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Research on Extreme Risk Spillover Effects between China's Carbon Market and Energy Market

-- Empirical Evidence based on GAS-Copula Method

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Abstract

As the construction of China's carbon trading system accelerates, it is necessary to systematically analyze the risk spillover effects between China's carbon market and energy market. On the basis that the energy market will be affected by the carbon market, some reasonable carbon trading policies can be formulated by using the risk mechanism between the carbon market and the energy market. This article takes the carbon price and energy market (petroleum, coal, gas and new energy) index data of three pilots (Guangdong, Hubei and Shanghai) in China's carbon emissions trading market as the research object, and conducts empirical research based on the GAS-Copula method. Static and dynamic risk spillover effects in China's carbon trading market and energy market. The results show that there are risk spillover effects between the carbon trading market and the energy market, and there are significant fluctuations in the spillover index of each market. Based on the research results, this article puts forward countermeasures and suggestions for accelerating the construction of a carbon trading market.

Keywords

Carbon Markets; Energy Markets; Extreme Risk Spillovers.

1. Introduction

In recent years, global climate and environmental problems have become increasingly serious, and global warming caused by excessive carbon emissions is an urgent problem that needs to be solved. In the past ten years, the carbon market has gradually developed in China. The pilot work of carbon market construction has been launched in eight provinces and cities including Beijing, Tianjin, Shanghai, Chongqing, Shenzhen, Hubei, Guangdong, and Fujian. Subsequently, the national carbon emissions trading The system (ETS , hereinafter referred to as the " carbon market ") will be put into operation in July 2021 . With the rapid development of China's carbon trading market, its connection with the energy market has become increasingly close. Energy or carbon market fluctuations caused by information shocks can easily be transmitted between markets. Moreover, the spillover effects between China's carbon market and energy market cannot be static. The degree of market fluctuations is different in different periods, and the intensity of the spillover effects should also be different. Carbon emissions trading is not only a driving force for the transformation of the energy structure of real enterprises, but also an important new resource in the financial market. However, China's carbon market still has the disadvantage of poor liquidity. Therefore, it is necessary to deeply examine the time-varying volatility spillover characteristics between China's carbon market and energy market, and

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study the spillover network between China's carbon market and energy market, which can clarify the price and volatility information transmission between the carbon market and energy market, and provide a basis for improving China's carbon market and energy market. Carbon market liquidity provides a theoretical basis.

2. Literature Review

In recent years , more and more studies have been conducted in the field of carbon market risk research, mainly focusing on carbon market risk measurement and spillover effects. Jiang et al . (2015) used the GARCH-EVT-VaR model to conduct an empirical analysis of the risks of the EU carbon market. Du et al. (2015) used the ARCH-VaR model to measure the risks of six carbon markets in Beijing, Shenzhen, Shanghai, Tianjin, Hubei and Guangzhou. Zhu et al. (2018) proposed a multi-scale VaR method based on empirical mode decomposition (EMD) to measure the risk of the EU carbon market. Balcılar et al . (2016) used the MS-DCC-GARCH model to study the risk spillover effects between the European energy and carbon markets. Hu et al. (2015) used the R-vinecopula model to explore the dependence characteristics of the EU carbon market and found that the R-vinecopula method can better describe the dependence structure of the carbon market. Wang et al. (2016) used multivariate GARCH(1,1)-BEKK to measure the volatility spillover effects between Guangdong, Hubei and Shenzhen carbon markets. Wang and Gao (2016) adopted a six-element VAR-GARCH-BEKK model with asymmetric t distribution to measure the spillover effects between the six carbon markets of Shenzhen, Beijing, Guangdong, Hubei, Tianjin and Shanghai. Dhamija et al. (2017) used the BEKK-MGARCH model to analyze the risk spillover effects between the EUA carbon market and the energy market. Sun[46] (2018) used the DCC-MGARCH(1,1) model to analyze the interaction between the EU carbon market and the Chinese carbon market. Ji et al. (2018) used the vector autoregressive (VAR) model to study the information linkage and dynamic spillover effects between carbon and energy markets, and measured uncertainty and extreme risks in the energy market through the time-varying copula - based CoVaR method. Spillovers , use the dependence switching CoVaR-copula model to measure risk spillovers between energy and agricultural products markets. Ji et al. (2019) used a time-varying entropy-based method to determine the direction of return spillovers to study the information interdependence between various commodities. From a firm-level perspective , a connectivity network approach is used to measure the information spillover effects between the carbon market and the electricity market. Kumar et al. (2019) used a dependence transformation correlation model to study the dependence between BRIC stocks and the foreign exchange market, and showed that the cocorrelation calculated using R-vine correlation is most suitable for calculating the portfolio VaR.Zhu (2020) used VaR and conditional VaR to measure risks in pilot carbon markets in Beijing, Shanghai, Guangdong, Tianjin, Hubei, Shenzhen and Chongqing in China. Zhu et al. (2020) proposed a risk conditional value method based on two-dimensional empirical model decomposition and explored the risk spillover effects of the carbon market and the electricity market. Jin et al. (2020) explored effective hedging tools for carbon market risks and studied the relationship between carbon futures returns and the returns of four major market indexes: VIX index, commodity index, energy index and green bond index.

