PRICING INTRADAY DYNAMICS ACROSS EUAS AND CERS MARKETS

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Abstract

The relative contribution of European Union Allowances (EUAs) and Certified Emission Reductions (CERs) to the price discovery of their common true value has been empirically studied using daily data with inconclusive results. In this paper, we study the short-run and long-run price dynamics between EUAs and CERs future contracts using intraday data. We report a bidirectional feedback causality relationship both in the short-run and in the long-run, with the EUA's market being the leader.

Key words: European Union Allowance, Certified Emission Reduction, cointegration tests, intraday analysis.

JEL Classification: G10.

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1. Introduction

The 2004/101/EC Directive of the European Parliament, known as the "Linking Directive", allows governments to use Kyoto certificates from the so-called project-based flexible mechanisms so as to cover their domestic greenhouse gas emissions. One of these mechanisms is the Clean Development Mechanism (CDM), through a CDM project; a developed country will implement an emissions reduction project in developing countries in order to generate credits known as Certified Emissions Reductions (CERs). Each CER represents a successful emission reduction of one tonne of carbon dioxide, which must be certified by the CDM Executive Board of the United Nations Framework Convention on Climate Change (UNFCCC).

Since 2008, CERs and EUAs are being traded in electronic markets. The possibility of having simultaneous prices in organized markets for both entitlements has encouraged the interest for analyzing the relative contribution of CERs and EUAs markets to the price discovery process in the energy and climate literature. In a cointegration setting, Mansanet-Bataller et al. (2011), for the period March 2007 to March 2009, and Chevalier (2010), for the period March 2007 to January 2010, find that EUA prices and CER prices have a significant causal influence on each other, but with EUA's future markets leading the price discovery. Quite the opposite, Nazifi (2010) concludes that EUAs and CERs do not have a common long-run component between May 2007 and September 2008. In the short-run, CER prices do not have a statistically significant effect on EUA prices, while EUA prices do drive CERs prices. Finally, for the period July 2007 to December 2008, Mizrach (2010) finds that the null of no common factors between the EUAs and CERs prices cannot be rejected, corroborating Nazifi's (2010) conclusion; he argues that the lack of cointegration is due to uncertainties about the eligibility and bankability of certain types of CER credits. In a nutshell, in spite of considering overlapping periods, the existing empirical evidence is inconclusive.

All previous studies have analyzed the relative role CERs and EUAs play in price discovery using exclusively daily data. Indeed, there are only a few empirical studies in the literature using intraday data about these markets.[1] Co-integration models capture "long-run" equilibrium relationships wherein prices can mutually diverge in the short-run but they readjust to persistent cointegrated patterns. As pointed out by Harris et al. (1995, p. 567), “we must guard against observation intervals so long that error correction takes place within rather than between [them]”. Accordingly, daily data may not detect error correction that takes place at higher trading frequencies.

In this paper, we use a unique database of intraday trading data from the most active future markets on EUAs and CERs to study the price discovery process.

[1] The following papers study CO_2 markets using intraday data. Benz et al. (2008) analyzes the liquidity of EUAs in ECX and Nord Pool platforms, for the period February 2005 - December 2007. Bredin et al. (2009) analyzes the market microstructure focusing on the interaction between trading volume and price volatility for the period April 2005 - May 2007. Conrad et al. (2010) models the dynamics of EUAs with data from November 2006 to December 2008. Mizrach and Otsubo (2010) analyzes the microstructure of the European Climate Exchange, both for EUAs and CERs, for data from the hole year 2009. Rittler (2009) models the relationship between Phase II EUA spot and futures prices, analyzing the causality in the first and second conditional moment, for the period from May 2008 to March 2009. Rotfuss (2009) analyzes the EUAs price formation and volatility for the period June 2005 to September 2008. Rotfuss et al. (2009) examines the prize formation in the EU ETS and proposes a model of expectation-formation. The data goes from April 2005 to September 2008. Finally Vinokur (2009) analyzes the impact of banking and submission constraints for both Phase I and II EUAs and CERs spot data, in Bluenext and for the period June 2005 - August 2009.

We find a bidirectional feedback causality relationship exists both in the short-run and in the long-run, with the EUA's market being the leader.

