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An Analysis of the EU Emission Trading Scheme

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Abstract

The European Union's Emissions Trading Scheme (ETS) is the key policy instrument of the European Commission's Climate Change Program aimed at reducing greenhouse gas emissions to eight percent below 1990 levels by 2012. A critically important element of the EU ETS is the establishment of a market determined price for EU allowances. This article examines the extent to which several theoretically founded factors including, energy price movements, economic growth, temperature and stock market activity determine the expected prices of the European Union CO_2 allowances during the 2005 through to the 2009 period. The novel aspect of our study is that we examine the heavily traded futures instruments that have an expiry date in Phase 2 of the EU ETS. Our study adopts both static and recursive versions of the Johansen multivariate cointegration likelihood ratio test as well as a variation on this test with a view to controlling for time varying volatility effects. Our results are indicative of a new pricing regime emerging in Phase 2 of the market and point to a maturing market driven by the fundamentals. These results are valuable both for traders of EU allowances and for those policy makers seeking to improve the design of the European Union ETS.

Keywords: CO2 prices, EU ETS, Energy, Kyoto Protocol, Weather
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1 Introduction

In January 2005 the European Union (EU) emissions trading scheme (ETS) was introduced formally. The scheme has been instigated as part of the EU agreement to cut worldwide emissions of carbon dioxide (CO_2) within the Kyoto Protocol. Under the Kyoto agreement, the EU has committed to reduce greenhouse gas (GHG) emissions by eight percent (relative to 1990 levels) by 2008-2012. The scheme issues a restricted amount of emission allowances to firms on an annual basis. At the end of the year firms must hold the required amount of emission permits to meet their emissions of CO_2 over the previous year.[1] The ETS allows firms to trade the amount of emission permits that they hold and as a result has applied a market value to this externality. In the EU ETS context the first phase of trading was 2005-2007 and the second one, which coincides with the first compliance period of the Kyoto Protocol, is 2008-2012. The third European trading phase will commence in 2013. Non-compliance with the commitments will result in a penalty of 40 (100) euros per tonne of CO_2 produced without allowances for the first (second) commitment period. The aim of the ETS is that this cost will encourage firms to reduce their emissions. Paolella and Taschini (2008) highlight that the ultimate aim of this scheme (as well as the US CAAA-Title IV scheme) must be to create an environment where there is scarcity of allowances which will lead to an upward trend in prices. As a result we might expect to see mean reversion around an upward trend. However, there has been a considerable amount of uncertainty associated with the price of CO_2 emissions over its short life to date.[2]

Concomitant to the recent dramatic fall in allowance prices (spot falling from 30 euro in the summer 2008 to just under 10 euro in the spring 2009) has been growing calls for intervention by the European commission into the market. Those calling for intervention see the low prices as incentivising higher rather than lower carbon based technology.[3] Any intervention is likely to seriously distort the market and may impede investment in low carbon technology in the future. As noted by Lowrey (2006) a centrally important element of the EU ETS is the establishment of a market determined price for EU allowances. In this article, we take account of market uncertainty and examine the extent of the emergence of an equilibrium relationship between the expectation of EU allowance prices and a set of theoretical determinants, including temperature and expectations of energy prices, specifically, coal, natural gas and oil futures contracts.[4] Unlike the vast majority of previous work in the area, we take account of both structural and time series properties in examining the behaviour of EU allowance prices. Taking account of both structural and time series properties will indicate whether prices, although currently low, are determined by a stable relationship. Given the relative paucity of data available and consistent with the

[1] A report must be submitted to verify the emissions in any year by the 31^{st} March of the following year.

[2] The trading scheme also provides developing business opportunities for intermediaries and service providers. The pricing behavior of CO_2 emissions will be particularly important to these players.

[3] Mark Lewis, director of global carbon research at Deutsche Bank, proposed (6 February 2009) to establish a reserve price for EU emissions allowances (EUAs) to avoid a price collapse in the third phase of the EU ETS, which starts in 2013.

[4] See Convery (2009) and Springer (2003) for a survey of the literature.

previous literature, our analysis will adopt data at a relatively high frequency, daily data. The fullsample of data covers the period 2005 to 2009 and so incorporates both Phase 1 and Phase 2 data. Unlike the vast majority of the previous studies, our focus will be on futures rather than spot contracts. The justification for examining futures is due to the greater volumes being traded on these contracts (see Mansanet-Bataller and Pardo, 2008).[5] The expiry on our futures contracts is December 2008 and 2009 and so given the restrictions on banking are only redeemable for Phase 2 emissions. These instruments were not exposed to the dramatic structural breaks that have been previously highlighted in the literature and so results in an additional advantage of adopting the futures based analysis. We will adopt the cointegration procedure to identify the existence of a long-run relationship. We also adopt a number of identifying restrictions to further refine our model. Finally we also carry out a number of sensitivity tests which take account of time varying volatility and the structural breaks in the data. Our results are consistent with previous work in that we find considerable evidence of uncertainty for EU allowances and the range of determinants. Although, there have been calls for intervention in the market, our results indicate that for a Phase 2 sample a stable relationship has formed between EU allowances and other determinants. There IS no evidence of this stable relationship occurring for the Phase 1 sample.[6] Our empirical results are also consistent when we take account of the time varying volatility in the data.[7]

The literature in the area of cointegration testing, in the context of ARCH effects, is in its infancy. The theoretical literature (see Lee and Tse (1996), Silvapulle and Podivinsky (2000) and Hoglund and Ostermark (2003)) indicates that ARCH effects aggrandise the size of the Johansen (1988) cointegration test. For example, Lee and Tse (1996) indicate that while the Johansen (1988) cointegration test tends to overreject the null hypothesis of no cointegration in favour of finding cointegration, the problem is generally not very serious. Silvapulle and Podivinsky (2000) report similar results. In contrast, Hoglund and Ostermark (2003) conclude that the eigenvalues of the long run information matrix for the Johansen (1988) cointegration test are highly sensitive to conditional heteroskedasticity and that therefore this multivariate statistic is only reliable in the context of homoskedastic processes. This latter finding, regarding the size of the cointegration test, becomes increasingly pronounced the more integrated the ARCH process considered. That said, these contributions pertain to low dimensional systems and, as a result, are of limited empirical relevance. For example, empirical contributions (see Alexakis and Apergis (1996), Gannon (1996) and Pan et al. (1999)), across a wider range of system dimensions, tend to indicate that these ARCH effects and their variants exert a significant and deleterious impact on the statistical test's power properties. Specifically, the aforementioned empirical literature identifies significant

[5]Mansanet-Bataller and Pardo (2008) report cumulative volumes traded in the different European Carbon markets since the start of the trade in each market until January 2008. The volumes traded in spot is 4%, futures 76% and over the counter (OTC) 20%.

