A study of price volatility in two phases of the Shanghai carbon market

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Abstract: With the development of industrial activities, the emission of greenhouse gases is getting more and more attention. Since the official launch of carbon emissions trading in China in 2013, there have been seven pilot provinces and cities, including Shenzhen, Guangzhou, Beijing and Shanghai. This paper selects Shanghai as a pilot city and conducts a two-stage empirical study on the volatility of the daily carbon price return series from its first trading date of 2013.12.19 to the present. The empirical regressions in this paper are conducted using MATLAB tools to establish a two-stage fitted model through model identification and fixed order, and Monte Carlo simulations are performed to explore and compare the two-stage volatility. Because of the lack of pricing mechanism, China is in a passive situation in the international carbon market. As the largest emitter of carbon dioxide, we need to sort out the factors influencing the fluctuation of carbon price, predict the carbon price, and reasonably realize the pricing of carbon assets. In this paper, we study and analyze the fluctuation of carbon price, in order to make a modest contribution to China's carbon market to the world, to make the price of China's carbon market converge with the international carbon market, and to take the carbon trading road with Chinese characteristics in a comprehensive view.

1. Introduction

In the 21st century, the rapid development of science and technology has been accompanied by a huge change in industry, which has resulted in the massive emission of greenhouse gases. The Stern Report has pointed out that the level of impact and damage of climate change is more severe in developing countries than in developed countries. The report also pointed out that if action to curb the greenhouse effect is not on the agenda within a decade, global GDP will lose 5 to 20 percent in each subsequent year. However, if countries respond sensitively in the shortest possible time with a developmental and sustainable vision, the effect will be immediate and the loss of GDP will be reduced to 1 percent. Climate change caused by carbon dioxide emissions is already causing great harm and seriously endangering our future generations. How to curb greenhouse gas emissions and protect the environment on which human beings depend has become particularly important, and this has become the focus of attention of international organizations, experts and scholars.

Since the start of carbon emissions trading in 2013, there have been seven pilot provinces and cities, including Shenzhen, Guangzhou, Beijing and Shanghai. On March 17, 2017, at the Paulson Foundation's 2017 Annual Sustainability Conference in Beijing, Mr. Xie Zhenhua, the representative of China, pointed out that a nationwide carbon emission rights market would be established to promote the development of a low-carbon economy and create a favorable market environment. market. In accordance with the principle of first easy and then difficult, the construction of a carbon trading market covering eight key industries will be carried out one after another, with the aim of initially building a mature nationwide carbon emissions trading market by 2020. This move indicates that China's carbon trading will enter a brand-new phase. However, compared with the mature trading system of the European Union, China's carbon market is still in a very imperfect stage of development, and there are many factors that affect trading, and carbon prices fluctuate significantly, which is not conducive to guiding the carbon market for reasonable resource allocation. Therefore, we urgently need to accurately grasp the various factors affecting the fluctuation of carbon prices, to clarify the

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mode of influence, and to be able to make reasonable and scientific predictions on the fluctuation of carbon prices.

Research on the volatility of China's carbon market plays an important role in promoting the operation and development of the carbon market. In this paper, we will conduct an empirical study on the price volatility of the Shanghai carbon market from two stages before and after the establishment of the national carbon market, and analyze and compare its development, with a view to generating favorable effects for the mature operation of the national carbon market.

2. Literature Review

Although the carbon trading market has its own special characteristics, it also has the same market attributes as other markets. Dackalaki et al. (2009) studied the EUAS price and found that the market was not stable and that market participants were willing to accept non-arbitrage prices. In general, the carbon price is positively correlated with the price of electric utility stocks, as the carbon price rises, so does the price of electric utility stocks, and vice versa, as the carbon price falls, so does the price of electric utility stocks, but it varies from country to country, for example, Spain is the opposite of Germany and the UK, where the carbon price and the price of electric utility stocks have a negative correlation. (2009) analyze the relationship between carbon price changes and common stocks based on Obemdorfer, where the demand for a stock and its price depends on the expected return of the company, and the price of carbon dioxide is related to the expected supply and demand in the market.

Benz and Trueck [1] found that the carbon spot price series in the EU carbon emissions trading system exhibits a clear "spike and thick tail" phenomenon through empirical analysis. The analysis found that the EUA price and the share price of European power industry have a positive correlation, but the EUA price and the share price of power industry in Spain, which is in Europe, show a negative correlation. Tianyan Xu [3] also used a GARCH model when studying the price volatility of CER futures listed and traded on the Chicago Climate Exchange, and their results showed that CER futures have the price volatility characteristics of financial products, and there is a higher-order ARCH effect in the time series data of their returns, and the GARCH model can explain these characteristics of CER futures with a good fit.

