Research on the weak-form efficincy of China’ s carbon trading market by time series analysis

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Abstract. As the world's largest carbon emitter, China has made great efforts to achieve its carbon peak and carbon neutral targets. China has adopted the carbon trading market as an important means to achieve its goals and set up seven carbon trading pilot markets from 2013 to 2015. Studying the efficiency of China's pilot carbon emissions trading market is an important guide to the construction of a unified market of carbon in China and the achievement of carbon neutrality targets. Based on the efficient market hypothesis (EMH), this paper verifies the weak form efficiency of the Chinese carbon market through unit root test, run test and variance ratio test. The paper finds that compared to the previous literature, the effectiveness of China's carbon market has improved after using the latest data, and it can be argued that the Chinese carbon pilot market has initially achieved the initial level of efficiency.

Keywords: market of emmission allowance; weak-form efficiency; unit root test.

1. Introduction

In recent years, greenhouse gas emissions (GHG) have exacerbated global warming and posed challenge to the sustainability of human society. The reduction of emmision has posed an unprecedend challenge to China, which is the largest carbon emmitter in the world[1].In 2020, China’s President proposed at the United Nations General Assembly the "Double Carbon Goal", in which China aims to peak its carbon dioxide emissions by 2030 and work towards achieving carbon neutrality by 2060. From 2013 to 2015, China's National Development and Reform Commission (NDRC) approved the development of a carbon emissions trading market in seven cities, including Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong and Shenzhen, as an important measure to achieve the "double carbon goal". [2, 3]

2. Overview of market of carbon and efficient market theory

2.1. Market of carbon

Under the carbon trading scheme, provincial governments allocates carbon emission allowances to companies to limit their carbon emissions, and then companies can sell the remaining allowances, or buy additional allowances if needed, thereby artificially allocating unregulated carbon emission allowances. At a micro level, corporate carbon emissions causing climate change are a negative externality problem, where companies emit greenhouse gases that cause damage to the outside world without paying compensation. The costs that should have been borne by companies are passed on to the outside world as social costs. Taxes, fines and financial subsidies, as traditional government instruments, can correct the externality, but they may be subject to rent-seeking behaviour, high regulatory costs and inefficient distribution. Carbon trading markets, on the other hand, effectively address the problem of externalities through market mechanisms. According to Coase's Law, as long as property rights are clearly defined, people can effectively choose the most favourable trading method, minimise transaction costs and solve various problems through trading.In 1997, the Kyoto Agreement decided to make emissions trading a new way to solve the problem of greenhouse gas emission reduction, which became the origin of carbon trading mechanism or carbon market in each country.

2.2. Efficient market hypothesis

The efficient market hypothesis is the core of modern capital market theory. Fama divides the efficient market hypothesis into three levels in terms of information sets. The weak form efficiency: the current price contains historical trading information, using historical trading information cannot obtain excess profit; The semi-strong efficiency: the current price contains current public information in addition to historical trading information, by analysing public information cannot obtain excess profit; the strong efficiency: the current price contains all available relevant information, using any information cannot obtain excess profit. As an emerging market, the effectiveness of the carbon emissions trading market contributes greatly to its allocative efficiency.

China's carbon trading market started late and has many systemic problems, such as inacurate quota allocation, lagged legislation, an imperfect market mechanism etc[4]. Xinghua Fan found that all carbon trading pilots have not reached market effectiveness by conducting a Detrended Fluctuation Analysis of seven carbon markets [5]. By introducing a market effectiveness value, it was found that the Chongqing market has the highest level of efficiency while Tianjin has the lowest level of efficiency; Xianfeng Liu uses variance ratio tests and Detrended Fluctuation Analysis to find that Hubei and Guangdong reach weak validity by analyzing the daily trading data of the seven carbon trading markets [6]; Xin-gang Zhao mainly examines the price data of Beijing, Tianjin, Shanghai and Shenzhen from June 2013 to Xin-gang to September 2015, and found that all four carbon markets had reached weak form validity through unit root test and run tests, and found that the validity of each market had gradually increased [7]. As the existing papers are inconclusive as to the initial level of efficiency of China's market of emmision allowance, this paper will provide new evidence by using the latest trading data and corporating new methods.

3. Empirical analysis

3.1. Methodology

The main way to determine whether weak form efficiency is achieved is by testing whether the price time series is consistent with random wandering. Commonly used methods are unit root tests, run tests and variance ratio tests [8]. The empirical models in this paper are divided into the following three categories.

3.1.1 unit root test

$$\Delta p_t = \mu + (\beta - 1)p_{t-1} + \varepsilon_t \quad (1)$$

Δp_t is the first-order difference of the average price of carbon emission rights traded on the day, μ is the intercept term, and ε_t is white noise [9]. And the original hypothesis of the test is proposed: H0: $\beta = 1$, the time series is a random wandering process, there is no serial correlation in carbon trading prices, and the market is weakly efficient. If the statistic does not exceed the significant level, the original hypothesis is accepted.

