Empirical analysis of the effectiveness and liquidity of the European carbon emission rights futures market

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Abstract. Global warming from greenhouse gas emissions is a worldwide concern and the European Emissions Trading System (EU ETS) is the largest market in the world and has a model role. Some researchers have argued that the carbon emissions futures market was not weakly effective at the beginning of its establishment, but there is a lack of sufficient research on the effectiveness of the market in recent years. Therefore, this study analyses market effectiveness and liquidity by using positions, trading volumes and settlement prices for carbon futures from 2 January 2014 to 23 November 2022, and calculates log returns from settlement prices to construct an ARIMA model for verifying the market efficiency. The analysis finds that the carbon futures market satisfies weak form validity and that the market's macro liquidity and micro liquidity are gradually increasing, and the ARIMA model finds that there is a large seasonality factor in the market. This is mainly related to the maturity of the market, the improvement of the trading mechanism and the global consensus, providing constructive reference for the improvement of the carbon emission rights futures trading market and trading mechanism in China.

Keywords: Carbon emissions futures; Weak-Form Market; Efficiency Market liquidity; ARIMA model.

1. Introduction

Since the signing of the Kyoto Treaty in 2005, the European carbon emissions trading system has been established and flourished, and with the signing of the Paris Agreement in 2016 and the re-accession of the United States to the Paris Agreement on 19 February 2021, the carbon emissions trading market has been developing at a rapid pace in recent years. The carbon futures market has become the mainstream commodity in the trading market, and the carbon futures market has become the most rapidly developing and regulated trading market, and is widely popular among investors. While carbon emission rights futures commodities have become the mainstream commodities in the trading market, the carbon emission rights futures market has become the most rapidly developing and regulated trading market, which is widely concerned and favoured by investors. Therefore, the study of the effectiveness and liquidity of the carbon emissions futures trading market is a research topic with practical and theoretical significance.

The development of the ETS can be divided into four phases, the first experimental period (2005-2007), the second reform period (2008-2012), the third maturity phase (2013-2020) and the fourth phase (2021-2030) [1]. However, a few research has been done in China in recent years on the effectiveness and liquidity of the European carbon futures market. In a study of the European carbon market, serial correlation analysis and variance ratio tests were used, leading to the conclusion that it is not market efficient [2]. Non-linear dynamics theory has also been applied to this market, again concluding that there is no weak form of market validity [3]. Study on the lower levels of the European Emissions Trading Market (EEX, ECX, BlueNext) from the perspective of holding costs also show that the ETS is not weakly effective [4]. Some people argue that the effectiveness of the EU carbon emissions trading market, in terms of holding costs, increased and recovered from 2005 to 2007 [5]. However, from the viewpoint of a log-return constructed GARCH model, the European spot market for carbon emissions from 2010 to 2013 is not weakly efficient [6]. The above studies, however, partly address the first and second stages of the development of the European carbon market, but the results are varied when the study is conducted from the third and fourth stages. The rank and signed variance ratio test was applied to test the market validity and obtained a weak form of validity

for the European carbon emissions trading market over the period 2011-2022 [7]. In the study on market liquidity, incomplete data were applied to the study of dynamic market liquidity in traditional futures trading pools in the US [8]. The new liquidity ratio indicator was constructed for a study of the EUA futures market, which concluded that market liquidity was increasing in the first phase [9]. The entropy method was used in a study on the comparison of the Chinese and European carbon emissions trading markets, which concluded that the European carbon emissions trading market is more liquid than the Chinese carbon emissions trading system [10].

From the existing research, although the research on the first and second stages of the European carbon emissions futures trading market is sufficient, the research on the third stage is still to be added. This paper takes the European carbon emissions futures trading market as the research object, conducts an effectiveness analysis based on the daily settlement price, integrates the Martin liquidity ratio and Hui-Heubel liquidity ratio to establish liquidity indicators, and conducts an ARIMA model prediction based on the monthly average settlement price to analyse the seasonal factors of the carbon emissions trading market, which helps to better build the Chinese carbon trading market system.