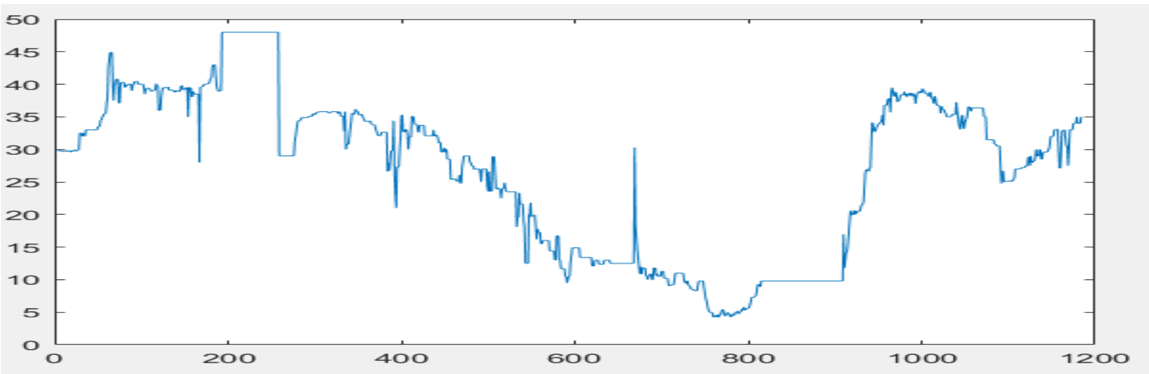
Chen Xiaohong and Wang Zhiyun[4] studied the price formation mechanism of the European emission trading system by establishing an EGARCH model to investigate the volatility of EUA yields, and analyzed the empirical results to find that the price mechanisms of different stages of EUA are different, and the price volatility of the two stages is very different. chevallier [5] used the EGARCH model to measure the volatility of EUA, and by the analysis of the empirical research results obtained that the fluctuation of EUA price mainly originates from the mechanism design, while the commonly believed speculative arbitrage factor of investors does not have a great influence on it. Zhang and Wei [6] empirically analyzed the operational characteristics of the EUETS carbon futures market by introducing the GED-GARCH model, and their results showed that the combined effects of political factors, energy prices, stock market movements, and other complex factors led to the inefficiency of the carbon market and the phenomenon of market overreaction. Huang et al [7] used normative analysis and GARCH model to study the price volatility of CER products under CDM, Yuan Lu [8] used GJR-GARCH-M model to empirically examine the price volatility characteristics of the EU carbon allowance market, and Wu Zhenxin et al [9] used EGARCH model to examine the price volatility characteristics of CER futures yields in the EU carbon market based on different distribution assumptions. These studies show that the "leverage effect" in the carbon trading market is obvious.

Benz [10] constructed an AR-GARCH model and a Markov mechanism transformation model to study the volatility behavior of the spot price and carbon price yield of carbon emission allowances in the short term, and compared the results with those of other different models, and the final analysis showed that the AR-GARCH model and the Markov mechanism transformation model can better reflect the carbon price volatility characteristics of EUETS. Wu Heng Yu et al [11] constructed a T-GARCH model and a nonlinear Markov mechanism transformation model in a linear econometric model to empirically investigate the dynamic effects of the futures and spot markets of CER products in the international carbon emission rights market, and their research results showed that the T-GARCH model could produce a good Daskalakis [12] empirical study on the price volatility of EUA and its derivatives in the European carbon emission trading market using a holding cost futures pricing model, and their findings showed that the negotiation and borrowing behavior of carbon emission allowances between different stages had a large impact on carbon futures pricing.

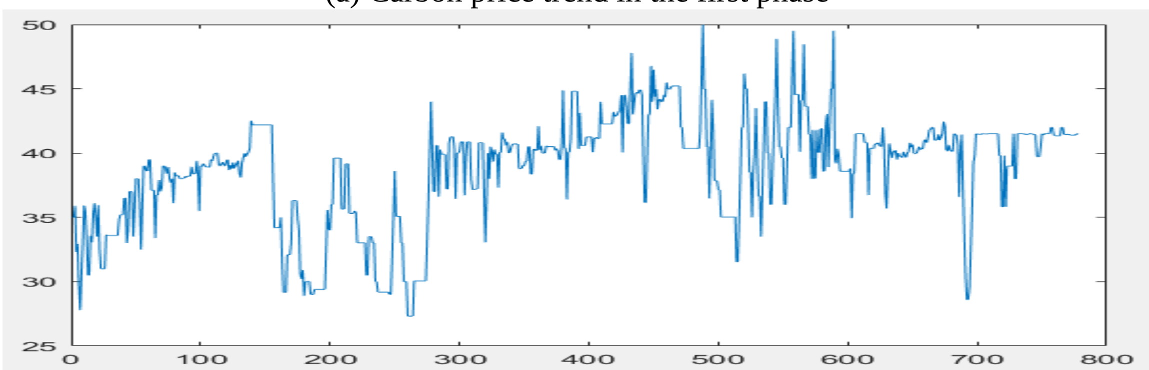
Guo Fuchun and Pan Xiquan [13] used Bai-perron structural mutation test and capital asset pricing one-factor model to empirically study the price volatility and risk of carbon futures contracts in the second phase of EUETS, and found that both EUA and CER carbon futures contract prices showed nonlinear characteristics with significant structural mutations during the sample period. Liu Weiquan and Guo Zhaohui [14] used the SV-N, SV-T, SV-MN and leverage-SV models to simulate the volatility of EUA carbon prices and found that the leverage-SV model performed optimally. Ying Gao and Kun Guo [15] used wavelet analysis and VAR model to study the EUETS market operation mechanism, price volatility law and market effectiveness, and their findings showed that two factors, international macroeconomic situation and investors' expectation on the development of carbon trading market, have a greater impact on carbon emission rights price volatility, and the European carbon trading market has certain market effectiveness. Kedi Jing et al [16] used the A-PARCH model to empirically analyze the volatility of EUA in the Bluenext carbon trading market, and the results showed that their model is an improvement of ARCH, but the model normality distribution assumption is not appropriate because most of the financial series are non-normal. Chen Zhang and Yachi Wu [17] constructed a variable-structure ASV model to statistically analyze the volatility process of CER carbon price returns and simulated it using the MCMC method based on Bayesian theory, and their results showed that the variable-structure ASV model can well fit the time-varying, strong persistence and weak asymmetry characteristics that exist in the volatility process of CER carbon prices.

