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The Efficiency Analysis of the European CO_2 Futures Market

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ABSTRACT

The European Union Emissions Trading System (EU ETS) is the main international carbon trading market, in which European Union CO_2 allowances (EUAs) are traded with increasing intensity. In order to help the market participants mitigate the market price risk, one possible way is to analyze the time range of market efficiency and the price discovery mechanism of EUA futures market and spot market. For this purpose, the paper provides the unit root test and the cointegration test for the EUA futures market during 2009-2011. Our result shows that the EUA futures market is efficient within 1 month. Furthermore, it illustrates that the impact of the price will continue for 3 months, examined by a vector error correction model (VECM).

Keywords: Market Efficiency; Cointegration; Vector Error Correction Model; European carbon futures market

1. Introduction

After the commencement of the Kyoto Protocol in 2005, there has been an explosive growth in the global carbon trading market. The value of the global carbon trading market reached 40 billion euros in 2007, increased by 81.8% of the value in 2006, which was 22 billion euros. The market value for the first half of 2008 even reached the level for the whole year of 2007. The United Nations and the World Bank predict that the annual size of this market would be up to $ 60 billion in the period of 2008-2012, and the market capacity would be $ 150 billion, expecting to replace the oil market as the world's largest market. The EU emissions trading system (EU ETS) is the major international carbon trading market, accounting for the 85.93% and 96.46% of the trading volume and turnover in the international carbon market.

Unlike other markets, emerging carbon market faces greater market price risk in parallel of its rapid development, since it was not only effected by the market mechanism, but also under the impact of the instable exogenous environment, such as national politics (the climate negotiations), the temperature, the financial crisis and other special events.

This paper outlines the time range of the EU ETS market efficiency by unit root test and cointegration test and then make forecast of the futures and spot prices by vector error correction model to help market participants mitigate the market price risk.

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2. Literature review

Current academic research on the efficiency and price discovery of the European carbon futures market mainly focused on demonstrating the existence of the equilibrium relationship between the future and spot market in different approaches. . Milunovich(2007) analyzed the relationship between futures and spot price of the EU carbon market by the Granger causality test and cointegration test. His result showed that carbon futures was not priced by the cost-of-carry model, but rather depended on the dynamic interaction between some futures prices and spot prices. Both prices change simultaneously and rapidly due to the information shared by the two markets. Eva Benz, Jordis Hengelbrock (2008) analyzed liquidity of the EUA futures market by studying traded bid-ask spreads following the approach of Madhavan et al.(1997) and price discovery by using the VECM framework of Engle and Granger(1987). The results indicated that, from 2005 to 2007, liquidity in the European CO2 futures market has remarkably increased and organized trading has rapidly expanded. Qi and Lu (2009) analyzed the price discovery mechanism of CERs futures market and spot market by applying the common factor model, and the similar findings were shown empirically by impulse response functions and variance decomposition. These results indicated that there was a long-run cointegration between CERs futures price and spot price; CERs futures price was Granger cause of spot price in the short-run. Huang, Li and Xiao(2010) made the theoretical and empirical analysis on the price discovery and hedging functions of CER futures market to determine the efficiency of the international carbon market. By Granger test, they found that CER futures market had a good short-term price discovery function, but it was not significant in the long-term. SVAR model further confirmed the connection between spot and futures prices in a short term, but CER and EUA market would reach to a dynamic stability in the long run.

In summary, all literatures above demonstrated the efficiency of the carbon futures market by various methods, such as cointegration, vector error correction model, the corresponding pulse, and the variance decomposition method. However, none of those methods estimated the time range of the persistence of such efficiency, which would be of little help for other purposes such as prediction on spot price. Also, most of the literatures drew a conclusion just analyzing on only 3-4 kinds of long-term futures contracts, which was not sufficient to reflect the whole futures market.

On the basis of these studies, this paper outlined the time range of the market efficiency by studying all the futures contracts in the European Climate Exchange (ECX), including short and long term contracts. Next, it revealed the cointegration relationship between the spot prices and futures prices by the vector error correction model in this time range, which would serve the further purpose of prediction on the spot price in carbon market.