[6]For the remainder of the paper, Phase 1 refers to the Phase 1 sample and Phase 2 refers to the Phase 2 sample.

[7]We find no evidence of a structural break in the data. This is not particularly surprising given that our analysis covers futures contracts that expire in Phase 2.

gains in statistical power once ARCH effects are controlled, when testing for cointegration, using the Johansen (1988) technique.

The burning of fossil fuels, irrespective of the catalyst, involves the emission of greenhouse gases including carbon and as a result constitutes a relatively direct determinant of the price of carbon. Springer (2003) also indicates the importance of economic growth as a potential driver of allowance prices. As well as fuel prices, temperatures are also likely to have an influence and in particular extreme temperature.[8] Extreme temperatures tend to be off-set artificially by systems of air conditioning which require electricity, often generated by the burning of fossil fuels and hence the emission of carbon. As a result it is envisaged that the demand for EU allowances may be impacted by extreme temperatures (see Moral-Carcedo and Viciens-Otero, 2005).[9] There have been a number of recent papers examining the time series behaviour of emission allowances, e.g. Daskalakis et al (2009), Benz and Trück (2009) and Paolella and Taschini (2008). Paolella and Taschini (2008) examine both SO_2 (in the US) and CO_2 (EU) spot price dynamics at a daily frequency and adopt a generalised autoregression conditional heteroscedastic (GARCH) model to account for the time varying return behaviour of the allowances. Daskalakis et al (2009) analyse a range of time series approaches to take account of the restrictions on banking allowances between different phases. As with Paolella and Taschini (2008) and Daskalakis et al (2009), Benz and Trück (2009) adopt a pure time series approach and so no structural relationships are investigated. The authors take account of the non-normality associated with the EU allowance returns and find that a regime switching model appears to provide a superior fit.

Redmond and Convery (2006) and Alberola et al. (2008) are the closest in nature to our study. Unlike the previous literature which adopted a pure time series approach, both studies examine the behaviour of the price of carbon in relation to energy commodities, meteorological factors and a number of other variables.[10] The authors highlight the existence of a structural break around April/May 2006 coincident to the unofficial release of the 2005 emissions data by some of the EU member states.[11] Having taken account of the structural break, the authors find that oil is the only variable to have a statistically significant influence on EU allowances. Alberola et al. (2008) extend the anlysis to take account of not only the structural break for April 2006, but also a break for October 2006 following the announcement of more stringent European Commission policy for Phase 2. The authors also find evidence of the impact of extreme cold temperatures on CO_2 prices for Phase 1 data.[12]

[8] Recent studies to examine the implications of weather on energy demand and carbon emissions include Considine (2009), Alberola et al. (2008) and Davis et al. (2002).

[9] A recent study by Alberola et al. (2008) found that using data for Phase 1, only extreme cold weather conditions had an impact CO_2 emission prices.

[10] The other variables include for example dummy variables to take account of policy and regulatory issues.

[11] EU ETS spot prices had reached a high of 30.50 euro prior to April 2006. Following the official release by the EU commission on the 15^{th} May 2006, showing a larger than expected surplus in the market, the spot price fell to 15.63 euro on the 17^{th} May 2006.

[12] The authors did not find any evidence of extreme hot or cold temperatures impacting prices for the full sample of Phase 1 data, but there was some evidence of cold temperatures having an impact at a sub-sample setting.

The remainder of this article is structured as follows, section 2 describes the methodology adopted, section 3 presents the data and empirical results. Finally, concluding remarks are presented in section 4.

2 Phase I Empirical Evidence & the Implications for Phase II

A number of studies have examined the performance of Phase 1 EU ETS, mainly using data of a daily frequency, given the paucity of data. Recent studies include Paolella and Taschini (2008), Daskalakis et al (2009) and Benz and Trück (2009) examine the time series properties of a range of different EU ETS instruments.[13] For example Benz and Trück (2009) adopt a pure time series approach and take account of the non-normality associated with the EU allowance returns and find evidence of regime switching.[14] Unlike the previous cited studies which adopted a pure time series approach, Redmond and Convery (2006) and Alberola et al. (2008) examine the behaviour of the price of carbon in relation to energy commodities, meteorological factors and a number of other variables.[15] Redmond and Convery (2006) include for example dummy variables to take account of policy and regulatory issues. While, Alberola et al. (2008) examine the extent of extreme temperature and find evidence that extremely cold temperatures have a statistically significant impact but only at a sub-sample setting.

The empirical studies to date have highlighted the difficulties associated with Phase 1 (pilot phase). In particular there was considerable uncertainty and volatility associated with the market price of EUA's. In April 2006, coincident to the unofficial release of the 2005 emissions data by some of the EU member states the price of EUA's collapsed. EU ETS spot prices had reached a high of 30.50 euro prior to April 2006. Following the official release by the EU commission on the 15^{th} May 2006, showing a larger than expected surplus in the market, the spot price fell to 15.63 euro on the 17^{th} May 2006. Given that banking EUA's was prohibited between phases, the price eventually converged to close to zero at the end of Phase 1. As well as the April 2006 break, Alberola et al. (2008) also highlight a break in October 2006. This break relates to an announcement by the European Commission (EC) of considerably stricter policy in relation to the allocation of permits for Phase 2.[16] Overall for Phase 1, it would appear that the cap placed on emissions was far too lax and so downward pressure on the spot and futures (those expiring in Phase 1) price continued.