3. An empirical analysis of the volatility of daily returns on carbon prices

3.1 Selection and statistical characterization of carbon price data



(a) Carbon price trend in the first phase



(b) Phase II Carbon Price Trend

Figure 1. Two-stage carbon price trend chart

In this paper, the price volatility of Shanghai carbon market is analyzed in a two-stage study, taking the establishment of a national carbon market at the end of 2017 as the cut-off point, and November 2013-December 2017 is selected as the first stage and January 2018-March 2021 as the second stage, with daily carbon price data from China Carbon Emissions Trading Network. The carbon price trend of the two phases is shown in Figure 1, and it can be roughly observed that the carbon price range of the first phase is mainly 10-50 RMB, and the carbon price range of the second phase is mainly 30-50 RMB. Among them, the carbon price in Shanghai once fell to 4.5 yuan/ton in April 2016, mainly because the carbon quota in Shanghai carbon market had fallen to 4.5 yuan/ton, mainly because Shanghai issued a one-time quota to emission-controlled enterprises for three years, and it was difficult for emission-controlled enterprises to have a clear grasp of carbon quota usage leading to a weak demand and inevitably a big decrease in trading volume, and the direct impact of weakened supply and demand was a price drop. The second reason is that Shanghai quotas are issued free of charge, there is no cost pressure on the emission control enterprises, the lack of price support, coupled with the possibility that the previous quota will be deferred which makes some enterprises are willing to sell quotas at low prices.

The simple yield method and logarithmic yield method are generally used in the theory of time series to describe the yield series, while the carbon price daily data used in this paper are continuous and compounded, so the logarithmic yield method is used in this paper to describe the carbon price data in two stages.

The daily return is expressed as

$R(t) = \ln(P_t/P_{t-1}) = \ln(P_t) - \ln(P_{t-1})$

The results of the calculations in this paper are implemented by MATLAB.

In order to better analyze the volatility of the yield series, this paper uses descriptive statistics such as mean, maximum, minimum, standard deviation, skewness and kurtosis to analyze the basic characteristics of the two-stage carbon price daily yield volatility. The descriptive statistics of the two-stage carbon price daily returns are shown in Table 1.

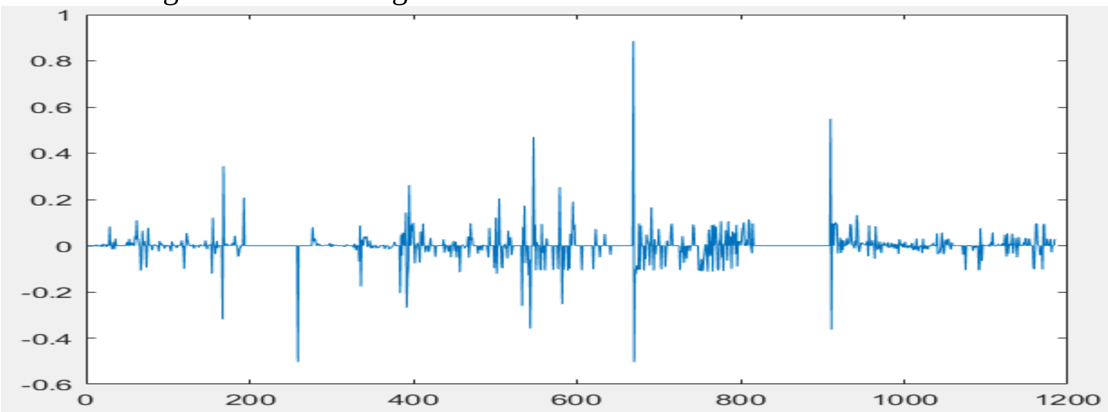
Table 1. Descriptive statistics of daily returns of carbon price in two phases