There are also studies that confirm the dynamic correlation between carbon markets and energy markets. These studies mainly analyze the dynamic fluctuation spillover effects between them, but they pay little attention to the time-varying spillover effects between the carbon market and the energy market, and do not consider the time lag and periodicity of the spillover effects, which is worthwhile between markets. important factors to consider. Paul and Subrata (2020) use a frequency-based spillover measure that captures the time-frequency dynamics of return spillovers between crude oil and major U.S. agricultural products. They

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found that return spillovers from energy to agricultural products vary with time and frequency. The extent of earnings spillovers varies over time and is greater during crises than during stable periods. Fasanya and Odud (2020) used the DY method to study the market spillover effects between the prices of major agricultural products in Nigeria. They recognized that returns and volatility spillovers in the Nigerian agricultural market were more unstable during the crisis, and used the time-lag structure of VAR to verify the reliability of the conclusions. (2017) used the wavelet -based GARCH-BEKK method to examine the spillover characteristics in the frequency dimension. At the same time, the entire sampling period is divided into pre-crisis, mid-crisis and post-crisis to examine the spillover characteristics of the period dimension. And Gong et al. (2021) used a time-varying vector parameter autoregressive model with stochastic volatility (TVP-VAR-SV model) and hedge based on weekly data of European carbon futures prices and three fossil energy sources (oil, coal, and natural gas) . The stimulus response function studies the time delay and periodicity between two types of markets. Therefore, studying the time lag and periodicity of spillover effects are important factors worth considering.

With the global expansion of carbon emissions trading mechanisms, research on the relationship between carbon markets and energy markets has proliferated. Most literature has confirmed the decisive role of energy prices on carbon prices. Oil (Dutta, 2018) and natural gas (Zhang and Wei, 2010) were found to be the main drivers of the EU carbon market. In China's carbon pilots, coal prices play a leading role (Zhao et al. , 2017).

In summary, the existing literature has provided useful inspiration for exploring the price fluctuation transmission mechanism between China's carbon market and energy market. However, the above studies lack the examination of the time-varying and directional characteristics of the spillover effect, and cannot combine the selected Various energy markets as a whole describe the fluctuation spillover relationship between the carbon market and the energy market as a whole. Based on this, this paper introduces the spillover index model to examine the time-varying two-way spillover effects between China's carbon market and energy market, and conducts an in-depth analysis of the specific characteristics of the correlation between China's carbon market and energy market. Compared with existing research, this paper effectively depicts the time-varying, directional characteristics and overall trends of the spillover effects between the two markets, making up for the shortcomings of previous studies in examining the time-varying characteristics of the spillover effects between China's carbon market and energy market. insufficient.

