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Dynamic Linkages among European Carbon Markets: Insights on price transmission

PRELIMINARY AND INCOMPLETE

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Abstract :

In this paper, we examine interactions among European carbon markets. We test for cointegration between carbon allowance prices from European Climate Exchange (ECX), Nord Pool, Powernext, European Energy Exchange (EEX), Energy Exchange Austria (EEA) and Climex and also, conduct causality tests to examine spillover dynamics. Our findings indicate that the markets exhibited a reasonable degree of efficiency in both long and short-run.

Keywords: EU CO2 emission allowance markets, Efficiency.

JEL Classification : Q52, Q53, C22, C32

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1. Introduction

The European Union (EU) has created the largest Emissions Trading Scheme (ETS) in the word in order to reduce CO2 emissions by companies from the energy and other carbon-intensive industries. The EU ETS is being introduced in two phases. The first phase (2005-2007) is a pilot phase during which the CO2 emissions were capped at 2.1 bilions tons per year. The second phase (2008-2012) coincides with the period when the EU must meet the 8% decrease from 1990 levels under the Kyoto Protocol. In order to improve the fluidity of the EU ETS, organized allowance trading has been segmented across trading platforms namely European Climate Exchange (ECX), Nordic Power Exchange (Nord Pool), Powernext, European Energy Exchange (EEX), Energy Exchange Austria (EEA) et SendeCO2.

This study attempts to investigate the price transmission among European carbon markets by providing an important insights as to how price shocks at any market is transmitted in all other market prices, thus reflecting the extent of dynamic market linkage, as well as the extent to which markets function efficiently and considers three questions:

- Is there long-run interdependence in European carbon markets in the sense that the equilibrium for one market depends on the equilibrium for other market?
- Is there short-run interdependence in European carbon markets? In other words, do short-run fluctuations in one market spill over to the other?
- What is the direction of causality between these carbon markets? Can we identify one market as being the « cause » and the other the « effect »?

The paper is primarily motivated by several reasons. First, investigating the price transmission is crucial, since it is an important indicator of carbon market efficiency as the objective of carbon markets is to enable firms to achieve their emissions reductions at *minimum* cost. Second, european carbon markets represent a large segment of international carbon markets and understanding the linkages between them is important for firms to design effective portfolio diversification strategies. If there is significant comovement across european carbon markets, the benefits of international diversification might not be realized in the long-run. Finally, prior studies primarily focus in assessing efficiency and price discovery from spot and futures carbon markets with less attention paid to transmission efficiency on distinct exchanges. Uhrig-Homburg and Wagner (2006) assume that the spot and futures price dynamics for CO2 emission allowances can be described sufficiently well with the cost-of-carry approach after December 2005, meaning that spot prices plus accrued interest should be equal to futures prices. Their empirical results suggest that after December 2005, the market efficiency increased, and spot and futures prices now actually seem to be linked by the cost-of-carry approach. Daskalakis and markellos (2007) assessed the weak form efficiency by analysing spot and futures market data from Powernext, Nordpool and ECX. Their empirical results reveal that emission permit returns are serially predictable and that simple trading strategies can be employed in order to exploit these predictabilities and to produce substantial risk-adjusted profits. They explain the inefficiency of the EUA market by the existing restrictions on short-selling and banking EUAs. Daskalikas, Psychoyios, and Markellos (2007) find that the pricing mechanism of intra-phase and inter-phase derivatives in Nordpool, Powernext and ECX is very different due to the prohibition of banking between the distinct phases of the market. They find also that the substantial stochastic convenience yields in inter-phase futures markets means additional uncertainty and hedging costs for market participants. They conclude that the EUA market is efficient. Using daily CO2 spot prices from the European

Energy Exchange (EEX). Seifert, Uhrig-Homburg, and Wagner test the hypothesis of no autocorrelation in CO2 returns and conclude that the CO2 allowance market seems to be relatively efficient compared to the U.S SO2 market and the DAX. Milunovich and Joyeux (2007) find that none of the futures contracts traded on the European Climate Exchange (ECX) follow a cost-of-carry relationship with the spot price and interest rates suggesting that the existence of arbitrage opportunities in the market for carbon permits. Benz and Klar (2008) is the only work which considered price discovery between future prices on distinct exchanges (ECX and Nord Pool). Their results revealed that trading frictions in forms of transaction costs have decreased over the first trading phase, trading volume has increased and price discovery takes place across exchanges.