This study utilises data on EUA futures from January 1, 2014 to November 23, 2022, using settlement prices, and performs a weak market validity test through three methods: variance ratio test, unit root test, and runs test, constructs a new liquidity ratio using trading volume, positions, and log returns, estimates the trend of liquidity changes in the EUA futures market, and finally determines whether the results of the weak market validity test are correct through a Box test based on the ARIMA model. The data source for this study is the wind database.

2. Methods

2.1. Market liquidity analysis

The main approach to determine whether weak form validity is achieved is by testing whether the price time series is consistent with random wandering. Commonly used methods are the unit root test, the wander test and the variance ratio test, and the autocorrelation test. The empirical models in this section are divided into the following four types:

2.1.1 Unit root test

$$\Delta p_t = \sigma + (\rho - 1)p_{t-1} + \varepsilon_t \tag{1}$$

Where $\Delta p_t$is the first-order difference of the settlement price of carbon trading on the day, σ is the drift and εt is the deterministic trend. The original hypothesis of the test is also proposed: H0: ρ = 1, i.e. 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 exceeds the significant level, the original hypothesis is rejected, otherwise it is accepted.

2.1.2 Variance ratio test

The variance ratio test is based on the principle that if a time series is randomly wandering, the variance of the random wandering increments should be a linear function of the interval time. Denoting VR as the variance ratio, it is defined as

$$VR(k) = \frac{Var(p_t + p_{t-1} + \cdots + p_{t-k+1})}{k * Var(p_t)} \tag{2}$$

Where k is the lag order chosen and in this paper 2, 4, 8 and 12 are chosen to be tested respectively according to the existing literature. The test hypothesis is proposed: H0: the time series obeys random wandering with VR(k) = 1. If the correlation statistic exceeds the significant level, the original hypothesis is rejected, otherwise the original hypothesis is accepted.

2.1.3 Runs Test

$$Z = \frac{Q - E(Q)}{e} \tag{3}$$

$$E(Q) = \frac{N+2n_1n_2}{N}, e = \frac{2n_1n_2(2n_1n_2-N)}{N^2(N-1)} \quad (4)$$

N is the total number of days of price development change in carbon credits, n_1 is the number of days that carbon credits are up from yesterday and n_2 is the number of days that carbon credits are down from yesterday. And the original hypothesis of the test is proposed: H0: the sample series has randomness. If the statistic exceeds the significant level, the original hypothesis is rejected, otherwise it is accepted.

2.1.4 Autocorrelation test

A In order to verify the weak-form market validity, this paper conducted a BOX-test on the log returns of the monthly average settlement price of the EUA futures market after constructing the ARIMA model

Box test on the residuals of the model. Its original hypothesis H0: the autocorrelation coefficient of the residuals is 0. If the original hypothesis is rejected, then the residuals are not independent of each other and affect each other, and the EUA futures market does not satisfy the weak-form efficient market. If the original hypothesis is accepted, then the residuals are independent of each other and the EUA futures market satisfies the weak-form efficient market.

2.2. Market liquidity analysis

Liquidity analysis in this section using a combination of daily and monthly data, mainly from the perspective of log returns, positions, trading volumes, turnover rates and liquidity indicators

2.2.1 Monthly analysis of trading volume

Trading volume is an intuitive variable that reflects market liquidity. The larger the market volume and the larger the trade size, the more dynamic and liquid the market will be. To conduct a monthly analysis of trading volumes, this study summed up the daily data for the same month of the same year and plotted the temporal trend of trading volumes.

2.2.2 Monthly analysis of positions

Position size is the total amount of open positions in the futures market. Studying changes in positions, it is possible to analyse the investment intentions of investors and the size of the total market capacity.

2.2.3 Monthly turnover analysis

The turnover rate, also known as the turnover rate, reflects the speed of movement of futures in the futures market and is a measure of how long futures contracts are held. There are two methods of calculating the turnover rate, the formula used in this study.

$$Trm = \frac{V_m}{Oi_m} \times 100 \quad (5)$$

Trm is the monthly turnover rate, V_m is the monthly total trading volume and Oi_m is the monthly total position. Trm is the monthly turnover rate, V_m is the total monthly trading volume and Oi_m is the total monthly position. The higher the turnover rate, the more liquid the market is. Below is a time trend graph of the monthly turnover rate.