3.1.2 run test

$$Z = \frac{Q - E(Q)}{e} \quad (2)$$

where $E(Q) = \frac{D + 2d_1d_2}{D}, e = \frac{2d_1d_2(2d_1d_2 - D)}{D^2(D-1)}$ D is the total days that changes of the carbon price happen, in which $d_1$and d_2 are the days that carbon allowance rose and fell compared to that of yesterday. And the original hypothesis of the test: H0: the sample series has randomness. If the statistic exceeds the significant level, the original hypothesis is rejected, otherwise it is accepted.

The run test is used in a wide range and does not need to consider the specific value of the change in the price of carbon emission rights, which can circumvent the influence of the absolute value on

the test results, but there is also the phenomenon of low precision. It also assumes that the statistic follows a normal distribution, which may be biased for tests with small samples.

3.1.3The variance ratio test

The variance ratio test is based on the principle that if a time series is a random walk process, the random walk increments' variance should be linear of the interval time [10]. Denoted VRas the variance ratio defined as

$$VR(k) = \frac{Var(p_t + p_{t-1} + \cdots + p_{t-k+1})}{k * Var(p_t)} \quad (3)$$

where k is the lag order chosen, and in this paper 2, 4, 8 and 16are chosen to be tested respectively according to the existing literature. The test hypothesis is proposed: H0: the time series obeys random walk process, VR(k)= 1. If the relevant statistic does not exceed the significant level, the original hypothesis is accepted.

3.2. Data

The data on the price of carbon credits were obtained from WIND database. All the seven pilot carbon markets are chosen for this paper. Data are daily data, from 18 June 2013, to 21 November 2022.

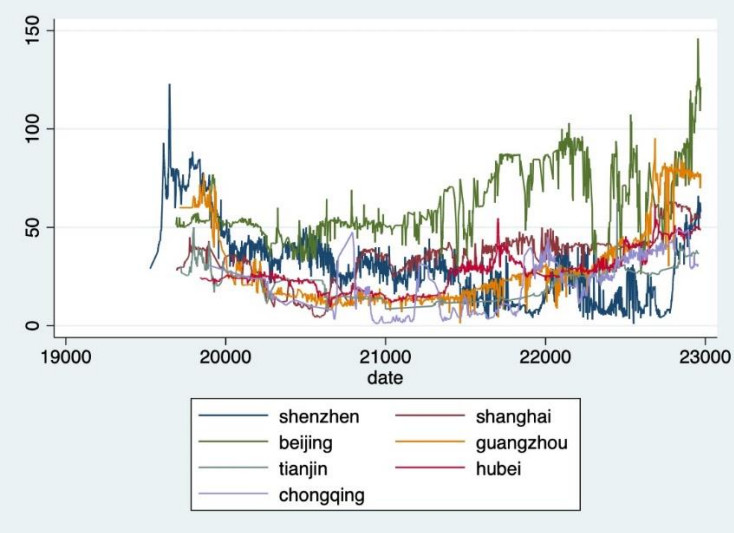


Fig 1. carbon emmision allowance price

3.3. Results

In this section, descriptive statistics are conducted on the prices of the seven pilot carbon trading markets, followed by unit root tests, run tests and variance ratio tests in order to quantify the weak-form efficient market hypothesis. The original hypothesis was that carbon trading prices are random walk process, i.e. the carbon market reached weakly efficient. The statistics and tests were conducted by Stata 17.0.

Table 1. statistical row descriptions

Variables	Obs	Mean	Std. Dev.	Min	Max	Skew.
shenzhen	2032	32.116	19.477	1	122.97	1.025
shanghai	1366	36.293	12.425	4.21	63	-.426
beijing	1341	62.59	19.06	24	145.94	.877
guangdong	1877	29.864	20.819	1.27	95.26	1.331
tianjin	815	25.063	6.427	7	62.38	.578
hubei	2025	26.903	9.857	9.38	61.89	.759
chongqing	796	18.599	13.539	1	49	.256

Table 2. unit root test

	t-value	1% significant value	5% significant value	10% significant value	P
shenzhen	-5.828	-3.430	-2.860	-2.570	0.0000
shanghai	-1.786	-3.430	-2.860	-2.570	0.3876
beijing	-2.934	-3.430	-2.860	-2.570	0.0415
guangdong	-1.660	-3.430	-2.860	-2.570	0.4519
tianjin	-3.661	-3.430	-2.860	-2.570	0.0047
hubei	-2.507	-3.430	-2.860	-2.570	0.1138
chongqing	-1.306	-3.430	-2.860	-2.570	0.6264

Table 3. run test

	Obs	run number	Z-value	P-value
shenzhen	2032	1224	9.25	0.00
shanghai	1366	708	1.58	0.11
beijing	1341	733	3.45	0.00
guangdong	1877	1133	8.02	0.00
tianjin	815	414	0.39	0.7
hubei	2025	1163	6.71	0.00
chongqing	796	351	3.13	0.00