This paper constitutes- to our best knowledge- the first empirical analysis on linkages among European carbon markets. Using weekly spot market price for CO2 emission allowance from February 2006 to December 2007, we have examined EU ETS efficiency by investigating interdependence between Climex, Powernext, European Energy Exchange (EEX), Energy Exchange Austria (EEA) and Nordpool. The analysis was performed with the aid of time series analysis techniques such as unit root tests, cointegration tests, Vector Error Correction models and Granger causality tests. Results show that the five carbon markets exhibited a reasonable degree of efficiency in both long and short-run. The rest of the paper is organized as follows. Section 2 presents the empirical methodology. Section 3 presents the data and the empirical results. Section 4 concludes.

2. Empirical methodology

The assessment of EUA market interdependencies is based on the joint testing for the presence and number of cointegrating vectors as well as on considering the relevant error correction model for causal relationship between these EUA markets. Cointegration allows estimation and testing on a long-run equilibrium relationship in the presence of short-run deviations from equilibrium.
The empirical analysis is done in three steps. The first step is to verify the non stationarity of the variables since the cointegration test is valid only if all the variables are integrated of order 1. The second step involves testing for cointegration using the Engle-Granger cointegration test (Engle and Granger, 1987). The Engle-Granger method consists in estimating the cointegrating regression by ordinary least square, obtaining residual, and applying unit root tests for the residuals. To obtain the residuals, the following static OLS regression that captures any potential long-run relationship among the variables is preformed:

$$X_t = \alpha_0 + \alpha_1 Y_t + u_{x,t} \tag{4}$$

and the ADF test is as follows:

$$\Delta\hat{u}_t = \phi\hat{u}_{t-1} + \sum_{i=1}^{p}\phi_i\Delta\hat{u}_{t-i} + \varepsilon_t \tag{5}$$

where $\Delta\hat{u}_t$ include the $u_{x,t}$ sequence and with the null hypothesis of $H_0 : \phi = 0$. The value of optimal lag length p is selected by the smallest Akaike information criterion or Schwartz Bayesian criterion. Since the residual series is calculated from a cointegrating equation, an intercept and time trend are not considered in the equation. The test statistics obtained is then compared against critical value in the table generated by Engle and Yoo (1987). If the variables are found to be cointegrated then some linear combination of them will be stationary. This means that there exists a long-run relationship among them. The third step involves the estimation of the vector error-correction model (VECM) which captures the short-run dynamics of the variables. In this case, the VECM equations take the form:

$$\Delta x_t = \beta_1 + \sum_{i=1}^{m} \alpha_{1i} \Delta x_{t-i} + \sum_{i=1}^{n} \alpha_{2i} \Delta y_{t-i} + \omega_1 ECT_{t-1} + \mu_{1t}$$

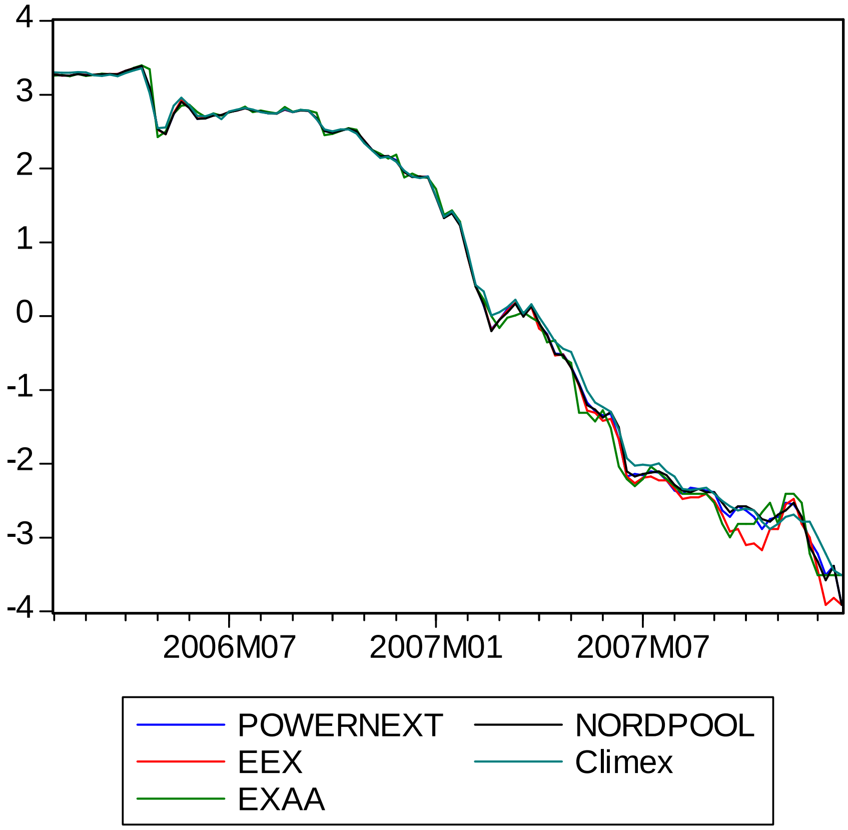
$$\Delta y_t = \beta_2 + \sum_{i=1}^{q} \alpha_{3i} \Delta x_{t-i} + \sum_{i=1}^{r} \alpha_{4i} \Delta y_{t-i} + \omega_2 ECT_{t-1} + \mu_{2t}$$