2.2.4 Current ratio analysis

In order to analyse the liquidity of the EUA futures market from a micro perspective, this part of the study uses daily data on EUA futures. The liquidity ratio indicator formula is as follows:

$$L = \frac{(\ln p_t - \ln p_{t-1})^2}{V/O} \times 100 \quad (6)$$

The liquidity ratios used in this paper are a combination of the Martin liquidity ratio and the Hui-Heubel liquidity ratio, where Pt and Pt-1 represent the current settlement price and the previous

settlement price respectively. V and O are the daily trading volume and daily position of EUA futures respectively

This formula is adopted for the following reasons: 1. This formula combines the advantages of the Martin liquidity ratio which takes into account price changes 2. This formula combines the advantages of the Hui-Heubel liquidity ratio which takes into account position and trading volumes. 3.The treatment of prices in this formula is essentially a treatment of their logarithmic yields, which are comparable. However, the formula used in this study also has certain shortcomings. Restricted by the data source, this study only uses the same day settlement price of the EUA futures market as the price factor, and the settlement price may not necessarily contain the full information of the EUA futures market on that day, and there is room for improvement.

The smaller the value of the liquidity ratio, the more liquid the market is; the larger the value of the liquidity ratio, the less liquid the market is.

2.3. ARIMA model validates market efficiency and liquidity

The Log rate of return of EUA futures for the basis of our modeling is computed as:

$$return = \ln p_t - \ln p_{t-1} \tag{7}$$

return is the monthly log return of the EUA futures market, pt is the log return of the current month and pt-1 is the log return of the previous month.

3. Empirical Study

3.1. Market Effectiveness Analysis

For this part of the study we used data from the wind database, from 1 January 2014, to 23 November 2022 for the European carbon credit futures settlement price. Settlement Price is the base price at which the margin and profit/loss of an open position is settled at the end of the day's trading. Its fluctuation can reflect the effectiveness of the market to a certain extent, according to the weak efficient market theory, the current price contains historical trading information, the use of historical trading information will not obtain excess returns.

3.1.1 Descriptive analysis

The chart below shows the daily settlement price time trend from January 2014 to November 2022.

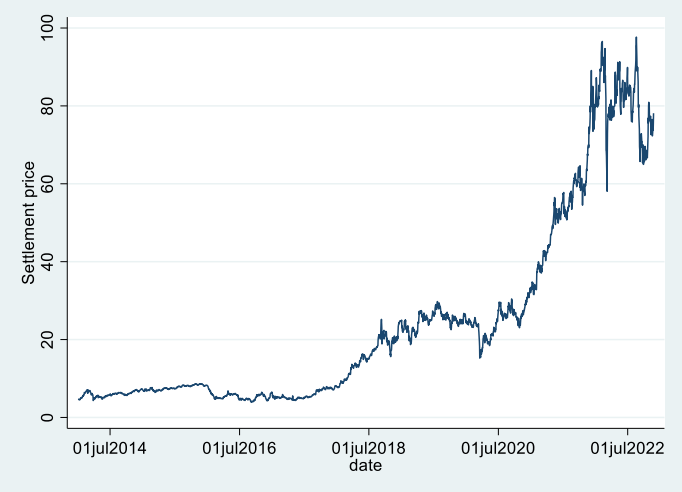


Fig 1. Daily settlement price time trend

Source: Wind [11]

As the Figure 1 shows, the change in prices during this period can be divided into three phases, Phase 1: 2014 to 2017 - a period of volatility, Phase 2 - a period of steady price growth, Phase 3: 2018 to 2022 --Period of dramatic price increases

Futures prices from 2014 to 2017 were relatively flat, fluctuating between a range of 4 and 7. With the signing and implementation of the Paris Agreement, prices steadily increased from January 2018 onwards, fluctuating in a range of 10 to 20 between January 2018 and 2020, which may have been influenced by some adjustments to the EU's rules on carbon trading, including raising the percentage of allowances auctioned to 10%, extending the scope of emissions to countries outside the EU and establishing a Market Stability Reserve Mechanism (MSR) to deal with the oversupply of allowances, causing futures prices to escalate in 2020-2022.