[13] Paolella and Taschini (2008) examine both SO_2 (in the US) and CO_2 (EU) spot price dynamics.

[14] The only study that has addressed the market microstructure issues for this market has been Benz and Hengelbrock (2009) and Bredin, Hyde and Muckley (2009). Both studies find evidence of an increase in market liquidity for phase 2 expiring futures contracts.

[15] Alberola et al. (2009a and 2009b) have also examined the role of market structure and industrial sectors.

[16] On 26 October 2006, the EC announced a stricter policy for national allocation plans (NAP) for Phase 2 of the EU ETS.

As has been highlighted by a number of authors including, Christiansen et al. (2005), Bunn and Fezzi (2007), Redmond and Convery (2006) and Alberola et al. (2008), energy prices are a key driver of carbon prices. Large installations, in particular power plants, are likely to switch between various forms of energy depending on the associated cost. In particular power plants pay close attention to the profits from producing electricity depending on whether the input is coal (profits are referred to as dark spread) or gas (profits are referred to as spark spread). Given the costs of CO_2 emissions, dark and spark spreads are adjusted further to take account of the additional cost and are referred to as clean dark and spark spreads. Along with energy prices, weather conditions are considered a theoretically important variable in determining the price of carbon. Studies that have incorporated weather conditions in explaining movements in Phase 1 EU ETS include the Redmond and Convery (2006), Mansanet-Bataller et al. (2007) and Alberola et al. (2008). In all cases the authors take account of temperature extremes and the likely effects with some evidence to suggest the importance empirically of these variables.[17]

Clearly a number of difficulties remain. These include the fact that the cap was only aimed at large emitters from the power and heat generation industries and in selected energy intensive industries.[18] As has been highlighted earlier the over allocation of allowances has been problematic. The national allocation plans (NAP) submitted by member states to the European Commission were not reviewed in Phase 1 and these were distributed free of charge by member states to the emitting firms.[19]

3 Methodology

In our examination of the presence or otherwise of cointegration in our sample we adopt both the classic versions of the Engle and Granger (1987) and Johansen (1988) cointegration tests alongside a modified Johansen cointegration test provided by Gannon (1996). The Engle and Granger (1987) and Johansen (1988) methodologies are well known in the literature and so are not discussed further here. We are concerned specifically with the over-all behaviour of the system and the evolution of the system with respect to the criterion of cointegration. With regard to the over-all behaviour of the system we perform static analyses. We also recursively estimate both approaches to gain an insight into the evolution of the system containing the European Union allowances alongside the other factors described in section 1. In particular, with regard to our recursive methodology, we perform the tests over the initial 250 observations and subsequently repeat the testing procedure over a lengthening window of data, where the window grows by a single observation prior to each incremental estimate of the test statistic.

[17] Redmond and Convery (2006) find no evidence of a statistically significant weather effect, while Alberola et al. (2008) do find evidence but only for certain sub-samples of Phase 1.

[18] The European Commission (2005) has estimated that these installations account for 45% of CO_2 emissions. Airlines will be included in the next phase of the EU ETS, from 2013-2020.

[19] Member states were allowed to auction up to 5% of their total allowance allocation in Phase 1 (Convery and Redmond, 2007). To date Denmark, Hungary, Ireland and Lithuania have used auction provisions.

A modified Johansen testing procedure is estimated with a view to mitigating for the deleterious implications of heteroskedasticity effects on the estimation of the rank of the long run information matrix in a specified vector error correction model (henceforth VECM). Specifically, following Gannon (1996) and Pan et al. (1999), we adopt a modified test for common roots in which we account for heteroskedasticity effects in the correlating combinations of residuals. Consider the m-dimensional VECM :

$$\Delta x_t = \pi x_{t-1} + \sum_{i=1}^{k-1} \pi_i \Delta x_{t-1} + \varepsilon_t \tag{1}$$

$$\pi = \sum_{i=1}^{k} \pi_i - I \tag{2}$$

$$\pi_i = -\sum_{i+1}^{k} \pi_j, (i = 1, ..., k-1) \tag{3}$$

The residuals, ϵ_t, are assumed independent normally distributed m-dimensional with mean zero and variance, Ω. The parameters $(\pi, \pi_1, ..., \pi_{k-1}, \Omega)$ are unrestricted and are estimated by maximum likelihood estimation. The x_t are vectors of series containing the EUA futures prices and theoretically founded determinants. Now, consider two auxiliary equations:

$$\Delta x_t = \sum_{i=1}^{k-1} \delta_{1i} \Delta x_{t-1} + r_{0t} \tag{4}$$

$$x_{t-1} = \sum_{i=1}^{k-1} \delta_{2i} \Delta x_{t-1} + r_{1t} \tag{5}$$

where δ_1 and δ_2 are estimated by ordinary least squares (see Johansen and Juselius, 1990 and Juselius 1991). The vectors of series r_{0t} and r_{1t} contain the residuals from the auxiliary regressions. Note that the VECM, equation (1) can now be reformulated as a two-stage estimation process:

$$r_{0t} = \alpha\beta' r_{1t} + \epsilon_t \tag{6}$$

The null hypothesis, H_0, that the components of x_t are cointegrated may be stated as

$$H_0 : \pi = \alpha\beta' \tag{7}$$

This implies that q = rank (π) < m. The rows of the (m×q) matrix β' are the distinct cointegrating vectors of x_t i.e., $\beta'(x_t)$ are I(0). The elements of α represent the loadings of each of the r cointegrating relations.

