedging portfolio: $\mu_p = \frac{r_s - hr_f}{1 + h\gamma}$;

2) Variance of the hedging portfolio: $\sigma_p^2 = \left(\sigma_s^2 + h^2\sigma_f^2 - 2h\sigma_{sf}\right)\left(\frac{1}{1+h\gamma}\right)^2$;

3) Target of hedging:

$$\min\left(VaR(h) = \mu_p - Z_\alpha \sigma_p = \frac{r_s - hr_f}{1+h\gamma} - \frac{Z_\alpha}{1+h\gamma}\sqrt{\sigma_s^2 + h^2\sigma_f^2 - 2h\sigma_{sf}}\right)$$

The margin rate γ is set at 10%. The solution results based on MATLAB (**Table 3**) show the following conclusions. 1) The correlation between "spot" and "futures" is high (the correlation coefficients are all greater than 0.6), the hedging ratio is close to 1, indicating a good hedging effect. 2) Compared with the idealized optimal hedging ratio, the real optimal hedging ratio is smaller (the hedging ratios from 2021 are 0.6267 and 0.3244 respectively), indicating a lower hedging efficiency. 3) Compared with previous periods, the hedging efficiency decreased recently (1.0627 to 0.5821 and 0.8828 to 0.3045), but there is a trend of recovery in the future (0.5821 to 0.6267 and 0.3045 to 0.3244). To sum up, this trading strategy is feasible and valuable for reference.

2.4.4. Pair Trading

Pair trading enables arbitrage by discovering correlations between stock pairs.

Table 3. Calculation results of hedging ratio over the years.

Time	2018	2019	2020	2021
Pearson correlation coefficient	0.7566	0.7984	0.6967	0.6614
Minimum variance (ideal)	0.6409	1.0627	0.5821	0.6267
Minimum VaR (real)	0.8211	0.8828	0.3045	0.3244

According to the above analysis, the correlation between brown assets and green assets is high, so it is suitable to carry out pair trading.

The premise of paired transaction is that there is a co-integration relationship between two price sequences. 1) The ADF test results show that the original price series of green and brown assets are not stable, while the first-order difference series are stable. Therefore, both of them are first-order unintegrated sequences, indicating that there may be a co-integration relationship between them. 2) Granger causality test is conducted on the two sequences (after first order difference), whose results show that brown assets is the one-way Granger cause of green assets. Therefore, brown asset price is taken as the independent variable and green asset price is taken as the dependent variable. 3) The simple linear regression is performed. The equation is $green = 0.4107 brown + 15.3619$, and the slope coefficient p value is 0.01, which is significant at the 1% level. 4) The residual test results of the regression equation show that the residual is stable and there is no autocorrelation, so there is a co-integration relationship between green assets and brown assets, the co-integration vector is (1, −0.4107), and the spread sequence is $ecm = green - 0.4107 brown - 15.3619$.

Based on the co-integration relationship, the corresponding pair trading strategy can be designed. Relevant researches prove that for the spread sequence of paired assets, plus or minus 0.75 standard deviation can be set as the opening and closing signals, plus or minus 2 standard deviation as the upper and lower stop loss boundaries. Therefore, the original paired trading strategy is (**Figure 3**):

1) When the spread is ($\mu - 2\sigma$, $\mu - 0.75\sigma$), buy one unit of green assets and sell 0.4107 units of brown assets.

2) When the spread is ($\mu + 0.75\sigma$, $\mu + 2\sigma$), sell one unit of green assets and buy 0.4107 units of brown assets.

By fitting the GARCH (1, 1) model with the spread, the corresponding conditional variance sequence σ_t can be obtained. By replacing the original constant σ with σ_t, the trading threshold line can be changed into a time-varying curve. At this time, the execution result of the trading strategy is shown in **Figure 4**. It can be seen that the new threshold lines better describe the time-varying characteristics of the volatility of the spread series, which reduce the stop-loss frequency compared with the original strategy and improve the efficiency and returns of the strategy.