Afterwards a series of policy adjustments, the change in the futures settlement price is a good reflection of market supply and demand, but whether it is a appropriate reflection of historical information needs to be further tested.

The main approach to determine whether weak form validity is achieved is by testing whether the price time series is consistent with random wandering. Commonly used methods are unit root tests, wander tests and variance ratio tests.

3.1.2 Unit root test

The following table 1 shows the results of the unit root test

Table 1. Settlement price and first order differential closing price test results

	Test statistic	P-value
Z(t)	-0.606	0.9787
Z(t)	-44.527	0.0000

The first row of Table 1 shows the test results for the settlement price and the second row shows the test results for the first-order difference series of the settlement price

Based on Table 1, both at the 1%, 5%, and 10% levels, the value of Settlement price of ADF is greater than the critical value, accepting the hypothesis of the existence of a unit root, while the value of ADF for the first-order difference series is much less than the critical value, rejecting H0, so that the EUA market reaches a weak-form efficient market.

3.1.3 Variance ratio test

Table 2. Results of variance ratio test

k	N	VR	R_s	p>|z|
16	2284	0.888	-1.4243	0.1543
12	2280	0.874	-1.3640	0.1726
8	2288	0.934	-3.1677	0.0015
4	2288	0.921	-2.0277	0.0426
2	2288	0.890	-1.7713	0.0765

According to Table 2, the original hypothesis that the market is weakly efficient can be rejected at lags 16 and 12, but not at lags 8, 4 and 2. This may be due to the large time span of the daily data selected for this study and the impact of major events such as the signing of the Paris Agreement, the announcement of the US withdrawal from the EUA and the announcement of the US rejoining the EUA during the period, and the random wandering hypothesis does not rigorously hold when the lags are small.

3.1.4 Runs test

Table 3. Results of runs test

Z(t)	N	N(runs)	10%	P
-47.63	2296	8	-3.120	0

The run test significantly rejects the H0 hypothesis, the specific reasons for this may be related to the extreme values brought about by the major events mentioned above and the climb in settlement prices after 2020 making it difficult to determine a random travel.

3.2. Market liquidity analysis

3.2.1 Monthly analysis of trading volume

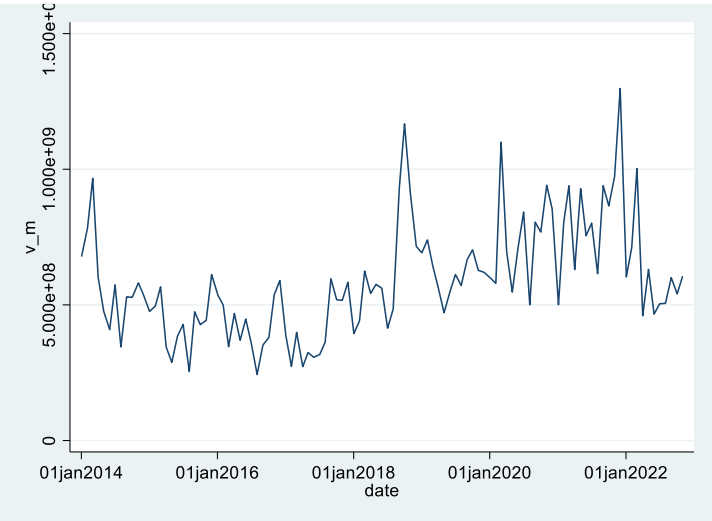


Fig 2. Temporal trend of trading volumes

According to Figure 2, the carbon futures market takes January 2018 as its nodal point, and the average level of trading volume thereafter is greater overall than the average level of trading volume before it. Therefore, it can be seen that even though the ETS was established earlier and the market is more mature compared to other countries' carbon trading systems, there is still potential for trading volumes to soar and liquidity is still on the rise. At the same time, it is normal for trading volumes to continue to oscillate upwards

