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LONG-RANGE DEPENDENCE IN THE CARBON EMISSION MARKET

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Abstract

This paper investigates the long-range dependence of returns and the volatility of the carbon emission permits in the Chicago Climate Exchange. It is found that contracts with different vintages demonstrate significantly variant long memory properties. In particular, strong long memory is found for vintages from 2003 to 2006, while no evidence of long range dependence in the return series is found for vintage 2007 to vintage 2010.

JEL Classification: *C22*
Keywords: *Long Memory; Modified R/S Statistic; Carbon Emission Market*

1. Introduction

The international market for the trading of greenhouse gas emission allowances has been developing considerably over the last decade. In 2003, The Chicago Climate Exchange (CCX) was launched as a voluntary, legally binding market for reducing and trading greenhouse gas emissions. The CCX members include 17% of the Dow Jones Industrial Average (BAC, DD, IBM, INTC, and UTC), 11% of the Fortune 100 (including: ABT, F, HON, IP, MOT and SWY) 22% of the largest CO_2 emitting utilities (AEP, AYE, DTE, DYN, LNT, MIR, NRG, RRI and TE), seven cities (Aspen, Berkeley, Boulder, Chicago, Fargo, Oakland and Portland) and two states (IL and NM). Members of the CCX are committed to make a six percent reduction from their baseline. Those who exceed their

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emission goals are required to purchase emission allowances from the other members who still possess additional commitment or credits. These allowance contracts are referred to as CCX carbon financial instrument (CFI) contracts. A CCX CFI contract, labeled as a "vintage t", represents the CCX CFI contract that is allocated to the member firm in year t. Each CFI contract corresponds to the equivalent of 100 metric tons of CO_2.

In 2005, the European Union emissions trading scheme (EU ETS) was also established. It currently covers more than 10,000 large plants from CO_2-intensive emitting industrial sectors. Feng *et al.* (2011) examined the volatility behavior of the carbon price using data from the EU ETS. They found that the long-term memory of carbon price is not significant. Other studies of carbon prices have primarily focused on the relationship between the price of carbon and other energy prices. For instance, Mansanet-Bataller *et al.* (2007) found that energy market prices (oil, gas, coal) and extreme weather events drive the carbon price. Alberola *et al.* (2008) investigated the influence of energy prices and weather on carbon prices as well as the impacts of structural breaks from 2005 to 2007 in EU ETS. The results illustrate that energy prices and unanticipated weather temperature have an impact on the carbon price. Benz and Truck (2009) applied the Markov switching and AR-GARCH models to study the returns of EU emission allowances. Chevallier (2009) investigated the relationship between EU ETS Carbon futures and macroeconomic factors using a GARCH model and found that EU emissions allowances are significantly influenced by electricity demand. Oberndorfer (2009) examined the relationship between price changes for EU emission allowances and electricity stock returns. It was found that the EU emissions allowances price increase along with rises in stock returns of the most important electricity companies covered by the EU ETS. Moreover, no positive relationship was found for the volatility spillovers between them.

This paper investigates the long-range dependence of the carbon market by employing the modified R/S statistic (Lo, 1991) on CCX CFI contracts of different vintages. The return and volatility series of vintages from 2003 to 2010 are examined.

A number of previous studies have explored the long-range dependence in the stock and other asset markets. The existence of long-range dependence indicates that there is a significant autocorrelation between asset returns at long lags, which implies that returns from the past may help to predict future returns. This contradicts the weak form of the market efficiency hypothesis, which states that future asset returns are unpredictable with regard to historical returns. Lo (1991) developed a modified R/S statistic for long memory and reported no evidence of long-term dependence in U.S stock market. Crato and de Lima (1994) found no evidence of long-memory for the stock returns series of the G-7 countries. Employing both the modified R/S method and the spectral regression method, Cheung and Lai (1995) also found no evidence of memory persistence in several international stock markets. Shibley and Param (2001) found evidence for long-term dependence in the stock markets of Korea, Malaysia, Singapore, and New Zealand. Cajueiro and Tabak (2004) showed that the stock markets of Hong Kong, Singapore, and China exhibit long-range