Stage	Observations	Average value	Maximum value	Minimum value	S.D.	Skewness	Kurtosis	JB Inspection	ADF
1	1184	0.00013	0.885	-0.504	0.0599	2.373	64.69	ans=1	1
2	778	0.000219	0.105	-0.2259	0.0455	-0.275	4.689	ans=1	1

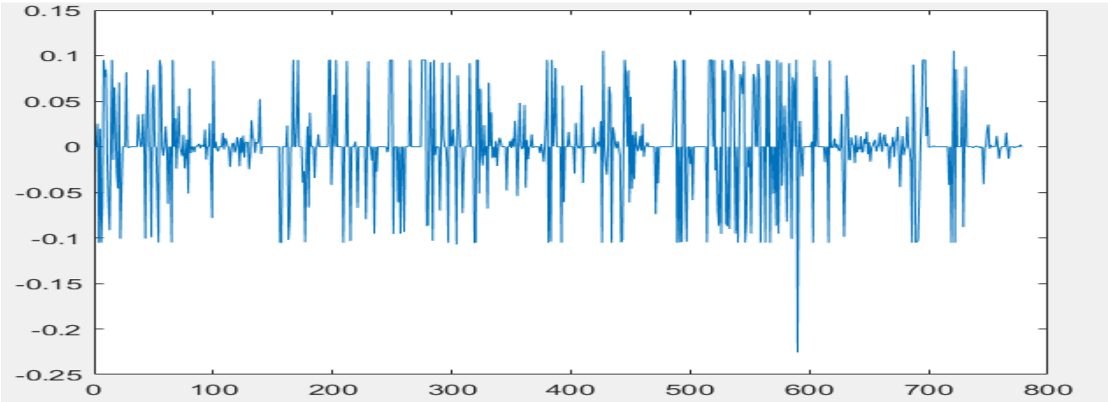
As can be seen from Table 1, the mean values of the daily carbon price yields in both phases of the Shanghai carbon market are close to 0 and greater than 0, indicating that the carbon prices in both phases are on an upward trend, and the mean value of the second phase is slightly greater than the mean value of the first phase, indicating that the carbon price level in the second phase has improved somewhat compared with that in the first phase. In terms of skewness, the skewness of the daily carbon price return in the first stage is greater than 0, showing an obvious right skew trend, indicating that the return is higher than the average value more often, while the skewness of the daily carbon price return in the second stage is slightly less than 0, showing a left skew trend, indicating that the return is lower than the average value more often; in terms of kurtosis, the kurtosis of the daily carbon price return in both stages is significantly greater than 3, and the kurtosis in the first stage is much higher than that in the second stage, indicating that the distribution of the daily carbon price return in the first stage is more concentrated. The kurtosis of the first stage is much higher than that of the second stage, indicating that the distribution of daily carbon price returns is more concentrated in the first stage. Overall, both stages of carbon price daily returns show the characteristics of spikes and thick tails, and the JB test values of both stages of data are 1, indicating that both stages of carbon price daily returns reject the hypothesis of obeying normal distribution.

3.2 Checking the smoothness of daily return series

At present, there are many theoretical methods to test the smoothness of time series, and the most commonly used methods are observation method test and unit root test. If the graph of the time series is basically fluctuating around its mean value and the fluctuation magnitude is similar, the series is judged to be smooth; if the graph of the time series is not fluctuating around the mean value and shows an obvious upward or downward trend, the series is judged to be non-smooth and needs further data processing to make it smooth. Further data processing is needed to make it smooth. Compared with the observation test, which can only roughly determine the smoothness, the unit root test is more accurate and reliable because of the statistical test using the statistics, the initial unit root test is generally completed by DF test, and then as the research continues to deepen the higher-order time series have higher requirements for the test, so the ADF test, which is expanded by Dickey and Fuller on the basis of DF test, is In this paper, the ADF test is used to test the smoothness of the daily carbon price returns of each exchange, and the "adftest" function is used to determine whether the data are smooth. The output of the "adftest" function for both stages is 1, which indicates that the daily carbon price yield series of both stages is a smooth series. The fluctuation trend of the daily carbon price yield series in the two stages is shown in Figure 2.