The canonical correlations can be estimated from the stacked residuals via equation (6) where the weights, $\omega_{1i}, ..., \omega_{pi}$ and $\kappa_{1i}, ..., \kappa_{pi}$ are canonical weights.

$$\hat{\nu} = \hat{\omega}_{1i} r_{01i} + ... + \hat{\omega}_{pi} r_{0pi} \quad (8)$$
$$\hat{\eta} = \hat{\kappa}_{1i} r_{11i} + ... + \hat{\kappa}_{pi} r_{1pi} \quad (9)$$

Where r refers to the residuals from equations (4) and (5) and the subscript i refers to the i^{th} pair of canonical variables. Therefore these variables $\hat{\nu}_i$ and $\hat{\eta}_i$ have a zero mean. Finally, estimate, using the GARCH(1,1) equation specification equations for $\hat{\nu}_i$ and $\hat{\eta}_i$ for $i = 1, ..., q$.

$$\hat{\nu}_{it} = \rho_i \hat{\eta}_{it} + u_{it} \quad (10)$$
$$h_{it} = Var(\hat{\nu}_{it}/\hat{\eta}_{it}) = \alpha_{i0} + \alpha_{i1} u_{t-1}^2 + \beta_{i1} h_{t-1} \quad (11)$$

and compare the t-statistic for ρ with the tabulated values of the statistic given in MacKinnon (1991). Hence, an estimate of each eigenvalue, λ_i, is available as $\rho_i \approx \sqrt{\lambda_i}$. Neglecting heteroskedasticity effects provides inefficient estimates of the λ_i's while allowing for heteroskedasticity effects accounts for simultaneous volatility effects in the system. If there is common volatility across the series entering the system then linear combinations of the deviations from long-run paths will capture these common factors. The concern is that in neglecting to account for common volatility shocks, the test statistics may fail to reveal significant common roots. The test statistics are estimated from the procedure described in equations 8, 9, 10 and 11. We perform the two-stage procedure with and without accounting for GARCH(1,1) effects. When we do not account for GARCH(1,1) i.e. when we do not adopt equation (11) in our estimation of the eigenvalues λ_i we use the Newey West (1987) procedure to control for heteroskedasticity which is critical when testing for the statistical significance of each eigenvalue, λ_i. The variables are constructed using canonical coefficients as weights. This procedure provides an estimate, robust to heteroskedasticity effects, of the number of cointegrating vectors.

3.1 Empirical Results

The Engle and Granger (1987), the Johansen (1988) multivariate likelihood ratio cointegration approach and Gannon (1996) modified cointegration tests are used to assess whether there are common forces driving the long-run movements of the full set of variables examined. Table 2 presents Engle Granger (1987) style results. Specifically, it contains linear regression coefficients (all variables are logged, with the exception of temperature) corresponding to the full sample, Phase 1 and Phase 2 of the EU ETS. The Dickey-Fuller test statistic (last column) is not statistically significant in any of the samples and indicates the lack of cointegration in the full sample, Phase 1 and 2. However it is noteworthy that there has been a marked heightening of the significance of elements in the cointegration equation during Phase 2, relative to the effects in Phase 1. The t-statistics are calculated using Newey West adjusted standard errors. The point coefficients give a preliminary indication as to the likely empirical relationships between EUA prices and the key variables of determination. Both equity prices and production are considered as representing the general state of the European economy and we would expect that a positive relationship would result. As we move from Phase 1 to 2, the sign on both variables switches. In particular the negative sign on production may be adversely affected by the dramatic decline over the 14 months representing Phase 2. CDS and CSS represent the profitability for electricity generators depending on whether coal or gas is the principle input. While one would expect a negative (positive) relation between EUAs and CSSs (CDSs), this is only emerges in the Phase 2. A negative relation between EUAs and CSSs is expected to arise as greater profitability from generating electricity from natural gas, ceteris paribus, would result in switching to natural gas fueled electricity generation and hence a short run abatement with respect to CO_2 emissions.[20] EUA prices are likely to decline following the fall in demand. Similarly, the opposite relation is expected to hold between EUAs and CDSs. Oil prices are statistically significant in both phases with a coefficient close to unity. Finally, the temperature variable capturing unanticipated innovations in temperature (measured in absolute terms) is statistically significant in Phase 2. These latter effects may reflect increased demand for entitlements to emit carbon as a result of heightened demand for heating or air conditioning due to unexpected changes in temperatures.

Table 3 presents the normalised distinct cointegration equations and related hypotheses testing results, with respect to the Johansen (1988) estimation of the vector error correction model specification, corresponding to the full sample and Phases 1 and 2 of the EU ETS. The model specification (deterministic components and lag length) is inferred with respect to the Schwarz information criterion.[21] The cointegration results indicate that a long-run relationship exists over the full sample and for Phase 1 and 2. In Panel A, the normalized cointegrating equations are presented alongside the t-statistics on the coefficients. The full sample results indicate that CSS, CDS, and equities all have a statistically significant influence and with an intuitively correct sign. While the oil price and production are statistically significant, the sign on the coefficients is not as expected. The adverse impact of the economic downturn over the last 12-18 months may explain the counter intuitive signs.[22] Panel B presents the hypotheses test results. The hypotheses that there are at most $r (r = 0...4)$ distinct cointegrating vectors are examined. The critical values are sourced in Osterwald-Lenum (1992). It appears, from an inspection of the Trace test, that the system exhibits a significantly greater number of cointegration vectors during the second phase of the EU ETS. Only the Trace test statistic and associated P-value for the null hypothesis of no cointegration against a general alternative is reported. Hypotheses tests (ii), (iii) and

[20] Gas fired energy plants emit considerably lower CO_2 pollutants compared to coal fired energy plants.

[21] These results are not presented here although they are available from the authors upon request.

[22] A further issue is that our production series has been interpolated from monthly data. A consistent approach has been adopted by Alberola et al. (2008).

(iv) correspond to null hypotheses of a zero loading coefficient on the disequilibrium error in the EUA equation, a zero coefficient on the EUA in the cointegrating equation and a joint null hypothesis with respect to these latter hypotheses, respectively. The results are robust to alterations of the deterministic components in the vector error correction model. In Phase 2, although the EUA futures contract does not appear to respond to disequilibrium, it is evident that the EUA futures contract plays a significant role in the long run relation that has emerged in the system. Moreover, in the full sample results, it is apparent that the EUA futures contracts do respond to disequilibria prevalent in the system.