where μ_{1t} and μ_{2t} are uncorrelated disturbance terms with zero means and finite variances and the lagged term (ECT) is the error-correction term, obtained from the cointegration analysis. It ensures deviations from long-run equilibrium are corrected gradually through a series of partial short-run adjustments. The magnitude of the coefficients ω_1 and ω_2 determines the speed of adjustment back to the long-run equilibrium state, once the system is shocked. The dynamic Granger causality can be captured from the vector error correction model (VECM). In a VEC model, there are three channels of causality:

1) The lagged values of the differenced variables (weak causality or short-run causality). This can tested using wald test or the t-test if the lag order of equations is 1.
2) The error-correction as a measure of long run causality. This can tested by the t-test
3) The joint significance of the first two channels of causation. This can be tested through a Wald or F-test. The joint test indicates which variable(s) bear the burden of short run adjustment to re-establish long run equilibrium, following a shock to the system

3. Data and empirical results

The data consist of weekly EU Allowance settlement price index of the five markets namely Powernext, EEX, EXAA, Nordpool and Climex. The choice of weekly frequency is explained by the fact that data at the EXAA exchange is available at only weekly frequency. Because these platforms have begun their operations at different dates, the sample period runs from February, 3, 2006 until December 28, 2007. As a preliminary step of analysis, the EUA prices were transformed into natural logs, their graphical representations were inspected and their statistical properties were investigated. Fig. 1 displays the time series for each EUA price. The graphs of the EUA markets reveal indications of some deterministic trend component or trend-stationarity in most cases. Table 1 presents descriptive statistics for the corresponding EUA price series. As measured by the standard deviation, EUA market price volatility is highest in EEX, followed by EXAA, Powernext, Nordpool and Climex. All series are skewed to the left. The Jarque-Bera statistic rejects the null hypothesis for normality for all EUA price series.



The correlation matrix between EUA price markets is studied for the estimation period. Table 2 shows the the EUA markets indicate high and positive pairwise correlations, implying strong interactions between these markets.

Table 1. Descriptive statistics for all EUA price series

	LOGBLUE	LOGEEX	LOGEXAA	LOGNORDP	LOGSEND
Mean	0.550	0.507	0.535	0.552	0.593
Maximum	3.382	3.383	3.395	3.386	3.355
Minimum	-3.912	-3.912	-3.506	-3.912	-3.506
Std. Dev.	2.370	2.429	2.395	2.366	2.335
Skewness	-0.337	-0.363	-0.329	-0.337	-0.343
Kurtosis	1.500	1.537	1.478	1.508	1.502
Jarque-Bera	11.265 (0.003)	11.116 (0.004)	11.453 (0.003)	11.170 (0.004)	11.312 (0.003)

Notes : The sample of weekly series is from February, 3, 2006 until December 28, 2007. The number of observations is 100. Jarque-Bera statistic is used to test whether or not the series resembles normal distribution. Probability values are in parentheses.

Table 2. Pairwise correlations matrix

	DLOGBLUE	DLOGEEX	DLOGEXAA	DLOGSEND	DNORDP
DLOGBLUE	1				
DLOGEEX	0.888	1			
DLOGEXAA	0.654	0.634	1		
DLOGSEND	0.809	0.828	0.599	1	
DNORDP	0.528	0.503	0.471	0.595	1

3.1 Stationarity tests:

As indicated above, the variables must be tested for stationarity before running the cointegration test. To this end, we conducted 3 different unit root tests, namely Augmented Dickey–Fuller (1979, 1981) (ADF), Phillips–Perron (1987) (PP) and Kwiatkowski–Phillips–Schmidt–Shin (1992) (KPSS). ADF and PP tests have a null hypothesis stating that the series in question has a unit root against the alternative that it does not. The null of KPSS, on the other hand, states that the variable is stationary. In the literature, KPSS is sometimes used to verify the results of ADF and PP because their probability of rejecting the false hypothesis is low. The unit root test results, shown in Table 3, indicate that there is a unit root in all the level series but not in the first-difference series. Therefore, we conclude that each series follows an I (1) process.