The reminder of this article is structured as follows: Section 2 focuses on the carbon market description, pointing out the offsets particularities, and shows the theoretical aspects which describe the relationship between EUAs and CERs. Section 3 describes the data and the methodology used in the study. Section 4 presents the empirical analysis and section 5 concludes.

2. Carbon market

2.1. European Union Emission Trading Scheme (EU ETS)

The EU ETS is the world's largest market in emissions allowances, each emission allowance being an entitlement to emit one tonne of carbon dioxide equivalent gas. EUAs are distributed by EU governments to the companies covered by the 2003/87/EC directive, a total of 11,500 energy-intensive installations across the EU, so as to limit the total amount of greenhouse emissions and thereby comply with their Kyoto emission targets. In the framework of the EU ETS it is possible to trade both EUAs and CERs as mechanisms of flexibility developed by the European Union in order to reach the reduction objective in the period 2008-2012.

It is important to emphasize some aspects of the EU ETS which have conditioned and will condition its development. Firstly, the EU ETS is constituted by different Phases, Phase I was a pilot/learning Phase which goes from 2005 to 2007, characterized by an excess of rights which inevitably produced a collapse in their prices leaving them near to zero. Phase II concords with the Kyoto Protocol accomplishment period and goes from 2008 to 2012. Phase III will contain the period 2013-2020. The importance of the Phases resides in the possibility of transferring EUAs between years in the same Phase. However, this possibility changes between Phases. Thus, banking was not allowed between Phase I and Phase II, but is accepted between Phase II and Phase III. Furthermore, borrowing is prohibited between Phases. [2]

2.2. Linking Directive and CERs

The 2004/101/EC Directive of the European Parliament permits the use of CERs to cover their domestic greenhouse gas emissions, in a certain percentage, in order to promote reductions of greenhouse gas emissions in a economically efficient manner. These CERs can be imported into the EU ETS for compliance purposes from project activities which have to be approved by one or more Annex I Parties in accordance with Article 12 of the Kyoto Protocol and the decisions adopted pursuant to the UNFCCC or the Kyoto Protocol, and are fully fungible with European Union Allowances (EUAs), with a limit which varies between countries. Following the Article 7 of the Linking Directive, each Member State will decide on this limit, having due regard to the relevant provisions of the Kyoto Protocol and the Marrakesh Accords, to meet the requirements therein that the use of the mechanisms should be supplemental to domestic action. Trotignon (2010) reports these percentage limits that vary between 0% and 20% depending on countries and sectors, being the average about 13.5% (1,420Mt for the period 2008-2012).[3] In addition and in accordance with the UNFCCC and the Kyoto Protocol, CERs generated from

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[2] Banking refers to the possibility of transfering entitlements from one year to the following one and borrowing to the possibility of using entitlements from the following year in the present one.

[3] The Kyoto Protocol allows all the countries to bank CERs from Phase II to Phase III up to a maximum of 2.5% of a country's assigned amount, but not borrowing. Additionally, any unused portion of their Phase II limits may be used in Phase III. The banking and borrowing within the years of the Phase II, are permitted until the respective country limits being reached, however, both of them are prohibited in Hungary, Latvia, and Lithuania, representing 7% of the potential CERs imports. Furthermore, the borrowing is prohibited in Italy, Norway, Poland, Spain and United Kingdom, and represents 37% of the potential CERs imports. See Trotignon (2010) for further details.

nuclear facilities can't be used for their commitments, as well as the totally from land use, land use change and forestry activities.

Theoretically speaking, the substitutability between EUAs and CERs should lead to the fulfilment of the Law of One Price, which establishes that assets that have the same expected future payoff should have the same price today. However, since CERs began to trade in 2008, EUAs have been quoted above CERs, both in spot and futures markets. Specifically, the difference between the future prices of EUAs and CERs with the same maturity date at any time *t* can be written as

$$EUA_t(T,T') = CER_t(T,T') + SPREAD_t(T,T') \quad t \leq T \leq T' \qquad [1]$$

where $EUA_t(T,T')$ and $CER_t(T,T')$ are the prices of an EUA futures contract and a CER futures contract, respectively, with maturity at *T* and corresponding to the same market Phase ending at *T'*. $SPREAD_t(T,T')$ is the difference between both prices.[4]