3. Methodology

3.1 Market Efficiency

According to the concept of the market efficiency proposed by the Fama (1970), if the carbon futures market is efficient, it should be a market with price discovery function, reflecting all the available information. In other words, the carbon futures price should be an unbiased estimate of the spot price at the maturity date. That is,

$$E(sp_t - fp_{t-k} \mid \Phi_{t-k}) = 0 \qquad (1)$$

assuming sp_t is the spot price at the maturity date t of the carbon futures, fp_{t-k} is the price of the futures contract at time k before the maturity date. Φ_{t-k} represents all the information you can get at the moment t-k. The efficiency of carbon futures market would be tested by the following formula under the null hypothesis $H_0 : (\alpha, \beta) = (0,1)$

$$sp_t = \alpha + \beta fp_{t-k} + \varepsilon_{t-k} \qquad (2)$$

ε_{t-k} is the white noise series. If null hypothesis is not rejected, the carbon futures price will be an unbiased estimate of the spot price, which validates that the carbon futures market is efficient.

After explaining the existence of the efficiency of the carbon futures market the next step is to find out the cointegration relationship between the spot prices and futures prices.

3.2The Cointegration Test

The stationarity of the different series of carbon futures prices (fp_t) and the series of the maturity date spot prices (sp_t) is tested by using the unit root test. If a time series become stationary process only after d times difference, then it can be named as $I(d)$. If both series sp_t and fp_t are $I(d)$ and their some kind of linear combination is stationary, the cointegration relationship is existed between them. Only when the cointegration relation is existed, the regression model of carbon futures prices and spot prices can be established.

After the determination of the cointegration relation between the nonstationary series the next step is to affirm the form of this long-run equilibrium relationship.

3.3 Vector Error Correction Model

Vector error correction model (VECM) is the vector autoregressive (VAR) model with all variable imposed cointegration constraints. And VECM is just suitable for series with cointegration relation.

The model of VAR (P):

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p} + Bx_t + \varepsilon_t \qquad (3)$$

where y_t is m-dimensional non-stationary series, x_t is d-dimensional deterministic variable, ε_t is innovation vector can be deformed as

$$\Delta y_t = \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + \Pi y_{t-1} + Bx_t + \varepsilon_t \qquad (4)$$

where $\Pi = \sum_{i=1}^{p} A_i - \mathrm{I}_m ; \Gamma_i = -\sum_{j=i+1}^{p} A_j$

As all the series in the vector of endogenous variables after the first-order differential are stationary, only if all the variable in the composition of Πy_{t-1} are $I(0)$, innovation vector can be stationary process.

Johansen(1995) advanced the likelihood ratio(LR) test on the coefficient matrix Π,the hypothesis test is

H_0: no more than r cointegration relations; H_1:m cointegration relations (full rank)

The test statistic:

$$LR_{tr}(r \mid m) = -T \sum_{i=r+1}^{m} \log(1-\lambda_i) \qquad (5)$$

Where λ_i is the eigen value ranked at the i order; T is total observation period. At last, we take the r cointegration relations confirmed into formula (5), then get the vector error correction model accordingly.

4. Data and analysis

4.1Data description

The period of the futures contracts in the European climate exchange (ECX) varies from one month to several years. In order to investigate the efficiency range of the carbon futures market, 17 contracts with the period of more than 3 months are selected. The time period covered is from March 2006 to December 2011. The spot price at the maturity date of the carbon futures is from the BlueNext website15 and the futures price is from the ECX website16.

Assuming sp is the spot price at the maturity date, fp_1 is the closing price of the futures with 1month before the maturity date. Similarly, get fp_2 and fp_3. To take the logarithm on them, get lsp 、lfp_1 、lfp_2 、lfp_3 ,then using them to test the market efficiency.

4.2 Market efficiency test

To test the efficiency of the market, the cointegration analysis should be used to analyze the logarithm series of spot price and futures price. The results of roots of unity test about lsp 、lfp_1 、lfp_2 、lfp_3 are shown in Table 1 and Table 2.