As a result of the prevalence of ARCH effects in the data, a modified cointegration test with GARCH effects is performed. Table 4 presents the results. The test statistics are estimated from the procedure described by Equations 10 and 11. The $\rho = 1$ test results are based on variates constructed from the weights for the maximum canonical correlation, whereas the second highest canonical correlation is used for $\rho = 2$, and so forth. Our results indicate evidence of cointegration for all samples (and 2 cointegrating relationships for Phase 2) and are consistent with the Johansen results reported in table 3. In light of the likelihood of evolving dynamics within the full system of data examined we turn to the recursive cointegration analyses, in relation to the Engle-Granger approach, the Johansen approach and finally the modified cointegration test accounting for heteroskedasticity. Figure 3 presents the results for Engle-Granger, Johansen and the modified cointegration approach. As can be seen the Engle-Granger (1987) recursive test indicates a lack of cointegration throughout and is clearly consistent with the results from table 3. The Johansen (1988) recursive analysis indicates, notwithstanding a brief period in early 2006, a lack of significant distinct cointegration vectors throughout the sample, until a marked strengthening of this result from 2008. The implication is that our finding of contegration is heavily influenced by long-run relationships emerging in Phase 2 of the EU ETS. Finally, turning to the recursive results provided by the robust cointegration methodology (using a Newey-West adjustment), the results again suggest a cointegrationing relationship developing over Phase 2 only.

4 Conclusion

In January 2005 the European Union (EU) emissions trading scheme (ETS) was introduced formally. The scheme has been instigated as part of the EU agreement to cut worldwide emissions of carbon dioxide (CO_2) within the Kyoto Protocol. The scheme issues a restricted amount of emission allowances to firms on an annual basis. The ETS allows firms to trade the amount of emission permits that they hold and as a result has applied a market value to this externality. In the EU ETS context the first phase of trading was 2005-2007 and the second one, which coincides with the first compliance period of the Kyoto Protocol, is 2008-2012. Paolella and Taschini (2008) highlight that the ultimate aim of this scheme (as well as the US CAAA-Title IV scheme) must be to create an environment where there is scarcity of allowances which will lead to an upward trend in prices. As a result we might expect to see mean reversion around an upward trend. A number of studies have examined the performance of the EU ETS market, however given the infancy of the market the emphasis has been on phase 1. Recent studies that examine the time series properties of a range of different EU ETS instruments include Paolella and Taschini (2008), Daskalakis et al (2009) and Benz and Trück (2009) Unlike the previous cited studies which adopted a pure time series approach, Redmond and Convery (2006) and Alberola et al. (2008) examine the behaviour of the price of carbon in relation to energy commodities, meteorological factors and a number of other variables. Our current study represent an extension of the later two studies on a number of levels.

In this article we have taken account of market uncertainty and examine the extent of the emergence of an equilibrium relationship between the expectation of EU allowance prices and a set of theoretically founded factors, including, energy spreads, the Eurex Dow Jones futures contracts, a measurement of European-wide industrial production and unanticipated temperature innovations as well as changes in expected oil prices. Our analysis covers the period 2005 to 2009, so we examine for both Phase 1 (2005-2007) and the current Phase 2 (2008-2012). Unlike the vast majority of the previous studies, our focus will be on futures rather than spot contracts. The justification for examining futures is due to the greater volumes being traded on these contracts (see Mansanet-Bataller and Pardo, 2008). The expiry on our futures contracts is December 2008 and 2009 and so given the restrictions on banking are only redeemable for Phase 2 emissions. These instruments were not exposed to the dramatic structural breaks that have been previously highlighted in the literature and so results in an additional advantage of adopting the futures based analysis. We have adopted the cointegration procedure to identify the existence of a long-run relationship. We have also carried out a number of sensitivity tests which take account of time varying volatility in the data.

Alongside Phase 2 of the EU ETS it appears that a new pricing regime is emerging in that market. The new regime is indicative of an increasingly active market, following the increased volumes of emissions trading in Phase 2. Specifically, it appears that theoretically established relations between the expectations on EU allowance prices and energy spreads and equities are particularly evident. This is not surprising in light of the heightened activity in the EU allowance market during the course of its development. It provides further evidence of the rising level of efficiency in the EU allowance market and is expected to be of interest both to traders, policy makers and those seeking to improve the design of the European Union's Emissions Trading Scheme.

5 Appendix: Data Description

Series	Description
Energy Spreads	Clean Dark and Spark Energy Spreads, denominated in Euro per MWh, are the discrepancies between the price of electricity at peak hours and the price of coal and the price of natural gas, respectively, required to generate that electricity, adjusted for the energy output of the coal / natural-gas fueled plants. These Energy Spreads are calculated by Caisse des Depots Climate Task Force for Tendances Carbone, and are observed at a daily frequency from July 1, 2005 to March 2, 2009. The methodology is available on the website http://www.caissedesdepots.fr, accessed May 2009.
EUAs	European Union Allowance daily futures contract prices, denominated in Euro, from July 1, 2005 through to March 2, 2009 with vintage December 2008, the vintage is switched to December 2009 in the third week of December 2008. The numeraire currency is the Euro. The underlying entitlement is the right to emit one tonne of carbon. Source: European Climate Exchange.
Equity	Eurex Dow Jones EURO STOXX 50-series of futures contracts switches on the first day of each expiry month to the subsequent expiry month futures contract, denominated in Euro, observed at a daily frequency. The Dow Jones EURO STOXX 50 is a stock index of Eurozone stocks designed by STOXX Ltd. The data covers the period July 1 2005 through to March 2 2009. Source: Thomson-Reuters, Datastream
Oil	ICE (Intercontinental Futures Exchange) Brent Crude Oil futures, United Kingdom daily contract prices from July 1, 2005 through to March 2, 2009 with vintage December 2005, December 2006, December 2007, December 2008 and December 2009. The vintage is altered in the third week of December each year. The numeraire currency is the Euro. Source: Thomson Reuters.
Production	The Eurostat industrial production index has a base 100 in 2000 and is seasonally adjusted. Data sourced at http://ec.europa.eu/eurostat. Observations are recoded between July 1 2005 and March 2 2009. Daily observations are estimated via interpolation adopting a piecewise cubic spline methodology, provided by Matlab.
Temperature	Temperature deviations from seasonal average temperatures (13-year average) for the Tendances Carbone European temperature index. The data spans the period July 1, 2005 through to March 2, 2009. The Tendances Carbone European temperature index is equal to the average of national temperature indices sourced withPowernext. These national temperature indices are computed using weights determined by intra-country regional populations. The European index is weighted by the share of NAP in the constituent countries: France, Germany, Spain and the United Kingdom.