dependence. Recently, Chong *et al.* (2012) found strong evidence for long memory in diamond volatilities using Lo's modified R/S statistic.[2] Thus far, however, no study has attempted to test for long-range dependence in the CCX CFI contracts. This paper investigates the long-range dependence of returns and volatility of the carbon emission permits in the Chicago Climate Exchange. Our results suggest that the returns from different vintages of carbon contracts have varied dependence characteristics. In particular, a strong long memory is found for vintages from 2003 to 2006, while no evidence of long range dependence in return series is found for vintage 2007 to vintage 2010. The remainder of the paper is organized as follows: Section 2 presents the data and the modified R/S statistic. Section 3 reports the empirical results and Section 4 concludes the paper.

2. Methodology and Data

2.1. Lo's modified Rescaled Range (R/S) statistic

The rescaled range or R/S analysis was first proposed by Hurst (1951) to test for long-term dependence. The R/S statistic refers to the range of partial sums of deviations of a time series from its mean, rescaled by its standard deviation. For a stationary time series $\{x_k\}$, k=1,2,...,N, a classical R/S ratio is defined as:

$$(R/S)_t = \frac{1}{s}\left[\max_{1\le t\le N}\sum_{k=1}^{t}\left(x_k-\bar{x}\right)-\min_{1\le t\le N}\sum_{k=1}^{t}\left(x_k-\bar{x}\right)\right] \tag{1}$$

$$s=\left[\frac{1}{N}\sum_{t=1}^{N}(x_t-\bar{x})^2\right]^{1/2} \tag{2}$$

$$\bar{x}=\frac{1}{N}\sum_{t=1}^{N}x_t \tag{3}$$

However, the distribution of the classical R/S test is not well defined, and the statistic is sensitive to homogeneity and nonstationarity in the data process (Aydogan and Booth, 1988). Lo (1991) found that it is sensitive to short-term memory and heterogeneity. Therefore, he modified the RS test statistic to

$$Modified\,(R/S)_t = \frac{1}{\hat{s}(q)}\left[\max_{1\le t\le N}\sum_{k=1}^{t}\left(x_k-\bar{x}\right)-\min_{1\le t\le N}\sum_{k=1}^{t}\left(x_k-\bar{x}\right)\right] \tag{4}$$

where

$$\hat{s}^2(q)=s^2+2\sum_{k=1}^{q}w_k(q)\gamma_k \tag{5}$$

$$w_k(q)=1-\frac{k}{q+1},\ q<N \tag{6}$$

[2] For the estimation of the long memory parameter, one is referred to Chong (2000).

and γ_k is the sample autocovariance estimator:

$$\gamma_k = \frac{1}{N}\left[\sum_{i=k+1}^{N}\left(x_i - \bar{x}\right)\left(x_{i-k} - \bar{x}\right)\right] \tag{7}$$

Therefore, the modified R/S statistic is the cumulative sums of mean deviations reweighted by its consistently estimated standard deviation $\hat{s}(q)$. For the optimal choice of q, Lo (1991) applied Andrew's data dependent rule. Under the null hypothesis that the data is short-term dependent, the distribution of the test is derived in Lo (1991).

2.2. Data

Following Chong *et al.* (2012), we apply the modified rescaled range (R/S) statistic of Lo (1991) to test for long memory in the carbon emission market. Several CCX CFI contracts are selected in the sample from the CCX database, including contracts with vintages from 2003 to 2010. The sample period is from December 2003 to December 2009. Table 1 presents a summary of the statistics for daily CFI returns.

Table 1
Summary statistics of the return series

Vintage	2003	2004	2005	2006	2007	2008	2009	2010
Mean of Returns	-0.00123	0.00121	0.00121	0.00122	0.00357	0.00357	0.00400	0.00357
Standard Deviation	0.0508	0.0483	0.0504	0.0546	0.0621	0.0683	0.0608	0.0526
Skewness	-1.9028	-2.1176	-1.9032	-1.5603	-1.4992	-0.2404	-1.7748	-0.4991
Kurtosis	39.35	42.43	44.46	37.92	30.86	36.30	34.64	22.83
Shapiro-Wilk	9.434	9.398	9.528	9.594	10.099	10.341	10.193	9.954
SW P-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ljung-Box(40)	91.11	83.16	98.97	140.85	98.56	120.37	95.00	88.68
LB P-value	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

3. Empirical results

The series of daily returns R_t, absolute returns $|R_t|$, and squared returns R_t^2 are investigated. Under the null hypothesis of no long-range dependence, the critical values of modified R/S statistic for the 1%, 5% and 10% significance levels are 2.1, 1.86, and 1.75, respectively. The testing results are reported in Table 2.