3.2.2 Monthly analysis of positions

The Figure 3 shows the monthly time trend of positions in EUA futures

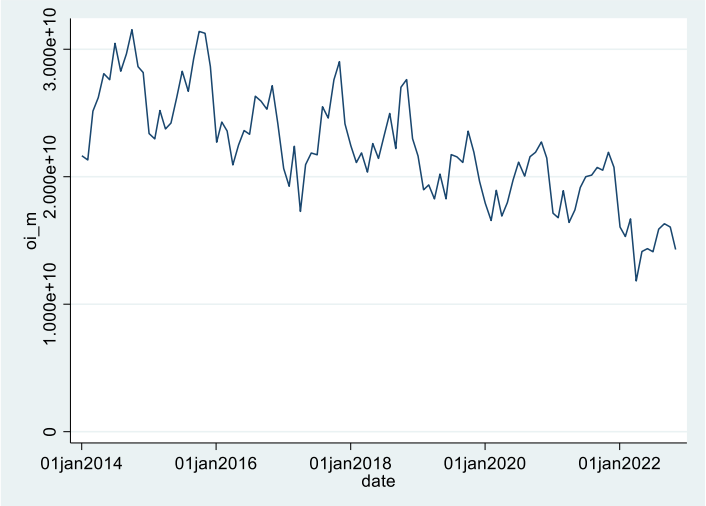


Fig 3. Monthly time trend of positions

Apart from the overall trend of rising trading volumes, positions show an overall annual trend of decreasing levels, which, considering the rising prices of EUA futures, may be related to the EU's curtailment of supply and the establishment of the MSR mechanism, and in this case, the increase in trading volumes, reflecting the increased liquidity of the market.

3.2.3 Monthly turnover analysis

Below is a time trend graph of the monthly turnover rate.

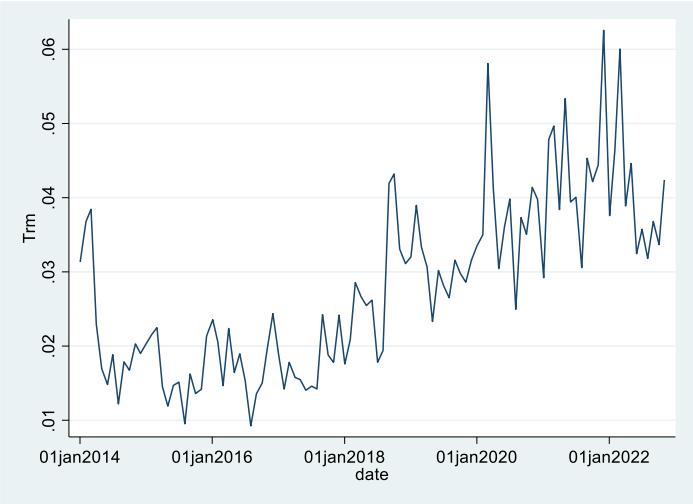


Fig 4. Monthly turnover rate

According to Figure 4, with the exception of January, February, March and April 2014, when there was a significant drop in the turnover rate, the overall turnover rate in the EUA futures market was increasing and reached a maximum of 6% in January 2022, but due to seasonality, there is a drop in the turnover rate at the beginning of each year. This shows that the liquidity of the EUA futures market is increasing, but the overall turnover rate is not high and there is still room for improvement.

3.2.4 Current ratio analysis

The daily liquidity ratios are calculated from the daily data and the time trends are plotted below.