Table 3. Unit root tests

Series in logarithms	ADF				PP		KPSS	
	Level		First difference		Level	First Difference	Level	First Difference
	Lags	Test statistics	Lags	Test statistics	Test statistics	Test statistics	Test Statistics	Test statistics
Logblue	2	0.068 (1)	1	-5.106* (1)	0.207 (1)	-6.022* (1)	0.228* (2)	0.093 (2)
Logexaa	1	-0.383 (1)	0	-7.857* (1)	-0.330 (1)	-7.842* (1)	0.222* (2)	0.117 (2)
Logsend	3	-0.357 (1)	2	-4.227* (1)	-0.309 (1)	-6.068* (3)	0.235* (2)	0.132 (2)
Lognordp	2	0.070 (1)	1	-5.217* (1)	-0.080 (1)	-6.058* (1)	0.229* (2)	0.094 (2)
Logeex	2	-0.198 (1)	1	-5.165* (1)	-0.137 (1)	-6.227* (1)	0.237* (2)	0.083 (2)

ADF: Augmented Dickey-Fuller test. PP: Phillips-Perron test. KPSS: Kwiatkowski–Phillips–Schmidt–Shin. (1): Model without constant or deterministic trend. (2): Model with constant and deterministic trend. The optimal lag structure is determined by the Durbin Watson test. If the regression model includes lagged dependent variables as explanatory variables, we use Durbin's h test. ADF and PP critical values are taken from MacKinnon (1991). KPSS critical values are sourced from Kwiatkowski et al. (1992). All null hypotheses except KPSS are unit root; while, in KPSS null is stationarity. *: Rejection of the null hypothesis at the 5% significance level.

3.2 Cointegration analysis

Having verified that all the variables are integrated of order one, the next step is to test for the existence of a cointegration relationship between the variables. The results of the Engle and Granger (1987) cointegration tests reported in table 4 indicate the existence 5 cointegrating vectors between the markets. ADF statistics reject the null hypothesis of no cointegration. The evidence of cointegration has several important implications. First, it eliminates spurious correlations, and suggests at least a unique channel for Granger causality test (either uni-directional or bi-directional). Second, the cointegrating vector is included as a (lagged) error correction term (ECT) in the relevant VECM model. Third, it shows a very high degree of price transmission, suggesting that future fluctuations of prices in one market can be determined or predicted to some extent using a part of the information set provided by the other market prices. Fourth, international portfolio diversification is less effective across the cointegrated markets, as investment risk cannot be reduced, and portfolio returns can exhibit similar behavior to internal and external shocks. Finally, cointegrated EUA prices converge towards a common long-run equilibrium path, as environmental policies tend to be coordinated.

Table 4. Static relations

	Powernext	Nordpool	EEX	EXAA	Sendeco2
C	0.002	-0.0033	-0.06***	0.001	0.06***
	(0.41)	(-0.06)	(-6.62)	(0.06)	(5.95)
Powernext	-	1.01***	0.79***	0.99***	0.66
		(15.04)	(3.30)	(2.73)	(2.54)
Nordpool	0.70***	_	-0.09	-0.18	0.15
	(15.04)		(-0.41)	(-0.57)	(0.69)
EEX	0.13***	-0.02	-	0.29*	0.21
	(3.30)	(-0.41)		(1.92)	(2.01)
EXAA	0.07***	-0.02	0.13*	-	-0.05
	(2.73)	(-0.57)	(1.92)		(-0.68)
Sendeco2	0.96**	0.03	0.19**	-0.10	-
	(2.54)	(0.69)	(2.01)	(-0.68)	
ADF test statistic	-7.30***	-5.92***	-5.05***	-5.25***	-3.95*

Note: Cointegration test statistic is ADF test statistics applied at residuals which obtained from the static relations between the variables. The rows refer to explanatory variables in the cointegrating relationships and columns to the dependent variables. Numbers into parenthesis are t-statistics. Critical values are taken from Engle and Yoo (1987): -4.75(1%), -4.22(5%) and -3.89(10%).