(a) Trends in daily carbon price yields in the first phase

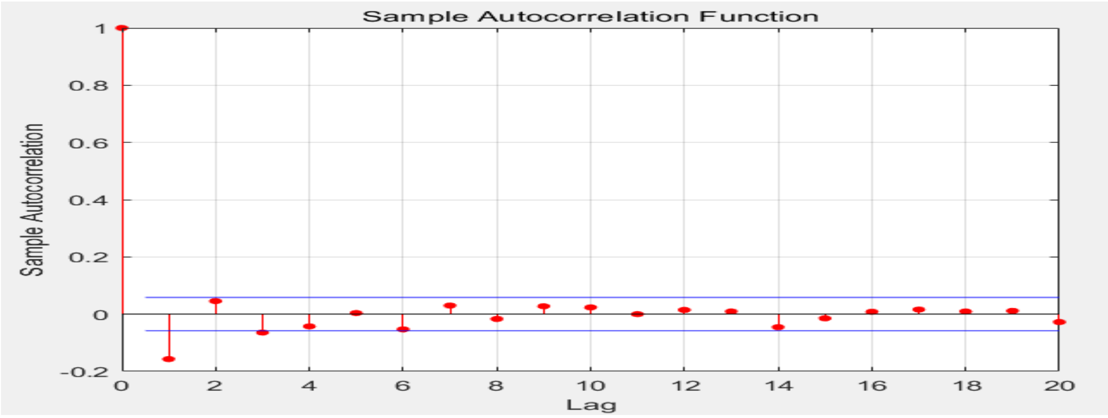


(b) Trends in daily carbon price yields in Phase II

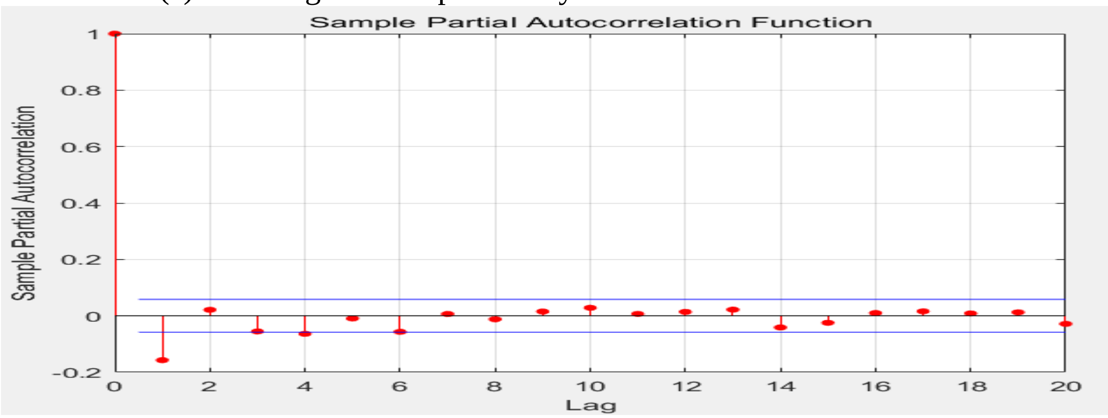
Figure 2. Trend of daily carbon price yields in two phases

3.3 Model Identification and Ranking

From the above analysis, we can know that the two stages of the daily carbon price return series are smooth, the following use the "autocorr" and "parcorr" function, respectively, for the two stages of data autocorrelation and partial autocorrelation test to determine the time series The model form and order.



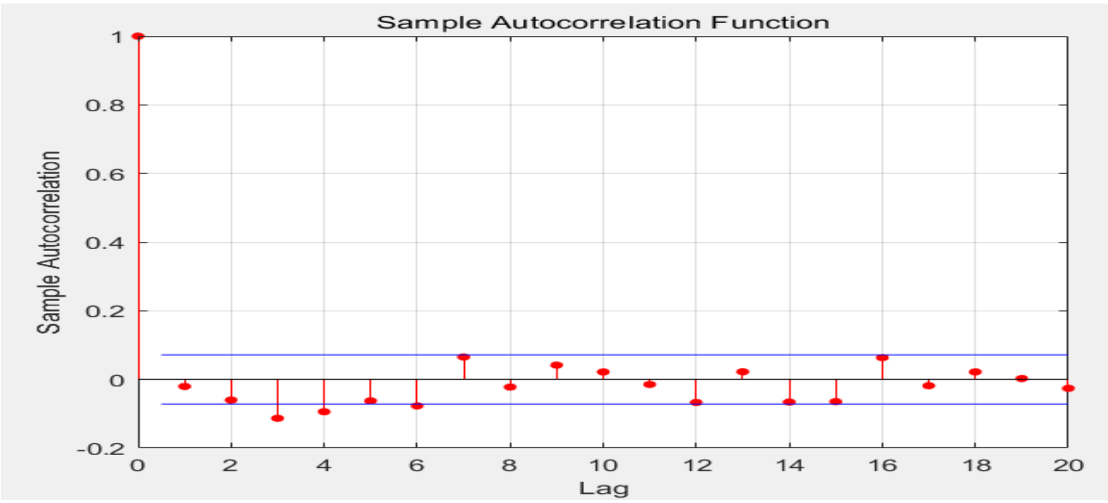
(a) First stage carbon price daily return autocorrelation results