Following Mansanet-Bataller et al. (2011), there are two main factors that may explain the positive observed spread: (i) market agents need to be able to buy CERs on the market and exchange them with actual EUAs from their own

[4] Technically any divergence in prices between EUAs and CERs that compensates for transaction costs, such as bid-ask spreads and fees, should be immediately exploited in the futures market by installations that have EUAs, by selling EUAs and buying CERs until its limit of CERs that can be surrendered is reached. Trotignon (2010) shows that, in 2008 and 2009, polluters have not surrendered as many CERs as they could have, meaning that either they are not taking profit from the lower price of CERs relative to EUAs or they are keeping the limit of CERs for future accomplishments.

registry in order to benefit fully from the arbitrage operation; and (ii), the limits established for countries and sectors concerning the use of CERs towards compliance within the European trading system.

This implies that the arbitrage opportunity of buying CERs and selling EUAs is limited in quantity and through time and it will be highly conditioned by uncertainties about the future demand and supply of both EUAs and CERs. On one hand, the recent international economic crisis has augmented the doubts among participants in the carbon market about the possible less final amount of EUAs that large emitters will need to cover their emissions in Phase II. On the other hand, the lack of a plain regulatory regime for CERs post 2012, and the likely exclusion or restriction in Phase III of CERs generated by certain type of projects, generate uncertainty about the future supply of CERs.[5] By supplying an extra quantity of CERs, the demand for EUAs would decrease and, consequently the EUA prices would also decrease. This is the reason why some carbon traders point out CERs as the main reason for weakening EUA prices. However, other traders think that a possible declining demand from EUAs, due to the crisis, and the consequent EUA price falling would lead to a decrease in CERs prices. The purpose of this research is to study the relative contribution of each market to the price discovery process.

[5] From 2013 on, the use of CERs from projects involving trifluoromethane (HFC-23) and nitrous oxide (N_2O) from adipic acid production will be limited because of the exceptionally high rates of chlorodifluoromethane (HCFC-22) derived from the destruction of HFC-23. Since these projects represent about 50% of the total supply of CERs, the effect over the total supply may be dramatic. For more details, see (http://ec.europa.eu/clima/news/news_2010_11_en.htm).

3. Data and Methodology

There exist several European electronic trading platforms that handle EUAs and CERs transactions. Among all of them, the ECX market is by far the most active, concentrating nearly the totality of the futures market volume. It is important to highlight the increasing liquidity reached in the ECX market fostered by the important number of potential users such as the companies covered by the Directive 2003/87/CE, external agents and market makers that operate in the ECX futures market. Figure I presents the liquidity development for ECX futures market data based in the definition of illiquidity presented in Amihud (2002) and defined as the daily ratio of absolute returns divided by its volume in Euros. It is important to highlight that the illiquidity has decreased sharply over the time in all the futures contracts.

[Please insert Figure I]

Specifically, the database consists on trade data from ECX futures market in London. For every trade, the database reports the time stamp measured in GMT, the traded price in Euros, the maturity of the contract, the traded volume, the sign of the transaction and the trade type. We analyze the case of futures contracts with maturity in December of each year (from 2008 to 2010) because they concentrate almost all the trading activity in the ECX derivative markets. Table I reports the most interesting facts derived from these contracts.

[Please insert Table I]

As table I shows, EUAs data is available since April 2005, however, CERs data is only available since March 2008, when CERs began to trade in screen in the ECX futures market. Thus, we discard the data prior to March 2008 to perform our price-discovery analysis. Another important feature is that the median price of the EUAs futures contract is higher than the median price of the CERs futures contract in all cases. This difference, however, has diminished over time from 5.6€ to 2.2€ per tonne. Regarding trading frequency, the EUA futures contracts are traded in average every 2 minutes, while in the CER futures market there is only one trade every fifteen minutes, in average. Because of this difference in trading frequency, our study about price discovery is implemented using intervals of fifteen-minute length.[6] We construct our database taking the last available price as the observation for the end of each interval. Overnight returns are excluded from the analysis.

Figure II presents the time-series of prices for 2008, 2009 and 2010 EUAs and CERs futures contracts in two different time resolutions: prices every fifteen minutes and daily closing prices. Notice that while the settlement price plots show the previously reported persistent positive spread between EUAs and CERs prices, the intraday data reveals that EUAs and CERs prices converge in specific moments along the trading session in the three maturities. These crossings in transactions prices are due to over the counter contracts that can be bring into the futures market at any time during trading hours.