Table 2
Modified R/S statistics for vintage 2003-2010

	Lo R/S statistics	Optimal lag
2003		
Return	1.92	2
absolute return	2.40	4
squared return	2.50	1
2004		
Return	2.05	1
absolute return	2.66	5
squared return	2.45	1
2005		
Return	1.93	2
absolute return	2.96	3
squared return	2.64	0
2006		
Return	1.84	1
absolute return	3.26	4
squared return	3.07	0
2007		
Return	1.63	0
absolute return	2.93	5
squared return	2.55	3
2008		
Return	1.48	0
absolute return	3.30	3
squared return	2.93	1
2009		
Return	1.55	2
absolute return	3.11	3
squared return	2.79	0
2010		
Return	1.70	4
absolute return	2.42	5
squared return	2.55	4

Note that a test value larger than the critical value indicates the presence of long memory. It is observed that contracts with different vintages have different dependence characteristics, while the evidence for long memory in volatility is strong across all vintages. For the 2003 vintage return series, Lo's R/S statistic of daily returns is larger than the critical value of 1.86, indicating that the return series exhibits long-range dependence at the 5% significance level. The values of Lo's modified R/S statistic for absolute and squared returns are larger than 2.1, indicating that long memory in return volatility is even stronger. Similar results can be obtained for 2004 and 2005 vintage return series. Long-range

dependence in returns and volatility are even more pronounced. For the return series of vintage 2006, the long range dependence is significant at the 10% level, while long memory in return volatility is significant at the 1% level. For the 2007-2010 vintage return series, the return series present no long memory, while strong evidence of long memory in the return volatility is found.

The results are different from those of Feng et al. (2011), who report insignificant long memory in carbon price in the European Union Emission Trading Scheme. The empirical results for FIGARCH (1, d, 1) models for the CFI returns across vintages are reported in Table 3. The estimated long memory parameters of FIGARCH model are significant and range from 0.261 to 0.552, which suggests that the volatility of return series across vintages can be characterized by a hyperbolic decaying long memory process.

Table 3
Estimation results for the FGARCH (1, d, 1) Model

Vintages	2003	2004	2005	2006	2007	2008	2009	2010
d	0.261	0.334	0.278	0.308	0.355	0.552	0.416	0.353
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
skewness	-1.757	-1.733	-1.965	-1.61	-2.388	-1.74	-1.647	-0.727
kurtosis(excess)	27.42	27.66	25.38	19.43	22.10	16.51	16.58	12.49
Q(20)	27.06	34.93	34.02	28.50	24.81	38.11	33.36	36.75
$Q^2(2)$	12.35	11.46	5.42	11.77	8.053	6.128	5.224	25.59
Jarque-Bera	48594	49420	41955	23823	19961	11108	11160	6177
N	1527	1527	1527	1475	938	938	938	938

4. Conclusions

This paper investigates the long-range dependence of the carbon market by employing the modified R/S statistic and the FIGARCH model on CFI contracts of different vintages. The return and volatility series of vintages from 2003 to 2010 are examined. In sum, contracts with different vintages have different dependence characteristics, while the evidence for long memory in volatility is strong across all vintages. Specifically, the results of the modified R/S test suggest that the null hypothesis of no long-range dependence is rejected for vintages from 2003 to 2005. For vintage 2006, the long range dependence is significant at the 10% level, while no evidence of long range dependence in return series is found for vintage 2007 to vintage 2010. Note that the long memory in the return series can be seen to be reducing over time. This suggests that the market has become more efficient in recent years. An implication is that the CCX market starts to perform its function in reducing and trading greenhouse gas emissions efficiently, and that governments should allow emissions problems be solved by market forces in the long run.

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