Table 4. variance ratio test

lag terms	2		4		8		16	
city	variance ration	P	variance ration	P	variance ration	P	variance ration	P
shenzhen	0.529	0.0000	0.375	0.0000	0.276	0.0000	0.179	0.0000
shanghai	0.666	0.0000	0.489	0.0001	0.579	0.0364	0.793	0.4983
beijing	0.888	0.0517	0.743	0.0175	0.780	0.2012	0.685	0.2244
guangdong	0.513	0.0000	0.320	0.0000	0.193	0.0000	0.116	0.0000
tianjin	1.208	0.0002	1.630	0.0000	2.253	0.0000	1.686	0.0066
hubei	0.795	0.0000	0.688	0.0000	0.564	0.0000	0.447	0.0000
chongqing	0.710	0.0273	0.780	0.3784	0.667	0.3993	0.786	0.7363

Table 5. empirical results

city	unit root test	run test	variance ration test
shenzhen			
shanghai	passed	passed	passed
beijing			passed
guangdong	passed		
tianjin		passed	
hubei	passed		
chongqing	passed		passed

The results of the statistical row descriptions of the data in this paper are shown in Table 1. Overall, the seven carbon markets show different statistical characteristics, and none of them strictly satisfy the standard normal distribution. The Shenzhen, Guangdong and Hubei carbon markets are more active, with significantly higher sample sizes of trading data than the other carbon trading markets. In terms of means, the carbon allowance price in Beijing is significantly higher than the other exchanges, while the price in Chongqing is the lowest. In terms of standard deviation, Shenzhen, Beijing, Guangdong and Shanghai have larger standard deviations, indicating that carbon emission rights prices are higher in these markets. In terms of skewness, all carbon markets are significantly

different from 0. In terms of kurtosis, all carbon markets are above the normal kurtosis value, showing a "sharp peak and thick tail".

The significance levels used in this paper are: 1%, 5% and 10%. The results of the unit root test are shown in Table 2. The t-values for Shenzhen, Beijing and Tianjin are -5.828, -2.934 and -3.661 respectively, which are all less than -2.860, so the original hypothesis can be rejected at the 95% significance level and the carbon markets in Shenzhen, Beijing and Tianjin are not weakly efficient. The t-values for the other carbon markets are all greater than the 10% significance level. Thus, the original hypothesis can be accepted. In these markets, investors are unable to predict prices from historical information and are unable to obtain excess returns.

The results of the run test are shown in Table 3. The z-value for Shanghai and Tianjin are smaller and correspond to larger p-values, which exceed the 10% significance level and cannot reject the original hypothesis. It can be concluded that the prices in the Shanghai and Tianjin carbon markets satisfy the random walk and reach weakly efficient, while all other carbon trading markets fail the run test.

This paper selects 2, 4, 8 and 16 order lags as the basis of judgment, and the results are shown in Table 4. four local carbon trading markets in Shenzhen, Guangdong, Tianjin and Hubei with different orders of variance ratio test have p-values less than 0.01, and can reject the original hypothesis of weakly effective at 99% significance level. In Shanghai, Beijing and Chongqing, the p-values are greater than 0.10% at the 16th order lagged variance ratio test, and it can be accepted that these carbon markets are weakly efficient.

The results of the above tests are shown in Tables 5, which show that the results of the different tests are not identical and that a combination of methods is needed to determine market efficiency. Both the run and variance ratio tests construct statistics that are assumed to be normally distributed over a large sample, but there may be small sample bias due to the still limited trading data. The Shanghai carbon trading market passes all tests and can be found to be weakly efficient. Shenzhen, on the other hand, failed all three tests and can be considered as not yet weakly efficient. Beijing and Tianjin did not pass the unit root test, but passed the range and variance ratio tests respectively, while Guangdong, Hubei and Chongqing passed the unit root test, but not the range or variance ratio tests, which may be due to small sample bias in the latter two tests due to limited trading data, and will need to be further explored in subsequent studies.

4. Conclusion

In this paper, unit root, range and variance ratio tests were conducted to fully quantify the initial level of efficiency of the China’s market of carbon emmision allowance. Compared to the previous literature, this paper has partially tested the weak-form effectiveness of the pilots after using the latest carbon trading data. The paper concludes that by 22 November 2022, China's pilot trading market has largely reached weak form efficincy.

The policy recommendations are as follows: first, continue to expand the varieties of carbon products and expand the scope of industries covered by carbon trading. Currently, China's carbon market has a single product, and developing financial derivatives for carbon trading and expanding the distribution of market participants by industry will help enhance the liquidity and activity of the financial market and allow market prices to respond to more trading information. Second, strengthen information disclosure and improve the carbon accounting system. Timely and accurate communication of trading information and relevant policies to enterprises, improvement of carbon quota allocation mechanism and penalty mechanism, reduction of transaction costs and alleviation of information asymmetry, thus improving the level of market effectiveness. Third, enterprises' awareness of carbon trading and market, market participants' confidence in the carbon market, and market participation should be improved.

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