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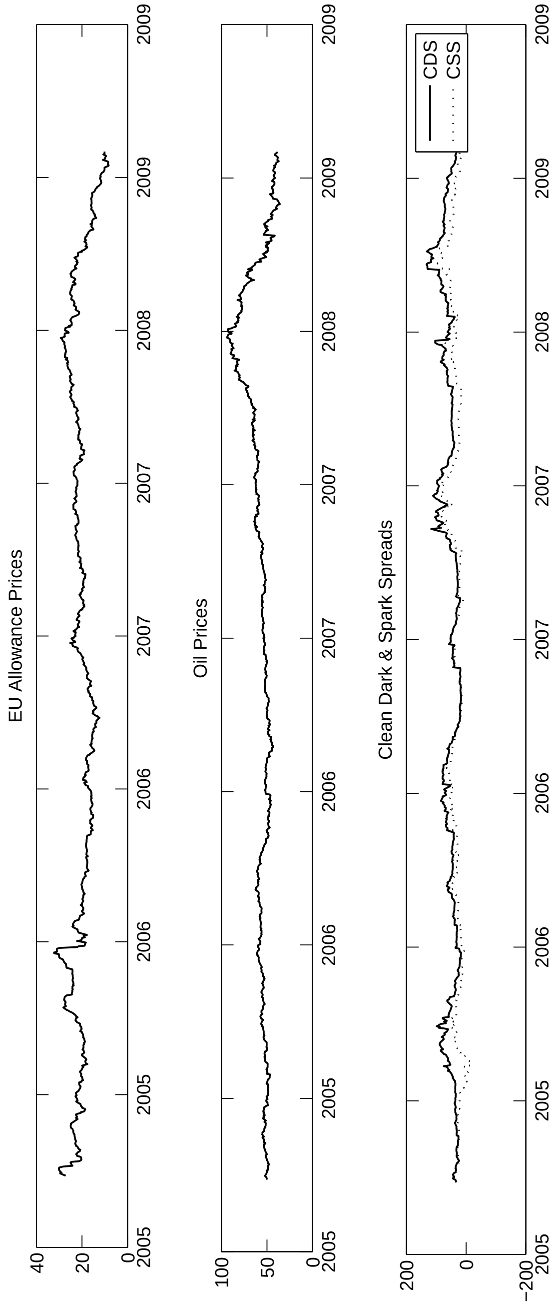
Figure 1



EU Allowance Prices
40
20
0
2005
2005
2006
2006
2006
2007
2007
2007
2008
2009
2009
Oil Prices
100
50
0
Clean Dark & Spark Spreads
200
0
−200
CDS
CSS

Figure 2

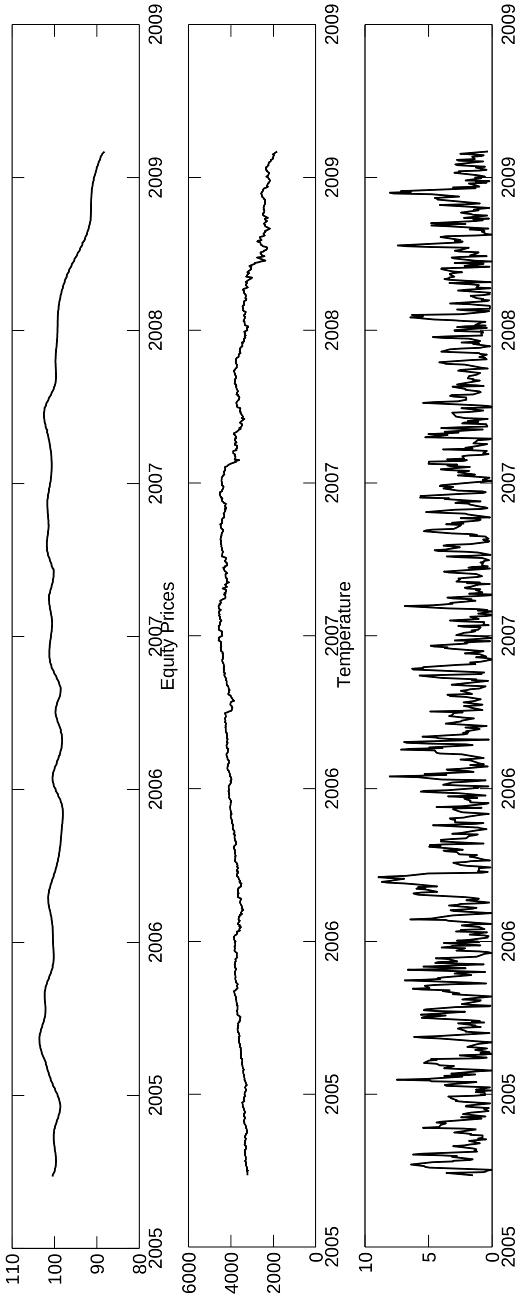

Production
110
100
90
80
Equity Prices
6000
4000
2000
0
Temperature
10
5
0
2005
2005
2006
2006
2007
2007
2008
2009
2009