3. Conclusions and Recommendations

In this paper, an index based on the carbon-neutral concept stock pool is built,

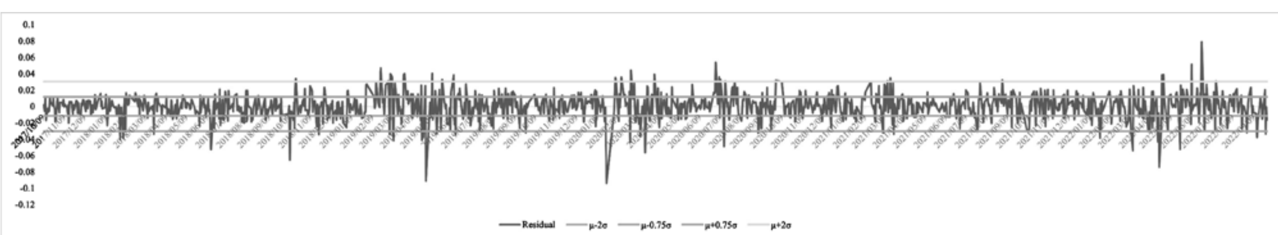

Figure 3. Fixed threshold strategy.

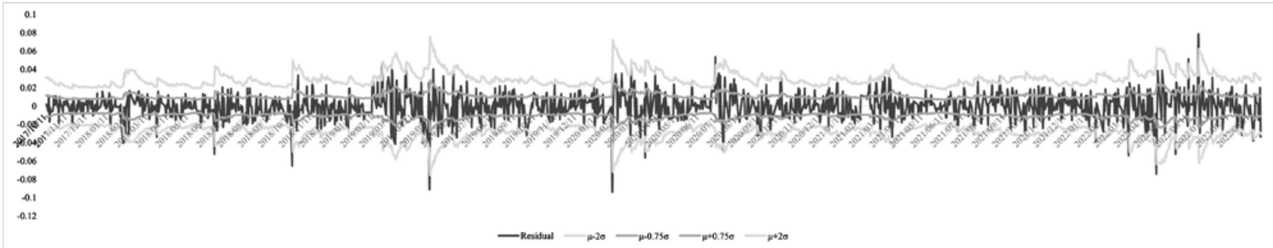

Figure 4. Time-varying threshold strategy.

and GARCH-dynamic Copula-CoVaR is used to study the risk spillover effect between the carbon market and the carbon-neutral index. The following conclusions are drawn. 1) There is a two-way risk spillover between the national carbon emission allowance market and the carbon-neutral index, and the positive correlation is becoming increasingly significant. 2) The correlation between local carbon emission market and carbon-neutral index is weak, and there is an asymmetric risk spillover relationship between them: the former can have a one-way risk impact on the latter. 3) In general, the carbon-neutral index is the net risk-receiver, indicating that carbon-neutral concept enterprises face the risk of carbon emission allowance price fluctuation in the process of green transformation. In addition, drawing on the research ideas existed, appropriate "brown assets" and "green assets" in the carbon market and stock market are found, and trading strategies including hedging and pair trading are designed, providing new ideas for investors' asset allocation.

This paper argues that in the process of green transformation, enterprises with carbon-neutral concept should attach importance to improving their risk management ability. On the one hand, they should carry out reform step by step and avoid to be too hasty. On the other hand, they can actively participate in green derivatives trading to effectively prevent the adverse effects of price fluctuations in the carbon market. Besides, for the majority of investors, designing investment strategies under the theme of "double carbon" and actively participating in market trading are all conducive to optimizing personal asset allocation.

Carbon neutrality is a hot topic of sustainable economic development. In order to better study this topic in the future, several shortcomings of this article are summarized. Firstly, due to the late establishment of China's carbon emission allowance markets, insufficient transaction data may lead to biases in the test of spillover effects. Secondly, only the relationship between the stock market and the carbon market is studied. However, other financial markets (such as green bond market, ESG fund market, etc.) are also worth exploring. Finally, only traditional and simple trading strategies are involved, and more complex structured financial products can be designed around the carbon neutrality investment theme in the future.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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