3. Variable Selection and Model Construction

3.1. Indicator Selection

Since 2011 , China has launched pilot carbon trading markets in eight provinces and cities, including Beijing, Tianjin, Shanghai, Chongqing, Shenzhen, Hubei, Guangdong, and Fujian. In addition, there is also the Sichuan carbon market, which currently has no carbon quota trading. Due to the large differences in the establishment time and trading volume of each carbon trading market, this article selects the carbon emission trading prices of four representative carbon emission exchanges, Shenzhen, Shanghai, Guangdong and Hubei, as the research object, combined with China Energy The price indexes of thermal coal and crude oil, the top two energy sources in the consumption structure, were constructed to construct the DY model and the LW model respectively.

The carbon emissions trading price data in this article comes from the Wind database, and the energy price index data comes from the Choice financial terminal. The sample data interception time is from May 5 , 2014 to December 26 , 2021 . In order to maintain the consistency of the time series and avoid unnecessary data deletion, this article uses Python 's Pandas package to

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complete the original data with linear interpolation and then take the logarithm, resulting in a total of 2792 daily data. The definitions and sources of each indicator of the model are shown in Table 1 , and Table 2 gives the descriptive statistics of each indicator. It can be seen from Table 2 : (1) Among the four carbon trading markets, the Shenzhen market has the largest average return rate of 0.0402% , but its degree of volatility is also the largest, with a standard deviation of 0.260375 . The other three carbon trading markets are all left-skewed . (2) The thermal coal index return rate is significantly greater than the crude oil price index return rate, but the crude oil price index return rate is less volatile. (3) All indicators have sharp peaks and thick tails. (4) The JB test rejects the null hypothesis that the returns of the four carbon trading markets and the returns of the two energy indexes follow a normal distribution.

Table 1. Indicator definitions and sources

index	symbol	source
Shenzhen carbon market daily closing price	SZEA	Wind
Guangdong carbon market daily closing price	GDEA	
Shanghai carbon market daily closing price	SHEA	
Hubei carbon market daily closing price	HBEA	
crude oil price index	OIL	Choice
Thermal Coal Price Index	COAL	

Table 2. Descriptive statistics

	SZEA	GDEA	SHEA	HBEA	OIL	COAL
mean	-0.000402	-0.000057	0.000032	0.000151	-0.000107	0.000423
Median	0.000000	0.000000	-0.000241	0.000000	0.000000	0.000152
maximum value	2.479478	0.095721	0.262364	0.095602	0.202801	0.092268
minimum value	-2.377147	-0.105790	-0.318454	-0.105525	-0.200702	-0.150942
standard deviation	0.260375	0.028946	0.028620	0.021771	0.019628	0.012589
Skewness	0.477541	-0.326456	-0.436601	-0.201341	0.209830	-1.485178
kurtosis	34.95349	7.179938	21.12162	10.58565	21.33119	22.46110
JB inspection	118885.40	2082.16	38291.76	6712.93	39112.28	45085.83
Observations	2792	2792	2792	2792	2792	2792

3.2. Model Construction

This paper's model constructs a generalized autoregressive score-driven (GAS) model to describe the marginal distribution of energy market uncertainty and carbon market price volatility. The joint distribution of energy market uncertainty and carbon price volatility is simulated by building a time-varying link (Copula) model to capture the tail dependence structure between the two markets. And use the Bayesian (BIC) model to measure the goodness of fit of the time-varying link (Copula) model. In order to measure the magnitude of extreme risk spillovers between China's carbon market and energy market, this article intends to define CoVaR as the extreme carbon price volatility risk value, based on Shanghai's carbon price volatility rate, and select CoVaR with rising and falling carbon price volatility And through link function calculation, we can further measure the size of extreme risk spillover.