Figure 3: Recursive Cointegration Tests

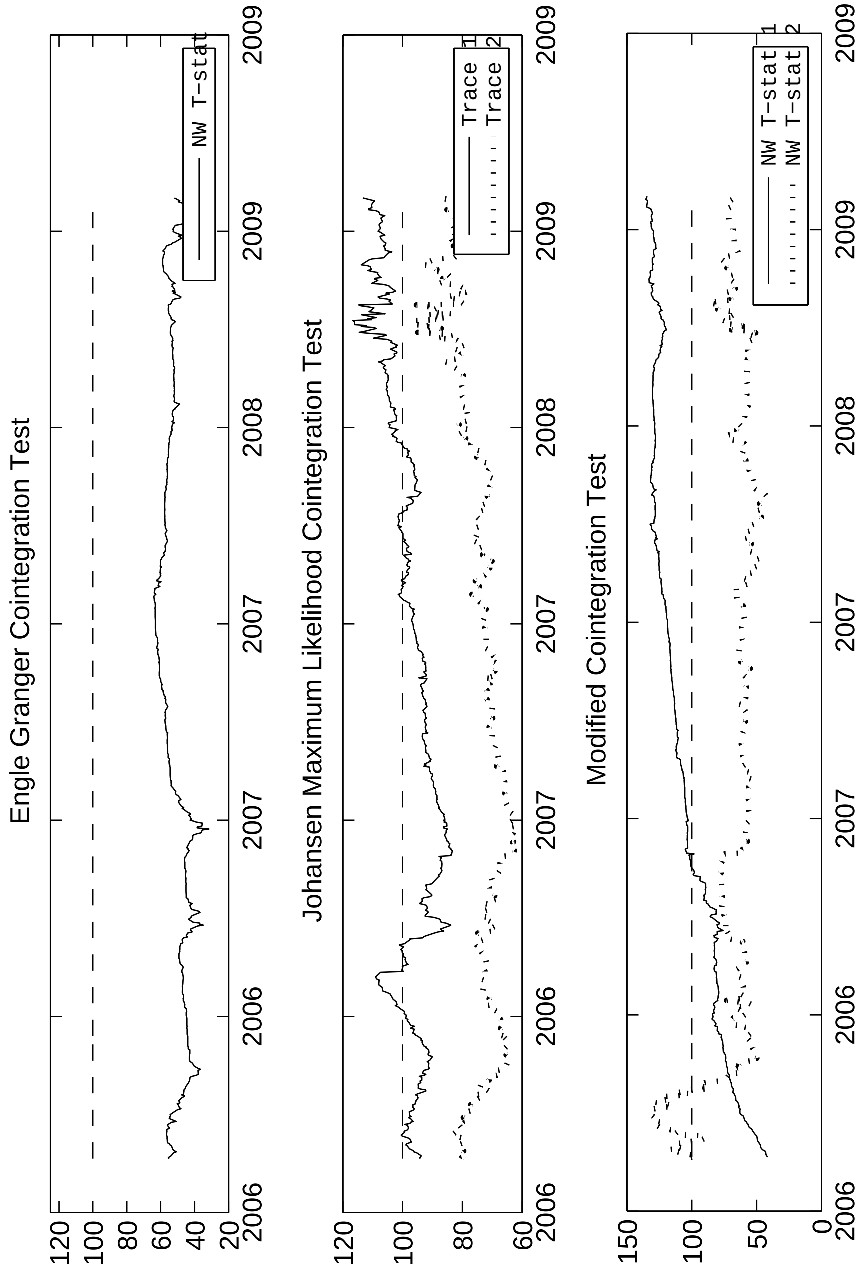


Table 1: **Summary Statistics**

Series	Mean	Variance	Skewness	Exc. Kurtosis	ARCH	PP Unit Root
EUA	-0.11	8.89	-1.08*	12.83*	35.5*	-2.26[-26.99*]
Clean Dark Spread	-0.01	60.71	2.25*	22.34*	0.35	-2.30*[-28.90*]
Clean Spark Spread	-0.02	74.83	-3.47	63.47*	16.28*	-2.99*[-28.91*]
Equity	-0.06	2.62	-0.06	10.06	212.56*	0.73[-31.95*]
Oil	-0.03	5.15	1.58*	20.45*	11.56*	-1.17[-34.25*]
Production	-0.01	0.00	-0.31	3.76*	164.45*	4.43[-4.18*]
Temperature	2.34	2.93	0.98*	0.72*	475.02*	-13.82*[-48.28*]

Panel B: *Phase I*

Series	Mean	Variance	Skewness	Exc. Kurtosis	ARCH	PP Unit Root
EUA	-0.03	9.38	-1.48*	16.36*	20.89*	-3.07*[-22.74*]
Clean Dark Spread	0.17	66.28	2.59*	21.57*	1.40	-2.02[-24.02*]
Clean Spark Spread	0.09	90.23	-4.01*	62.73*	0.91	-2.33[-28.25*]
Equity	0.05	0.82	-0.39*	.99*	49.11*	-1.46[-26.63*]
Oil	0.04	2.53	0.39	2.88	3.46	-1.93[-27.76*]
Production	0.00	0.00	0.29	0.20	42.72*	-1.29[-5.33*]
Temperature	2.46	3.16	0.89*	0.43*	329.32*	-11.13*[-40.17*]

Panel C: *Phase II*

Series	Mean	Variance	Skewness	Exc. Kurtosis	ARCH	PP Unit Root
EUA	-0.28	7.85	0.02*	2.33*	61.71*	.29[-14.52*]
Clean Dark Spread	-0.34	66.28	0.97*	23.41*	1.40	-1.87[-15.98*]
Clean Spark Spread	-0.23	48.60	1.05*	14.29*	0.91	-2.52[-18.63*]
Equity	-0.30	6.43	0.23	3.83*	49.11*	-0.62[-18.22*]
Oil	-0.17	10.77	1.66*	13.70*	1.67	-0.13[-19.53*]
Production	-0.05	0.00	-1.36*	9.55*	42.72*	3.43*[-3.92*]
Temperature	2.09	2.37	1.13*	1.53*	138.13*	-8.44***[-26.44*]

Panels A, B and C correspond to the sample periods examined in this study. Panel A spans the full sample period. Panel B spans part of *Phase I* of the European Union Emissions Trading System (July 1 2005 to December 31 2007) and panel C spans part of *Phase II* (January 2 2008 to March 2 2009) of that system. A constant of 30 is added to the Clean Spark Spread observations to facilitate logarithmic calculations. In column 5 the Lagrange Multiplier (LM) test results are reported for fifth order ARCH effects. In column 6 the Phillips-Perron (PP) unit root test statistics are reported. The test statistics for each of the series in logarithmic differences are reported in square brackets, while the test statistics with respect to levels are adjacent. A * indicate statistical significance at the 5% level.