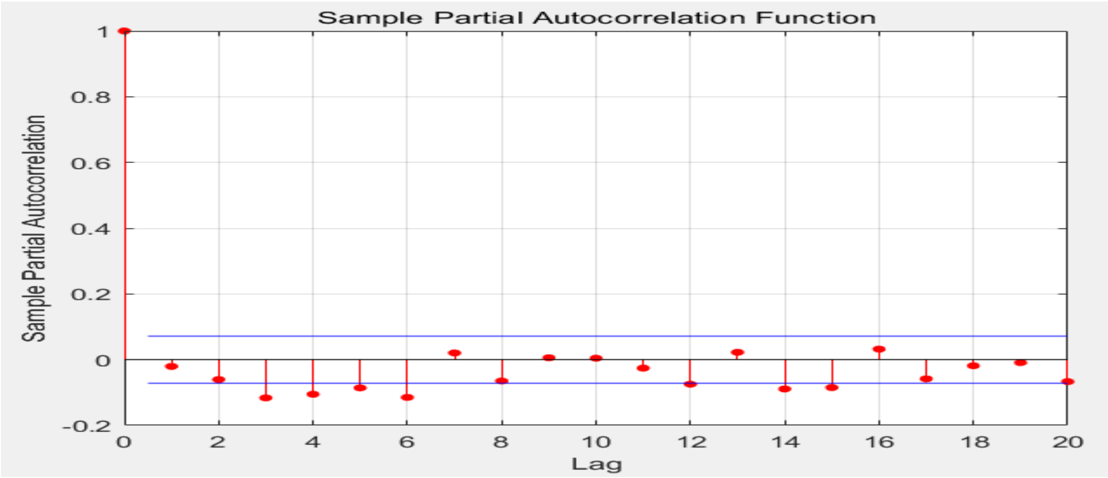
(b) First stage carbon price daily return bias autocorrelation results

Figure 3 Autocorrelation and partial autocorrelation results of daily carbon price returns in the first stage

Figure 3 shows the results of autocorrelation and partial autocorrelation calculations for the daily carbon price return series in the first stage. From Figure 3, we can learn that the autocorrelation lag order is 1 and the partial autocorrelation lag order is 1. The final prediction error FPE value of the corresponding established ARMA(1,1) model model is 0.003508 and the mean square error MSE value is 0.003496.



(a) Autocorrelation results of daily carbon price returns in the second stage



(b) Phase II Carbon Price Daily Yield Bias Autocorrelation Results

Figure 4 Autocorrelation and partial autocorrelation results of daily carbon price yields in the second stage

Figure 4 shows the results of autocorrelation and partial autocorrelation calculations for the second stage carbon price daily return series. From Figure 4, we can learn that the autocorrelation lag order is 3 and the partial autocorrelation lag order is 6. The ARMA (3,6) model is established accordingly, and the final prediction error FPE value of the model is 0.001979 and the mean square error MSE value is 0.001934.

3.4 Model diagnostic tests

According to the ARMA (1,1) model and ARMA (3,6) model built in the first stage and the second stage respectively, the residual series are tested for white noise. If the residual series is not white noise series, it means that there is some valuable information in it and the model needs further improvement. In this paper, we first use the "resid" function to generate the residual series of the two models, then use the "lbqtest" function to test the autocorrelation of the residual series, and use the "archtest" function to test the autocorrelation of the residual series. Then, we use the "lbqtest" function to test the autocorrelation of the residual series and the "archtest" function to test the ARCH effect of the residual series.

The first stage ARMA (1,1) model with the output of both the LBQ test and the ARCH effect test for autocorrelation of the residual series is 1, which indicates the existence of autocorrelation and ARCH effect in this residual series, and the model needs to be improved accordingly. In the second stage of ARMA (3,6) model, the output results of both the LBQ test and ARCH effect test for the residual series are also 1, indicating that the residual series are autocorrelated and have ARCH effect, and the model needs to be improved accordingly. Moreover, the ARCH effect test of the residual series of the corresponding model in the two stages with 10, 15, and 20 lag orders respectively, the output results are all 1, indicating that there is a higher-order ARCH effect, i.e., GARCH effect, in the daily carbon price return series in the two stages, so further GARCH models are considered.

3.5 GARCH modeling and simulation of daily returns on carbon prices

The GARCH model is derived from the extension of the constraints of the ARCH model. The variance equation of the GARCH model is based on the variance equation of the ARCH model with the addition of a time-lag structure, thus solving the problem of insufficient efficiency of parameter estimation of the higher-order ARCH model, which is more widely used in empirical studies. For the two stages of carbon price daily return series, GARCH (1,1), GARCH (1,2), and GARCH (2,1) models are developed for each respectively.

In the first stage, the outputs of the three models are as follows.

	Value	StandardError	TStatistic	PValue
Constant	0.0011075	9.0772e-05	12.201	3.0605e-34
GARCH{1}	0.56064	0.035923	15.607	6.5471e-55
ARCH{1}	0.13619	0.021972	6.1984	5.7038e-10

	Value	StandardError	TStatistic	PValue
Constant	0.0011306	0.00016514	6.8459	7.5981e-12
GARCH{1}	0.55121	0.065534	8.411	4.0639e-17
ARCH{1}	0.13319	0.027216	4.8936	9.9007e-07
ARCH{2}	0.0065305	0.032534	0.20073	0.84091

The output shows that the GARCH (1,1) model fits better, so the GARCH (1,1) model is chosen to fit the daily carbon price return series in the first stage.