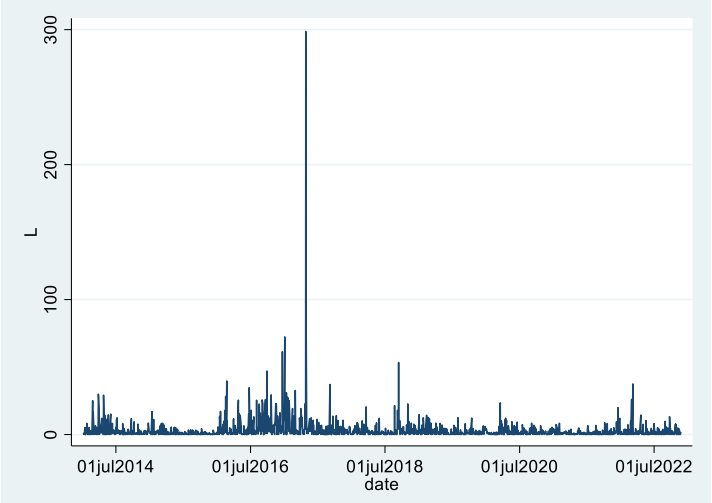


Fig 5. Time trends of current ratio

According to Figure 5, it can be observed that liquidity in the EUA futures market has been increasing since 2022 and that the market was still highly liquid for the majority of the time period studied. However, during 2016 and 2017, there were abnormally high levels of liquidity in the EUA futures market, but this quickly returned to normal, which may be related to market expectations arising from the signing of the Paris Agreement in 2016, which reformed the market mechanism to address the oversupply problem, and the increased liquidity in January and February 2020, which may be related to expectations arising from the re-entry of the US into the Paris Agreement. And what can be seen is that as the Paris agreement continues to advance and be implemented, the liquidity of the market is increasing, after excluding seasonal factors.

3.2.5 ADF test for main variable

In order to determine the stationarity of the time series variables, the following ADF test is performed on the main variables.

Table 4. Results of ADF test

		Test statistic	1%	5%	10%	P
L	Z(t)	-26.047	-3.960	3.410	-3.120	0.0000.
D(L)	Z(t)	-52.174	-3.960	3.410	-3.120	0.0000
V	Z(t)	-20.142	-3.960	3.410	-3.120	0.0000.
D(V)	Z(t)	-52.601	-3.960	3.410	-3.120	0.0000.
O	Z(t)	-5.298	-3.960	3.410	-3.120	0.0001.
D(O)	Z(t)	-277.008	-3.960	3.410	-3.120	0.0000.

As shown in Table 4, each of the main variables is a time series variable with stationarity.

3.3. ARIMA model validates market efficiency and liquidity

This part of the study averages the monthly futures settlement prices of EUA carbon credits to obtain monthly futures settlement price data. For better model fitting and to investigate the impact of seasonal factors on the price and market effectiveness of carbon futures.

Graphing its time series yields (Figure 6).

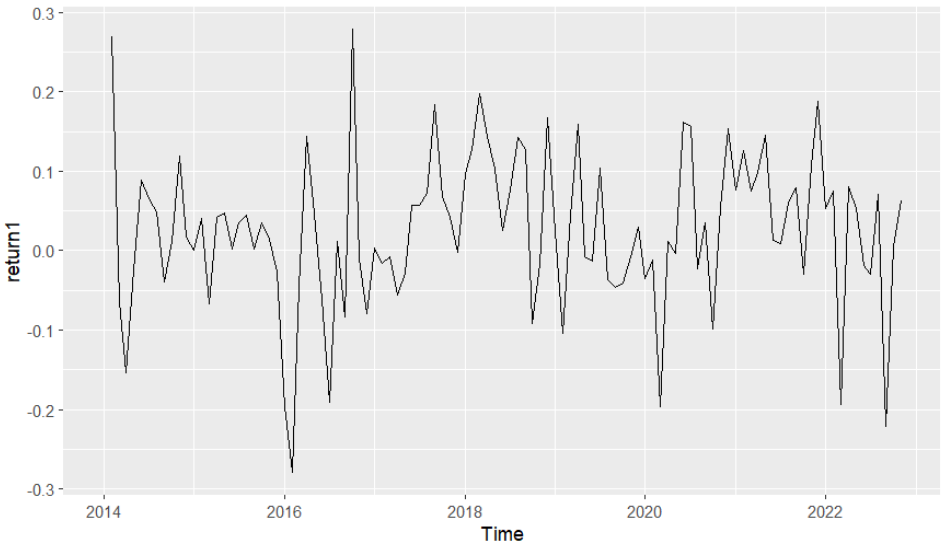


Fig 6. Return graph

Overall, log returns are more volatile and the magnitude of volatility begins to diminish around 2022, suggesting that market liquidity and effectiveness are improving, but the impact of specific time series data characteristics on market efficiency and effectiveness remains to be further investigated

The returns are differenced to 1st order, plotted against their time trends and subjected to the ADF PACF test (Figure 7).