Table 2: **Preliminary Investigation of Cointegration Equations**

Panel A: *Full Sample*

	CDS	CSS	Equity	Oil	Production	Temperature	DF T-Stat
European Union Allowances	-.001	-.04	.16	.81*	-.29	.01	2.44
	(.21)	(1.07)	(1.24)	(11.89)	(1.12)	(1.12)	

Panel B: *Phase I*

	CDS	CSS	Equity	Oil	Production	Temperature	DF T-Stat
European Union Allowances	-.04	.07	-.66*	1.04*	.92*	-.00	2.97
	(1.41)	(1.77)	(4.68)	(5.44)	(3.42)	(.96)	

Panel C: *Phase II*

	CDS	CSS	Equity	Oil	Production	Temperature	DF T-Stat
European Union Allowances	.38*	-.22	.63*	.74*	-1.27*	.01*	3.00
	(4.14)	(1.85)	(6.11)	(11.40)	(6.24)	(2.36)	

Panels A, B and C correspond to the sample periods examined in this study. Panel A spans the full sample period. Panel B spans part of *Phase I* of the European Union Emissions Trading System (July 1 2005 to December 31 2008) and panel C spans part of *Phase II* (January 2 2008 to March 2 2009) of that system. The results are Newey-West Linear regression coefficients and coefficient t-statistics in brackets. The Newey- West T-Statistics (far right hand side column) are reported regarding the null hypothesis of a unit root in the residual from the hypothesised Cointegration Equations. The critical values are sourced in MacKinnon (1991). A * indicate statistical significance at the 5% level.

Table 3: **Maximum Likelihood Cointegration Test and Hypothesis Testing**

Panel A: *Normalized Cointegration Vectors*

Full Sample						
	Oil	CSS	CDS	Production	Equity	Constant
Coeff.	-0.36*	-0.59*	0.23*	-10.22*	1.40*	35.52*
	(2.77)	(5.36)	(3.29)	(7.74)	(6.36)	(7.64)

Phase I						
	Oil	CSS	CDS	Production	Equity	Constant
Coeff.	0.28	-0.09	0.06	9.99	0.34	-50.65
	(0.23)	(0.21)	(.24)	(1.22)	(0.39)	(1.44)

Phase II						
	Oil	CSS	CDS	Production	Equity	Constant
Coeff.	-0.64*	1.35*	-1.30*	-2.12	0.02	9.42
	(3.76)	(3.38)	(4.06)	(1.03)	(0.05)	(1.42)

Panel B: *Hypotheses Tests*

Full Sample Period		*Phase I*		*Phase II*	
(i)		(i)		(i)	
Trace Test	113.11	Trace Test	104.22	Trace Test	468.72
P value	0.01	P value	0.05	P value	0.00
(ii)		(ii)		(ii)	
Test Statistic	6.94	Test Statistic	0.01	Test Statistic	0.08
P value	0.01	P value	0.91	P-Value	0.78
(iii)		(iii)		(iii)	
Test Statistic	16.30	Test Statistic	2.17	Test Statistic	7.45
P value	0.00	P value	0.14	P value	0.01
(iv)		(iv)		(iv)	
Test Statistic	17.29	Test Statistic	2.17	Test Statistic	7.47
P value	0.00	P value	0.34	P value	0.02

Panel A presents a distinct normalised cointegration equation, with associated t-statistics in brackets, for each sample period examined in this study. The full sample period extends from July 1 2005 through to March 2 2009. Part of *Phase I* of the European Union Emissions Trading System (July 1 2005 to December 31 2007) is examined and part of *Phase II* (January 2 2008 to March 2 2009) of that system is also examined. A * indicate statistical significance at the 5% level. The model specifications (deterministic components and lag length) are inferred with respect to the multivariate version of the Schwarz Bayesian information criterion. These results are not presented here. Panel B presents related hypotheses tests. The likelihood ratio Trace test statistic (i) indicates that there is at least a single cointegrating equation (CE) in each of the sample periods examined. The remaining hypotheses tests (ii), (iii) and (iv) assess the null hypotheses of a zero loading coefficient on the disequilibrium error in the EUA equation, a zero EUA coefficient in the distinct cointegration equation and a joint hypothesis test to assess these latter two null hypotheses, respectively.

Table 4: **Modified Multivariate Test for Cointegration**

Panel A: *Full Sample*						
				Critical Values		
	OLS Coeff.	GARCH Coeff.	t-statistic	10%	5%	1%
$\rho = 1$	0.22	0.13	6.64*	3.81	4.10	4.65
$\rho = 2$	0.18	0.14	3.57	3.45	3.75	4.29
Panel B: *Phase I*						
				Critical Values		
	OLS Coeff.	GARCH Coeff.	t-statistic	10%	5%	1%
$\rho = 1$	0.18	0.16	6.26*	3.81	4.10	4.65
$\rho = 2$	0.18	0.11	2.99	3.45	3.75	4.29
Panel C: *Phase II*						
				Critical Values		
	OLS Coeff.	GARCH Coeff.	t-statistic	10%	5%	1%
$\rho = 1$	0.26	0.15	4.58*	3.81	4.10	4.65
$\rho = 2$	0.26	0.22	5.50*	3.45	3.75	4.29

Panels A, B and C correspond to the sample periods examined in this study. The *Full Sample* period extends from July 1 2005 to March 2 2009. This study examines part of *Phase I* of the European Union Emissions Trading System (July 1 2005 to December 31 2007) and part of *Phase II* (January 2, 2008 to March 2, 2009) of that system. The Panels report coefficients for $\rho = 1, 2, 3$ which are the estimated square roots of the eigenvalues, while accounting for t-distributed GARCH effects, of the Johansen long-run information matrix. The coefficients are estimated by equation 10. See McKinnon (1991) for critical values. A * indicates statistical significance at the 5% level.