3.3 Error correction model and Granger causality tests

An error correction model is used to analyze the speed of adjustment to the equilibrium path and causalities running from any EUA market to the other EUA markets. The following table show the results of Granger causality test between each pair of markets. The estimated ECMs suggest that the adjustment process is very slowly for each VECM. We find bidirectional short-run causal relationship between Powernext and Nordpool, EEX and Powernext, EXAA and Powernext, EXAA and Nordpool, and EEX and SendeCO2; while there is no indication of causality running between SendeCO2 and Powernext, EEX and Nordpool, EEX and EXAA, EXAA and SendeCO2, and Nordpool and SendeCO2 fail to demonstrate at least unidirectional short-run causality. This indicates that the markets are not well interrelated in the short run, with changes in one market price being partially transmitted to the other market price. In the long run, we find an unidirectional long-run causality between Powernext and the other markets because we cannot reject the null hypothesis that the coefficients on the ECTs and the interaction terms are jointly zero. We find the same case for Nordpool. However, we find a bidirectional long-run causal relationship between EXAA and the rest of markets. SendeCO2 is Granged caused in one direction by Powernext, Nordpool and EXAA. Overall, the Granger causality test support the leading role of Powernext, Nordpool, and EXAA, as short-run channels of causality run from changes in these markets, and exert a strong impact on all markets in the estimation period.

Table 5. Vector error correction model

	ΔPowernext	ΔNordpool	ΔEEX	ΔEXAA	ΔSEND
C	-0.0005	-0.0008	0.04	-0.01	-0.02*
	(-0.147)	(-0.19)	(0.526)	(-0.79)	(-1.95)
ECT_{t-1}	-0.75***	0.90***	0.007	1.33**	0.44
	(-6.99)	(7.57)	(0.26)	(2.20)	(1.46)
ΔPowernext	-0.05***	1.03***	0.65***	1.36***	0.19
	[-2.33]	(19.01)	(2.64)	(2.91)	(0.80)
ΔNordpool	0.79***	0.05*	-0.006	-0.90**	0.10
	(19.28)	(1.77)	(-0.03)	(-2.12)	(0.46)
ΔEEX	0.12***	-0.01	0.02	0.28	0.37***
	(2.81)	(-0.19)	(0.26)	(1.30)	(3.92)
ΔEXAA	0.09***	-0.008***	0.04	-0.12	0.04
	(3.79)	(-3.03)	(0.84)	(-1.42)	(0.70)
ΔSEND	0.05	0.01	0.38***	0.17	0.05
	(1.21)	(0.203)	(3.65)	(0.82)	(0.94)

Note: The rows refer to explanatory variables in the VEC models and columns to the dependent variables. Numbers into parenthesis are t-statistics.

4. Conclusion

A number of studies have tested for cointegration between spot and futures prices in the carbon markets. These studies tend to focus on the convergence of spot and futures prices towards delivery or the price discovery role of futures vs. spot prices. In the present study, we draw the attention to the short- and long-run linkages among European carbon markets. . We test for cointegration between carbon allowance prices from European Climate Exchange (ECX), Nord Pool, Powernext, European Energy Exchange (EEX), Energy Exchange Austria (EEA) and Climex and also, conduct causality tests to examine spillover dynamics. Our findings indicate that the markets exhibited a reasonable degree of efficiency in both long and short-run.

Table 6. Granger causality tests

Variables	Short-run effects (t-statistics)					ECT effects (t-statistics)	Joint short-and long-run effects (F-statistics)				
	Δpower	Δnordp	ΔEEX	ΔEXAA	ΔSende		ECT& Δpower	ECT& Δnordp	ECT& ΔEEX	ECT& ΔEXAA	ECT& ΔSende
Δpowernext	-	19.28***	2.81**	3.79**	1.21	-6.99***	-	192.20	69.16	63.50	24.70
Δnordpool	19.01***	-	-0.19	-3.03***	0.203	7.57***	189.52	-	28.73	31.79	30.51
ΔEEX	2.64***	-0.03	-	0.84	3.65***	0.007	12.19	0.0003**	-	0.38**	6.92
ΔEXAA	2.91***	-2.12**	1.30	-	0.82	2.20**	4.40***	2.93**	3.48***	-	3.16***
ΔSendeco2	0.80	0.46	3.92***	0.70	-	1.46	1.08**	2.69**	9.14	1.68**	-

Note: ** or *** indicate significance at the levels 5% or 1%, respectively.

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