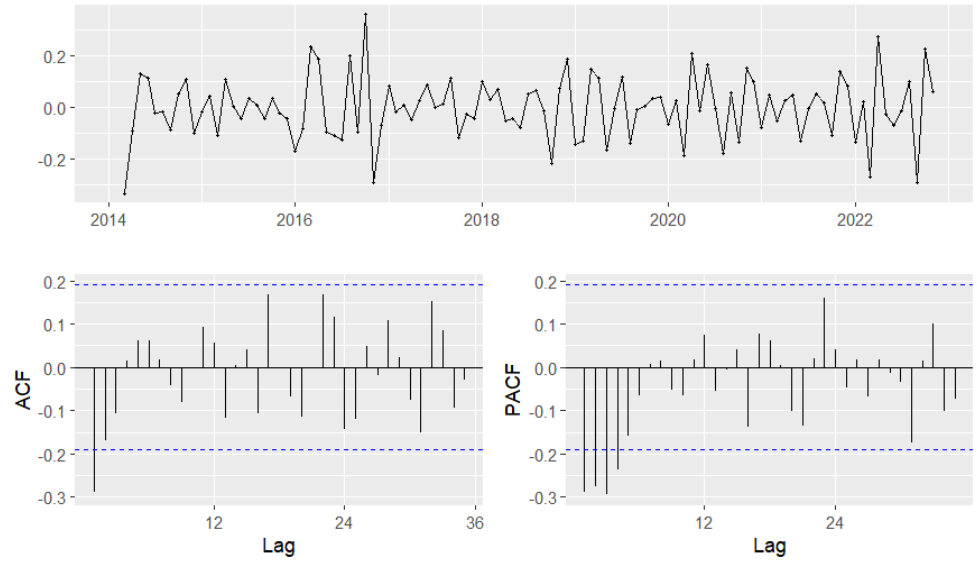


Fig 7. ACF PACF time trend of return differenced to 1st order

After comparing the degree of model fit, ARIMA (0,0,0) (2,0,1) [12] was selected for the fit and its time trend and residual plots are as Figure 8.

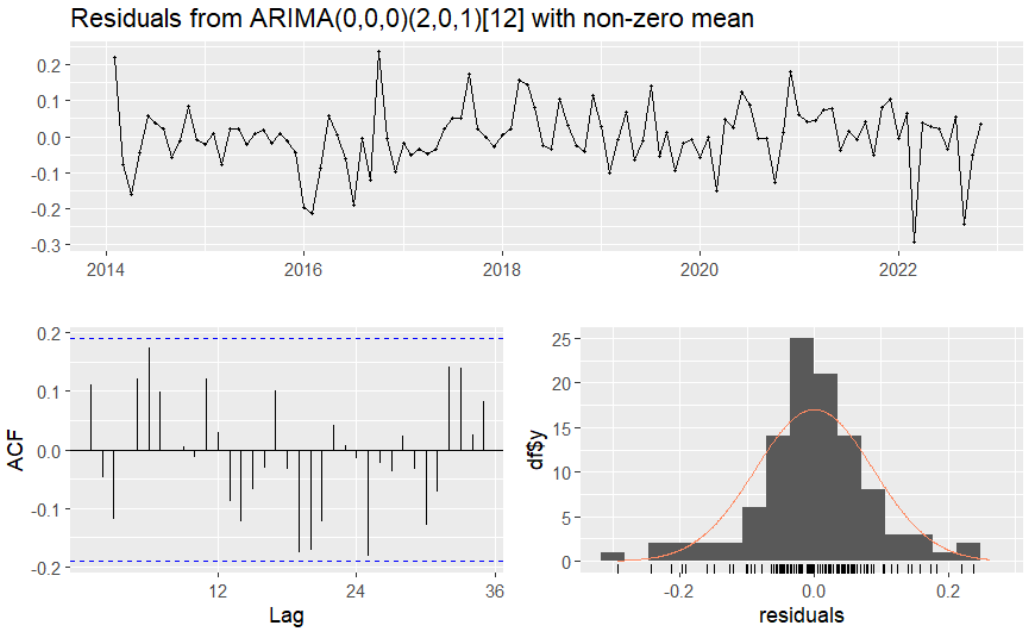


Fig 8. Residual ACF and Time trend graph

The residuals obtained from this model are tested for normal distribution, and if the data satisfy a normal distribution, the points in the data should be on the line, as illustrated Figure 9.