The specific model is as follows:

$$\%CoVaR^{d,\alpha}_{r_{c|U,d,t}} = 100 \times (CoVaR^{d,\alpha}_{r_{c|U,d,t}} - V\alpha R^{d,\beta}_{U,t})/V\alpha R^{d,\beta}_{U,t}$$
$$\%CoVaR^{U,\alpha}_{r_{c|U,u,t}} = 100 \times (CoVaR^{U,\alpha}_{r_{c|U,u,t}} - V\alpha R^{d,\beta}_{U,t})/V\alpha R^{u,\beta}_{U,t}$$

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4. Empirical Analysis

4.1. Analysis of Static Risk Spillover Effects

Table 3. Static overflow index comparison table

	COAL	OIL	SZEA	SHEA	GDEA	HBEA
COAL	98.96	0.6	0.06	0.07	0.19	0.12
OIL	0.22	98.68	0.05	0.51	0.08	0.46
SZEA	0.07	0.08	99.26	0.24	0.08	0.28
SHEA	0.03	0.6	0.27	98.44	0.64	0.03
GDEA	0.14	0.2	0.04	0.3	99.23	0.09
HBEA	0.28	0.48	0.5	0.02	0.09	98.64

Table 4. Data description of regional carbon market volatility

Statistics	Regional carbon market			
	Shenzhen	Guangdong	Shanghai	hubei
mean	0.0178	0.0142	0.0235	0.0057
Median	0.0020	0.0086	0.0032	0.0018
maximum value	0.3122	0.2331	2.0278	0.3018
minimum value	0.0000	0.0000	0.0000	0.0000
standard deviation	0.0330	0.0249	0.1325	0.0196
Skewness	3.8002	5.7733	13.4163	13.2602
kurtosis	27.4050	44.3103	199.4324	199.6361

Table 5. Spillover index between regional carbon market and various energy markets

energy market	Shenzhen Carbon Market		Guangdong carbon market		Shanghai carbon market		Hubei carbon market	
	overflow index	overflow index	overflow index	overflow index	overflow index	overflow index	overflow index	overflow index
H=8								
coal	1.79	1.10	0.29	0.09	22.01	28.96	0.45	0.38
crude	3.18	3.67	3.99	3.74	0.06	0.05	0.29	0.21

Table 6. Spillover index between regional carbon market and overall energy market

overflow type index	Shenzhen Carbon Market		Guangdong carbon market		Shanghai carbon market		Hubei carbon market	
H=8								
Directional spillover index *	5.95		4.78		22.23		0.87	
Directional spillover index **	5.57		4.47		29.48		0.78	
net spillover index	-0.38		-0.31		7.26		-0.09	
total spillover index	4.08		3.58		12.10		2.13	

*indicates that the direction of spillover effects is “energy market → regional carbon market”;
**indicates that the direction of spillover effects is “regional carbon market → energy market”

First, the static volatility spillover effect between China's four carbon markets and energy markets is analyzed by constructing a static volatility spillover index table. The static

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fluctuation spillover index table is the result of generalized variance decomposition based on the full sample data. In the actual calculation process, the lag order of the autoregressive process of each carbon market and energy market in China is determined to be 1st order based on the AIC and SC criteria . The prediction period of generalized variance decomposition is selected as 8 periods (approximately 2 months). Table 3 shows the volatility spillover index between China's Shanghai carbon market, Guangdong carbon market, Shenzhen carbon market and Hubei carbon market and the energy market. The spillover index of each carbon market indicates the impact of selecting each energy market on the carbon market forecast error. The size of the variance contribution rate is the size of the volatility spillover effect of each energy market on the carbon market. The spillover index represents the size of the volatility spillover effect of the carbon market on each selected energy market. The directional spillover index is calculated by selecting the sum of the spillover index and spillover index of each carbon market for each energy market. Since the spillover index results can be summed, this method can be used to examine each single energy market as a whole. Spillover relationships between energy markets. The net spillover index of each carbon market is the spillover index value minus the spillover index value. Furthermore, the total spillover index in the last row refers to the mean of the spillover effects of all other variables on a certain variable.