Table 1 ADF Test on Logarithm Value of Spot Price and Futures Price

ADF TEST	lsp	lfp_1	lfp_2	lfp_3
ADF VALUE	-1.74	-1.51	-0.96	-0.97

Test critical value at 5% level is -1.97.

Table 2 ADF Test on First-order Difference Logarithm Value of Spot Price and Futures Price

ADF TEST	Δlsp	Δlfp_1	Δlfp_2	Δlfp_3
ADF VALUE	-5.81	-6.42	-6.77	-7.33

Test critical value at 5% level is -1.97.

The datum of Table 1 and Table 2 show that at the 1% significant level, for price logarithm series, the original hypothesis cannot be rejected and the series display non-smooth characteristics. However, for the first-order difference series of price logarithm series, the original hypothesis can be rejected and the series becomes smooth series. Consequently, the series of price logarithm is first-order integration and there may be cointegration relationship between futures price logarithm series and spot price logarithm series. If the futures market is efficient, the cointegration relationship exists between futures price and spot price. What's more, the difference of them is white noise series. Since the objective of the study is the price logarithm series, the validity of the market is slightly modified. If

$$\varepsilon(q) = lsp - lfp(q) \tag{6}$$

is the white noise series, the futures market within q months is efficient.

According to this idea, we provides the unit root test for $\varepsilon(q)$, the result is shown in Table 3.

Table 3 ADF Test on the difference between Logarithm Value of Spot Price and Futures Price

ADF TEST	$\varepsilon(1)$	$\varepsilon(2)$	$\varepsilon(3)$
ADF VALUE	-2.03	-1. 74	-1.07

Test critical value at 5% level is -1.96.

The datum of Table 3 show that only $\varepsilon(1)$ is the white noise series while $\varepsilon(2)$ and $\varepsilon(3)$ are not the white noise series. Therefore, the conclusion can be made that European Climate Exchange (ECX) futures market is effective in one month.

The conclusion is associated with the reality, the futures price is an expectation of future prices; the longer the duration and the more confounding factors lead to the greater the corresponding prediction errors. Finally, the futures market will become inefficient.

4.3 Price forecast

Since the table 1 and table 2 depict that all the time series above are first-order integration $(I(1))$, VECM model is suitable for them.

When establishing the VAR（p）model for lsp and lfp_1 ,we should find out the most appropriate lag order first .

Table 4 Results of the Lag Order Determination

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-14.520 57	NA	0.043 564	2.541 626	2.628 541	2.523 761
1	-12.869 46	2.540 163	0.063 556	2.902 994	3.163 740	2.849 399
2	-5.101 450	9.560 628*	0.038 042	2.323300	2.757 876	2.233 975

3	2.361 701	6.889 063	0.026 486*	1.790 507*	2.398 914*	1.665 452*
4	5.812 039	2.123 284	0.042 408	1.875 071	2.657 309	1.714 286

The table 4 shows the LR、FPE、AIC、SC and HQ value of the 0 to 4-order VAR model, and selects the lag order with "*" according to the corresponding rules. It shows that 3-order is selected by 4 rules. Consequently, the lag order of the VAR model can be defined as 3.

Then the number of cointegration relationship between lsp and lfp_1 has been fined by using Johansen (1995) test. The result is shown in Table 5 and Table 6.

Table 5 Johansen Trace test on Logarithm Value of Spot Price and Futures Price

Hypothesized No.of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None	0.71	19.71	15.49	0.01
At most 1	0.16	2.47	3.84	0.11

Table 6 Johansen Max-Eigen test on Logarithm Value of Spot Price and Futures Price

Hypothesized No.of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.
None	0.71	17.24	14.26	0.01
At most 1	0.16	2.47	3.84	0.12

Both Johansen Trace test and Max-Eigen test show that there is one cointegration relationship at the 0.05 level (shown in Table 5 and Table 6). The cointegration relationship in mathematical expression is

$$ec = lfp_1 - 0.77lsp - 0.61 \quad (7).$$

Formula (7) shows the cointegration relationship between spot price and futures price, which is the core part of the vector error correction model.