[6] Regarding spot markets, there is one trade, in average, every 15 minutes in the ECX EUA spot market while in the ECX CER spot market there is on trade every 176 minutes on average. Because of the low trading frequency in CER spot market, we concentrate on derivative markets.

[Please insert Figure II]

In order to study the short-run and long-run dynamics between EUAs and CERs futures prices, we use a traditional co-integration approach. Firstly, we test for the existence of unit roots in the time series or prices using the Kwiatkowski et al. (1992)[7] test. Secondly, we test for co-integration using the very-well known methodology proposed by Johansen (1988, 1990, and 1992). Finally, if co-integration is accepted, we estimate a Vector Error Correction Model (VECM), the most common efficient parameterization of a vector of co-integrated variables (see Engle and Granger, 1987). The standard error-correction representation of the EUAs and CERs prices is:

$$\begin{aligned} \Delta EUA_t &= \alpha^{EUA} + \delta_{EUA} Z_{t-1} + \sum_{i=1}^{k} \beta_i^{EUA} \Delta EUA_{t-i} + \sum_{i=1}^{k} \gamma_i^{EUA} \Delta CER_{t-i} + \varepsilon_t^{EUA} \\ \Delta CER_t &= \alpha^{CER} + \delta_{CER} Z_{t-1} + \sum_{i=1}^{k} \beta_i^{CER} \Delta EUA_{t-i} + \sum_{i=1}^{k} \gamma_i^{CER} \Delta CER_{t-i} + \varepsilon_t^{CER} \end{aligned} \qquad [2]$$

This model allows capturing both the short-run and long-run causality between prices. Long-run causality is captured by the error correction term; where Z_{t-1} is the normalized error-correction term that captures deviations from the long-run equilibrium relationship. The parameter α^j term is the response of the market j to a divergence from the other market's prices. If both δ_{EUA} and δ_{CER} were statistically significant, we would be facing a two-way price discovery process (see Harris et al., 1995). Everything else equal, if the deviation from the

[7] Given that standard unit root tests fail to reject the null hypothesis of a unit root, Kwiatkowski et al. (1992) provides a straightforward test of the null hypothesis of stationarity against the alternative of a unit root.

equilibrium turns to be positive ($Z_{t-1}>0$), the CER prices would be expected to rise ($\delta_{CER} > 0$) and the EUA price would tend to fall ($\delta_{EUA} < 0$). Model [2] indicates that EUAs and CERs returns change not only in response to deviations form the long run equilibrium, but also in response to previous changes in returns and to stochastic shocks.

Finally, in order to test long-run and short-run relationships among the time series, restrictions on the cointegration vectors, the adjustment coefficients and the short-run coefficients in VECM have been imposed to determine if the variables are statistically significant.

4. Empirical results

Table II summarizes the unit root tests on the six time-series of EUAs and CERs prices in logs. The null hypothesis of the Kwiatkowski et al. (1992) test is that the time series is stationary. We shorten the sample period of each EUAs futures contract so that it overlaps the sample period of each CERs futures contract. Table II shows that, in all cases, the hypothesis of level and trend stationarity is rejected at the 1% level. When the first difference of the time-series of prices is considered, however, the null cannot be rejected at the 1% level of statistical significance. Therefore, we conclude that all the time series of EUAs and CERs prices are integrated of order one, or I(1), time series.

[Please insert Table II]

Next, we study the existence of a long-run or co-integration equilibrium relationship between EUAs and CERs futures prices following Johansen (1988, 1992) methodology. We estimate three bi-variate Vector Autoregressive (VAR) models for the EUAs and CERs futures prices, one for each maturity, 2008, 2009 and 2010. The models incorporate intercept and time trend in data and the appropriate lag length has been chosen following the Schwarz Information Criterion. The optimal number of lags is 5 for the 2008 VAR, 2 lags for the 2009 VAR, and 1 lag for 2010 VAR. The likelihood ratio test procedure proposed by Johansen (1988) is applied to test for co-integration. The results of our co-integration analysis are summarized in Table III. In general, the null hypothesis of no co-integration is rejected in all cases. Both the trace statistic and the maximum eigenvalue test suggest that there is at least one co-integration vector.