The static fluctuation spillover effect index is shown in Tables 5 and 6. The results show that the spillover index and spillover index between each carbon market and the energy market are both greater than 0 , and the total spillover index is also greater than 0. This means that China's four carbon markets and There are volatility spillovers between energy markets, but the volatility spillover effects between Shenzhen, Guangdong and Hubei carbon markets and energy markets based on the full sample are relatively small, not exceeding 10% . In addition, the directional spillover index and net spillover index results in the table show: First, the volatility spillover effect between the four carbon markets and the energy market is two-way. Second, there are certain differences in the net spillover relationship between the four carbon markets and the energy market. The Shanghai carbon market is a net exporter of fluctuations in the energy market, while the Shenzhen, Guangdong and Hubei carbon markets are net receivers of fluctuations in the energy market. . Third, it can be concluded from the size of the spillover index between different energy markets and carbon markets that the carbon markets in different regions are asymmetrically affected by the fluctuations of the energy market. Among them, the spillover effect of Shanghai's carbon price fluctuations mainly comes from the fluctuation of coal prices, while the spillover effects of the Shenzhen and Guangdong carbon markets mainly come from the crude oil market.

5. Main Conclusion and Policy Recommendations

Based on the empirical evidence of the GAS-Copula method, this paper systematically analyzes the spillover effects between China's carbon market and energy market in a quantitative manner to explore the impact of energy market price fluctuations on China's carbon market. Based on the measurement results of the inter-market spillover index in the empirical part, the following conclusions are drawn: First, the measurement results based on the full sample show that there are two-way volatility spillovers between markets, but the characteristics of the spillover effects and the net spillover relationship between different carbon markets and energy markets are different. sex. In terms of spillover characteristics, the Shanghai carbon market has the closest linkage with the coal market, while the Shenzhen and Guangdong carbon markets are more prone to be affected by fluctuations in the crude oil market; in terms of net spillover relationships, the Shanghai carbon market provides a net spillover for energy market fluctuations. The carbon markets in Shenzhen, Guangdong and Hubei are net importers of the energy market. Secondly, the calculation results based on rolling windows show that the

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volatility spillover between China's carbon market and energy market has significant time-varying characteristics. The total spillover and directional spillover between markets show strong time variability in the spillover size, and the net spillover shows strong time variability in the spillover size and spillover direction. The time-varying nature of the size and direction of spillover effects shows that the information transmission mechanism between China's carbon market and energy market is highly uncertain. Thirdly, further analysis of the trends of various types of spillover indexes between markets found that the total spillover level between the domestic carbon market and the energy market showed a significant upward trend mainly during the energy market shock period; overall, during the energy market price shock period, China The spillover effect of each carbon market from the energy market is significantly higher than in other periods. However, there are certain regional differences in the degree to which China's different pilot carbon markets are affected by energy market fluctuations in the corresponding periods.

As an emerging trading market, the carbon trading market needs further improvement in relevant laws, regulations and risk management and control mechanisms.

Based on this, this article puts forward the following relevant policy recommendations to promote the stable operation of China's carbon trading system:

(1) Form an intrinsically stable price mechanism between China's carbon market and energy market. The research results show that the fluctuation transmission mechanism between China's carbon market and energy market is highly uncertain. In order to effectively prevent energy price fluctuations from intruding on China's carbon market, it is necessary to incorporate carbon emissions trading prices into China's energy price system. Comprehensive consideration will be carried out to form an intrinsically stable price mechanism between China's carbon market and energy market.

(2) Learn from the advanced experience of the EU carbon market, such as the continuous reduction of emission permit caps, the tightening of reserve methods (the addition of an auction mechanism), and the gradual expansion of coverage. Provincial authorities can expand the scope of the pilot carbon market to companies below the threshold and companies in industries that have not yet been covered, gradually improve carbon financial derivatives (carbon forwards, carbon options, carbon swaps, etc.) and expand the market size , to improve the scope of influence and risk resistance of the carbon trading market as a whole.

(3) Investors should pay close attention to the spillover relationship between the carbon market and the energy market, as well as relevant policies for the development of each market, and make rational investments. In addition, investors need to pay different attention to price and volatility changes. The empirical results of this article confirm that the two present different patterns. Consider appropriate multi-portfolio strategies under different market conditions to obtain optimal risk returns, and adopt dynamic portfolio management.

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