GARCH(2,1) Conditional Variance Model (Gaussian Distribution):

	Value	StandardError	TStatistic	PValue
Constant	0.001194	0.0001574	7.5857	3.3075e-14
GARCH{1}	0.44967	0.17393	2.5853	0.0097294
GARCH{2}	0.077667	0.12366	0.62807	0.52996
ARCH{1}	0.14448	0.030133	4.7949	1.6276e-06

In the second stage, the outputs of the three models are as follows.

GARCH(1,1) Conditional Variance Model (Gaussian Distribution):

	Value	StandardError	TStatistic	PValue
Constant	0.00018597	1.9919e-05	9.3363	9.973e-21
GARCH{1}	0.68545	0.023571	29.08	6.3789e-186
ARCH{1}	0.24263	0.030088	8.064	7.3858e-16

The output in the second stage shows that the second stage carbon price daily return series is also chosen to fit the GARCH (1,1) model better.

The first stage GARCH (1,1) model fit GARCH term coefficient sum is 0.56064, which indicates that the shock of current variance still has some influence on the next period, and more than 50% of the shock still exists in the next period; the total coefficient sum of GARCH term and ARCH term is 0.69683, which is less than 1 to satisfy the parameter constraint.

GARCH(1,2) Conditional Variance Model (Gaussian Distribution):

	Value	StandardError	TStatistic	PValue
Constant	0.00018596	2.4399e-05	7.6218	2.5015e-14
GARCH{1}	0.68545	0.030943	22.152	9.9229e-109
ARCH{1}	0.24264	0.045716	5.3075	1.1116e-07
ARCH{2}	2e-12	0.049794	4.0165e-11	1

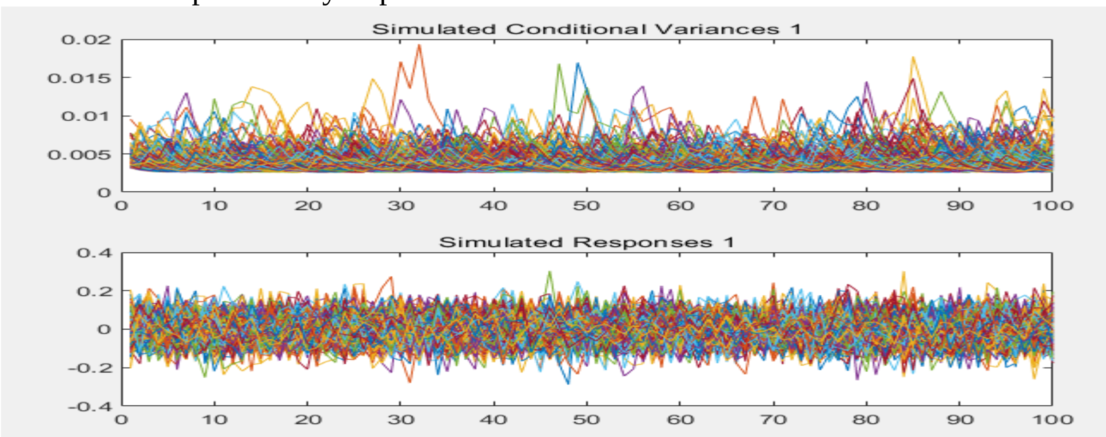
GARCH(2,1) Conditional Variance Model (Gaussian Distribution):

	Value	StandardError	TStatistic	PValue
Constant	0.00019199	2.9241e-05	6.5656	5.181e-11
GARCH{1}	0.53076	0.16188	3.2787	0.0010429
GARCH{2}	0.13282	0.12285	1.0811	0.27965
ARCH{1}	0.26187	0.044748	5.8522	4.8521e-09