[Please insert Table III]

Panel A of Table IV reports the maximum likelihood ratio tests on the statistical significance of the variables in the estimated co-integration vectors (see Johansen, 1992, for details). We find that both EUAs and CERS futures prices enter in a statistically significant way into the co-integration vectors for all maturities. Therefore, in contrast with the daily data analyses of Nafizi (2010) and Mizrach (2010), we do find a significant long-run equilibrium relationship between EUAs and CERs futures prices.

[Please insert Table IV]

In Panel B of Table IV we report the results of testing the null that a deterministic time trend does not enter into the co-integration vector. The presence of deterministic components in the co-integration vector would suggest that the progressive convergence in EUAs and CERs futures prices discussed earlier has an effect on their long-run equilibrium relationship. We find that the null of no deterministic trend is rejected at the 1% level of statistical significance in all cases. Therefore, we confirm the steady approximation of both prices through time.

Confirmed the existence of a long-run equilibrium relationship between EUAs and CERs futures prices, we proceed to estimate the Vector Error Correction Model (VECM) in equation [2] for each maturity. Furthermore, as discussed earlier in section 3, Gonzalo and Granger (1995) shows that under the assumption that the underlying efficient price is an exact linear combination of the observable prices, and it is not Granger-caused by the transitory components, the contribution of each market to the discovery of the efficient price is given by the vector of factor weights, which is orthogonal to the long-run adjustment coefficients vector (δ_{EUA}, δ_{CER}),

$$\omega_{EUA} = \frac{\delta^{CER}}{\delta^{CER} - \delta^{EUA}} \quad \text{and} \quad \omega_{CER} = \frac{-\delta^{EUA}}{\delta^{CER} - \delta^{EUA}} \qquad [3]$$

Table V includes the estimated parameters of the VECM model (Panel A) and the contributions to price discovery according to Gonzalo and Granger (1995) (Panel B). Firstly, the error-correction adjustment coefficients δ_{EUA} and δ_{CER} are both statistically significant and with the expected signs. In absolute terms, the coefficients that accompany the ECT in the CER equations are bigger than those in the EUA equation, indicating that CER futures market is more sensible that the EUA futures markets. Secondly, according to Gonzalo and Granger (1995), the weight for the EUAs future market in price discovery is slightly superior to that of CER market, indicating that the price discovery process in the long-run is mainly conducted by the EUA market in the three equations. We can therefore conclude that EUAs lead clearly the market with a notable influence of CERs.

[Please insert Table V]

Regarding the short-run dynamics, Table V reveals that EUAs returns and CERs returns depend negatively on their own lagged values, while they depend positively on lagged returns of the other market. We have also performed short-run causality tests. Specifically, for each equation in the VECM, we have tested whether the lagged coefficients of the other endogenous variable are jointly statistically different from zero. Table VI presents the results of the tests. The null hypothesis of joint significance cannot be rejected at the 1% level in the 2008 futures contract, indicating that EUAs and CERs prices, in spite of sharing a common trend in the long-run, do not cause each other in the short-run. The picture changes in the 2009 case. Although the null hypothesis cannot be rejected for the EUAs futures market, it is rejected for the CER market, showing a predominant role of the EUAs market over the CERs market in the short-run. Finally, in the 2010 case, we find evidence of bi-directional short-run causality. We can therefore conclude that the level of short-run integration of EUAs and CERs markets has increased through time.

[Please insert Table VI]

5. Conclusions

EUA and CER assets are traded in informationally linked electronic markets which share the same market microstructure (e.g. timetable, trading rules, settlement prices, etc.). In this paper, we extend previous literature on the EUA-CER linkage by using, for the first time, intraday data. Firstly, we show that there is a long-run equilibrium relationship between EUAs and CERs futures prices. Secondly, we obtain that the EUAs market leads price discovery, although the role of CERs markets is also highly important. Thirdly, we show that the progressive convergence in EUAs and CERs futures prices through time affects the long-run equilibrium relationship between both markets. Finally, regarding the short-run dynamics between both markets, we find a transition from the absence of bidirectional causality in the 2008 futures contract to a clearly bidirectional feedback causality in the 2010 futures contract.