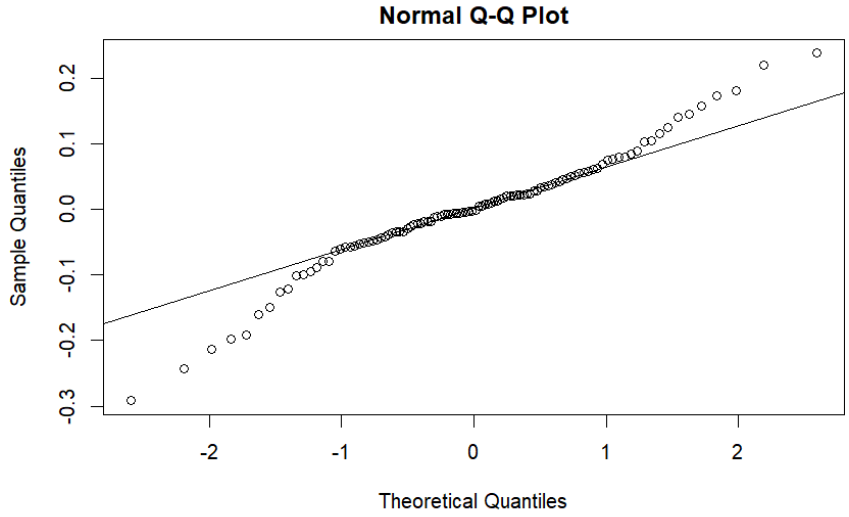


Fig 9. Fitting the residuals to a normal distribution

Table 5. Results of Box test

X-squared	df	p-value
1.2974	1	0.2547

In this research, we can argue that the residuals of the ARIMA model of log returns do not pass the significance test and we can argue that the log returns are independently uncorrelated across periods, i.e. the EUA futures market has weak form validity

4. Conclusion

With the empirical analysis of the effectiveness and liquidity of the EUA futures market from 2014 to November 2022, following conclusions could be drawn.

In the third and fourth stages of the ETS, the EUA futures market has weak market validity, passing the unit root test and the variance ratio test, while the run tests did not pass, probably because the time horizon selected was long and the outliers brought about by changes in major events could not be well identified, as can also be seen by observing the time trend graph of the settlement price in 2017 This is due to the change in market expectations brought about by the signing of the Paris Agreement and the subsequent improvement in oversupply and the creation of the MSR mechanism, while the Box test based on the ARIMA model also tests the conclusion that the EUA futures market has weak form validity. It can be seen that the EU policies and events such as the improvement of supply, the creation of the MSR mechanism and the signing of the Paris Agreement have contributed strongly to the weak form validity of the EUA futures market.

Liquidity in the EUA futures market is increasing. Both from direct data such as turnover rates, positions and trading volumes, and from newly constructed liquidity indicators, the EUA futures market is becoming increasingly liquid. And by looking at the liquidity ratio trend graph, it can also be observed that there were large outliers and fluctuations in 2017, but liquidity quickly returned to normal and began to grow, which is also in line with the conclusions of the empirical evidence section on weak market effectiveness, where a series of policies such as the implementation of the Paris Agreement in 2017 contributed to the maturity and development of the market.

Overall, this study shows that the EUA futures market has weak market efficiency and liquidity, and that the ratification of the Paris Agreement in 2017, the MSR mechanism implemented by the EU and supply-side reforms have improved market efficiency and liquidity, which provides a reference for the development and progress of China's carbon emissions market, which should be reformed from the supply side and system.

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