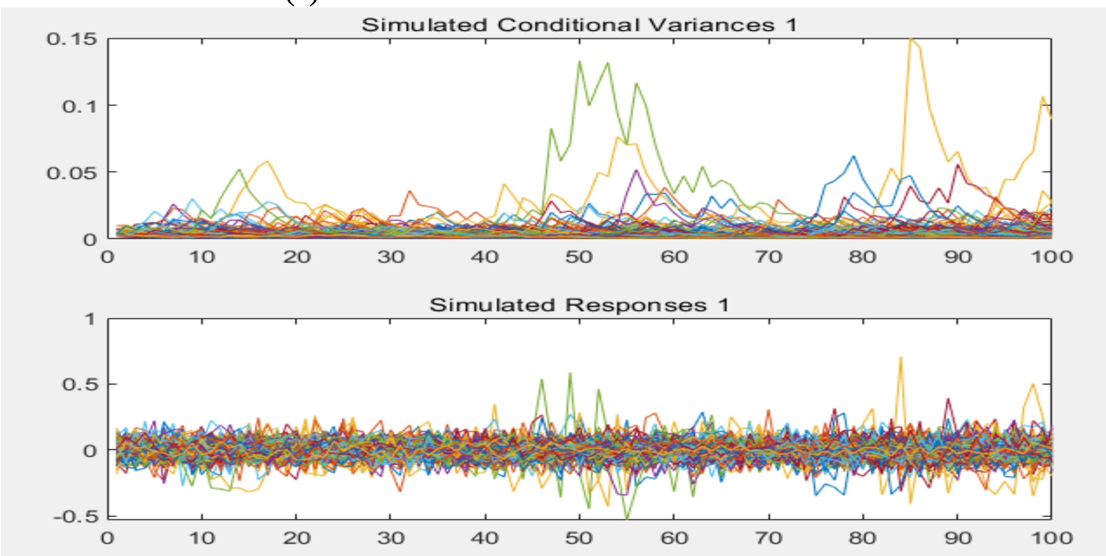
The second stage GARCH(1,1) model fit GARCH term coefficient sum is 0.685, indicating that the shock of the current variance still has a large impact on the next period, and nearly 70% of the shocks still exist in the next period; the total coefficient sum of GARCH term and ARCH term is 0.927, which is less than 1 satisfying the parameter constraint and close to 1, indicating that the shocks to the conditional variance are persistent and the volatility decays slowly, and once large fluctuations occur it is difficult to eliminate them in the short term, and the shocks are important for all future forecasts.

Next, Monte Carlo simulations are performed using the "simulate" function to compare the volatility of the two stages of the daily carbon price return series. The number of Monte Carlo simulation paths is 500, and the simulation results are shown in the following figure.

From the results of the two-stage Monte Carlo simulation, it is clear that the volatility of the daily carbon price return series in the second stage is significantly larger than that in the first stage, which indicates that after the formal establishment of the national carbon market, the Shanghai carbon market has increased its price volatility as the carbon price rises, and the carbon market risk prevention and control mechanism is particularly important.



(a) Phase I Monte Carlo simulation results



(b) Phase II Monte Carlo simulation results

Figure 5 Two-stage Monte Carlo simulation results

4. Summary

As the trading time is getting longer and longer, the scale of carbon trading in China's provinces and cities is getting larger and larger, and the domestic carbon market is gradually converging with the international carbon market. At present, compared with the mature trading system of the European Union, China's carbon market is still in a very imperfect stage of development, and there are many factors that affect trading. Therefore, in order to meet the arrival of the day when a comprehensive national carbon trading market is built, we urgently need to accurately grasp the various factors that affect the fluctuation of carbon prices, to clarify the way of influence, and to be able to make reasonable and scientific predictions on the development direction of carbon price fluctuations.

The study of the volatility characteristics of carbon market yields helps us to gain insight into the development and implementation status of the carbon market in order to make reasonable predictions and forecasts of future development trends. In addition, volatility represents the uncertainty of ups and downs as well as irregularity, which to some extent can reflect the market risk profile, and studying the volatility characteristics over time development is a prerequisite to further study the value-at-risk of the whole market. This paper empirically investigates the volatility of the daily carbon price return series in the Shanghai carbon market in two stages, using the formal establishment of the national carbon market at the end of 2017 as the cut-off point, and establishes a fitted model for the two stages through model identification and fixed order, and conducts a Monte Carlo simulation to explore and compare the volatility in the two stages. Combining the descriptive statistics of the data and the results of the empirical analysis of the model, it is obtained that.

First, the performance characteristics of the daily carbon price yields in the two phases of the Shanghai carbon market are different. The price range of the first stage is significantly smaller than that of the second stage, indicating that the price range rises as carbon trading becomes more active after the formal establishment of the national carbon market; the kurtosis of the second stage is much higher than that of the first stage, indicating that the distribution of daily carbon price yields is more concentrated in the second stage, and the extreme values are more obvious in the second stage.

Second, the daily carbon price yield series in both phases of the Shanghai carbon market exhibit significant spikes and thick tails, and the first phase has significant volatility persistence. the JB test results show that the yield series in both phases do not obey normal distribution, and their kurtosis is significantly greater than 3, revealing the significant spikes and thick tails of the daily carbon price yield series in both phases; the first phase model fitting results also show that The results of the first-stage model fitting also show that the volatility of the current daily carbon price yield in the Shanghai carbon market before the formal establishment of the national carbon market is significantly influenced by the volatility of the previous period, and the external shocks from the previous period will aggravate the volatility of the current daily yield, and the duration of the volatility is generally longer, which is not conducive to the stability of the carbon price.

Last, the design of mechanisms to guard against extreme risks in the carbon market is particularly important. The analysis of the volatility of the daily return series of carbon price in the two phases of Shanghai carbon market shows that the second phase, which is more affected by extreme events, is more volatile, which indicates that the impact of extreme events will significantly increase the carbon market risk and is not conducive to the development and smooth operation of the national carbon market. The optimal design of the risk prevention and control mechanism plays an important role in enhancing market confidence and giving full play to the efficacy of the carbon market.

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