The overall results indicate that both markets play an important role in price discovery. Despite its low relative share in the total trading activity in the carbon market, CERs contribution to discovery of the common efficient price is almost as important as the EUAs contribution. This finding together with the fact that the spread between EUAs and CERs prices has decreased over time, suggests that the policy uncertainties about CERs are disappearing.

Table I. Data facts

The first and second lines present the data series. Third line indicates the number of transactions for each series. Forth to eighth lines present price facts such as the price mean, standard deviation, maximum, median and minimum prices. Ninth to twelfth lines show several volume facts such as the total and the average volume in lots (1 lot stands for 1,000 CO2 EU allowances), and the maximum and minimum volume in a transaction. Thirteenth and fourteenth lines indicate the time stamp of first and last transaction. Fifteenth and sixteenth lines present the first and last trading days for each contract. Seventeenth line shows the total number of trading days. Eighteenth and nineteenth lines point out the average number of transactions per day and per minute, respectively. The later is calculated as the total number of transactions divided by the total trading days and minutes, respectively. Twelfth line shows the average minutes between transactions, excluding non-trading time. Finally Twenty-firth and twenty-secondth lines present the total number of price changes and it average per day, respectively.

Contract		**EUA Futures**			**CER Futures**	
Maturity	**December 2008**	**December 2009**	**December 2010**	**December 2008**	**December 2009**	**December 2010**
Number of transactions	238,647	312,130	330,390	8,253	19,107	26,509
Price mean	21.93	13.85	14.61	18.55	13.06	12.99
Price std. deviation	3.38	2.77	1.61	2.46	3.00	2.23
Maximum price	33.70	32.50	32.22	26.80	26.20	25.25
Median price	22.25	13.73	14.70	19.20	12.45	12.49
Minimum price	10.75	7.70	8.25	12.65	7.15	7.35
Volume (in lots)	2,188,980	3,057,609	3,598,073	162,478	469,491	578,943
Average volume per transaction (in lots)	9.17	9.80	10.89	19.69	24.57	21.84
Maximum volume (in lots)	4,000	4,000	3,000	2,000	4,500	1,825
Minimum volume (in lots)	1	1	1	1	1	1
First transaction	17/06/2005 16:04	12/10/2005 13:20	26/01/2006 17:05	14/03/2008 07:00	14/03/2008 13:37	14/03/2008 13:37
Last transaction	15/12/2008 16:41	14/12/2009 17:17	20/12/2010 16:59	15/12/2008 16:59	14/12/2009 16:56	30/09/2010 15:57
First trading day	22/04/2005	22/04/2005	22/04/2005	14/03/2008	14/03/2008	14/03/2008
Last trading day	15/12/2008	14/12/2009	20/12/2010	15/12/2008	14/12/2009	20/12/2010
Number of trading days	934	1,188	1,447	194	448	707
Transactions per day	255.51	262.73	228.32	42.54	42.64	37.49
Transaction per minute	0.43	0.45	0.38	0.07	0.07	0.06
Average minutes between transactions (ex overnight)	2.30	2.25	2.59	14.10	14.04	15.96
Number of price changes	134,265	135,350	133,535	8,060	18,664	22,109
Number of price changes per day	143.75	113.93	92.28	41.55	41.66	31.27

Table II. Unit root test

KPSS stationarity test used both in levels and in first differences: First, the test with time trend and intercept in the model (a) has been carried out and, in case the time trend is not significant, we proceed to estimate the model only with intercept (b). The critical values at the 1% level are, for the model with intercept and time trend 0.216, and for the model only with intercept 0.739. (Kwiatkowski et al.,1992, Table 1, p. 166).

	Level	Model	Differences	Model
2008 EUA Futures Contract	2.2635	(a)	0.1095*	(b)
2009 EUA Futures Contract	2.6734	(a)	0.1055*	(b)
2010 EUA Futures Contract	3.6481	(a)	0.1208*	(b)
2008 CER Futures Contract	2.5598	(a)	0.5041*	(b)
2009 CER Futures Contract	2.2049	(a)	0.1610*	(b)
2010 CER Futures Contract	2.8002	(a)	0.0571*	(b)

*Indicates that the null of stationarity cannot be rejected at the 1% level.