The VECM model can be got from the VAR (3) combined with the cointegration relationship as follows

$$\Delta LP_t = \begin{pmatrix} 13.31 & -11.23 \\ 15.47 & -13.05 \end{pmatrix} * \Delta LP_{t-1} + \begin{pmatrix} 7.02 & -5.96 \\ 8.51 & -7.28 \end{pmatrix} * \Delta LP_{t-2} + \begin{pmatrix} -16.51 \\ -18.82 \end{pmatrix} * ec_{t-1} + \begin{pmatrix} 0.038 \\ 0.043 \end{pmatrix} \quad (8)$$

where,

$$LP = \left[lfp_1 \quad lsp \right]' \quad (9)$$

$$ec_{t-1} = \left[1 \quad -0.77 \right] * LP_{t-1} - 0.61 \quad (10)$$

The AIC and SC value of the model are 2.83 and 3.47. It reflects the good overall fit of the model and reveals the intrinsic characteristics of the EU ETS carbon futures market.

At last, this paper tests the cointegration relationship between the spot prices and futures prices with the whole 36 futures contracts with the period of 1 month. The Figure 1 shows the good prediction function of the spot price. As there is a certain single value prediction error, that's because of the small sample size, which affects the precision of the model.

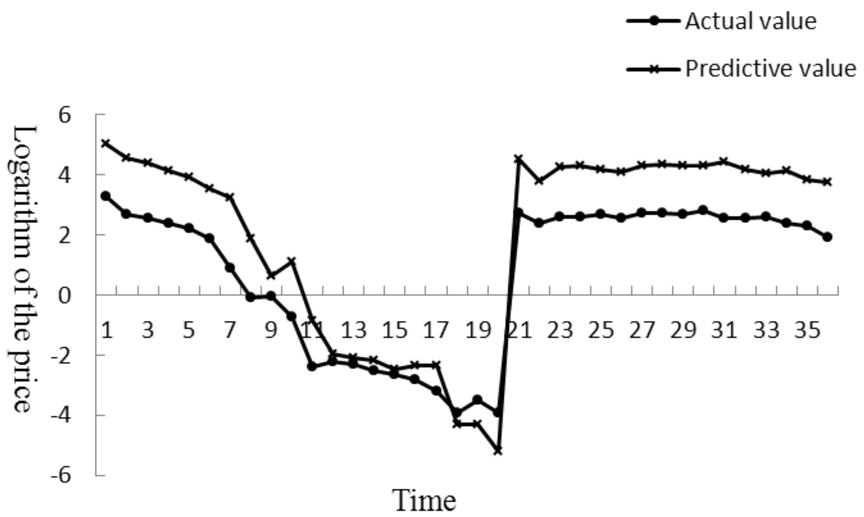

Figure 1 Predicted and Actual Value of Spot Price in logarithms

5. Conclusions

Through the analysis above, we can get the following conclusions:

1. The logarithms of spot and futures prices in EU ETS carbon futures market are non-stationary, whereas their first order differences are stable. This indicate that although it's hard to control the long-term variation, the long-term equilibrium relationship may exist between them, which is confirmed by the following analysis and modeling.

2. The EU ETS carbon futures market is efficient in one month with a price discovery function of futures prices and can accurately predict the spot price. Therefore, the market participants can hedge the risk of spot trading price by using one month futures.

3. The optimal lag duration of VAR model established is 3. This shows that in the efficient range, the effect of EU ETS carbon futures market at special moment will last 3 terms, namely 3 months. Consequently, when using EU ETS carbon futures market to hedge risks, should not only operate within a limited range, but also pay close attention to the prices variation in three months.

4. The cointegration relationship between the two variables has been found through Johansen test on two price logarithm seriess. This shows that the indicators of futures market price which seems no rules to follow exist variety of long-term equilibrium relationship, which is useful to grasp the intrinsic characteristics of the market and take full advantages of the market.

The inadequacy of this article is that because the carbon futures market is the emerging market, and it aims to use economic measures to control the allocation and transference of carbon dioxide emission permits units in Europe. So, the categories of the current futures contracts are limited, leading to a smaller sample of this study and a lower credibility of analysis. We hope this problem can be solved by increasing the categories of futures contracts and accordingly increasing the number of samples.

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