Table III. Cointegration tests

The trace statistic tests the null hypothesis (H_0) that there are r cointegration vectors, against the alternative hypothesis (H_1) that exist, at least, r+1 cointegration vectors, where r goes from 0 to 1. The maximum eigenvalues tests the null hypothesis (H_0) that there are, as maximum, r cointegration vectors, against the alternative hypothesis (H_1) that exist, as maximum, r+1 cointegration vectors, where r goes from 0 to 1. The models incorporate intercept and time trend in data and has been chosen following the Schwarz Information Criterion. The optimum number of lags has been 5 for the model in Panel A, 2 for the model in Panel B, and 1 for the model in Panel C. The critical values are based on the response surface coefficients from MacKinnon et al. (1999).

Panel A	**EUA and CER 2008 Futures Contract**		
H_0	H_1	Trace	λ Max
r = 0	r > 0	41.5518*	37.1968*
r ≤ 1	r > 1	4.3550	4.3550
Panel B	**EUA and CER 2009 Futures Contract**		
H_0	H_1	Trace	λ Max
r = 0	r > 0	195.5907*	191.6219*
r ≤ 1	r > 1	3.9688	3.9688
Panel C	**EUA and CER 2010 Futures Contract**		
H_0	H_1	Trace	λ Max
r = 0	r > 0	198.5527*	193.3681*
r ≤ 1	r > 1	5.1847	5.1847

*Indicates rejection at 1% level.

Table IV. Restrictions on the cointegration vector

Panel A presents the long-run tests for the hypothesis that *j* variable does not enter in any cointegration vector (H_0: B(i,j) =0), where B(i,j) is the cointegration coefficient where *i* is the bivariate system (2008, 2009 and 2010 EUA and CER futures contracts) and *j* is the variable number in the cointegrating equation (j=EUA, CER). The reported statistics are distributed as a χ^2 random variable with 1 degree of freedom. Panel B presents the long-run tests for the hypothesis that *TREND* variable does not enter in any cointegration vector.

Panel A	**EUA and CER 2008**		**EUA and CER 2009**		**EUA and CER 2010**	
Variable	χ^2	p-value	χ^2	p-value	χ^2	p-value
EUA_{t-1}	32.21156	0.000000	174.4765	0.000000	181.1691	0.000000
CER_{t-1}	31.01296	0.000000	186.3839	0.000000	183.6680	0.000000

Panel B	**EUA and CER 2008**		**EUA and CER 2009**		**EUA and CER 2010**	
Variable	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Trend	4.00E-05	3.2E-06	1.36E-05	1.2E-06	4.16E-06	7.4E-07

Table V. Vector error correction model

Panel A shows the adjustment and short-run estimated coefficients for the estimated VEC Model based on Schwarz Information Criterion. ECT_{t-1} stands for the error correction term of the cointegrating equation. * indicates rejection of the null hypothesis of zero coefficient at the 1% level. Panel B presents the weights ω_j (j=EUA, CER) with which each market enter the common long memory component defined by Gonzalo and Granger (1995).

Panel A	**EUA and CER 2008**		**EUA and CER 2009**		**EUA and CER 2010**	
Variable	ΔEUA	ΔCER	ΔEUA	ΔCER	ΔEUA	ΔCER
C	-0.000087	-0.000039	-0.000006	-0.000023	-0.000049	-0.000023
ECT_{t-1}	-0.015435*	0.016243*	-0.009787*	0.021305*	-0.007108*	0.007944*
ΔEUA_{t-1}	-0.737684*	0.014100	-0.459157*	-0.016248	-0.236353*	0.022459*
ΔEUA_{t-2}	-0.543076*	0.032642	-0.257012*	0.025499*	-	-
ΔEUA_{t-3}	-0.413451*	0.026375	-	-	-	-
ΔEUA_{t-4}	-0.303392*	0.018613	-	-	-	-
ΔEUA_{t-5}	-0.114401*	0.014813	-	-	-	-
ΔCER_{t-1}	0.029095	-0.340992*	0.001735	-0.283514*	0.059448*	-0.120322*
ΔCER_{t-2}	0.038430	-0.219308*	0.011421	-0.160581*	-	-
ΔCER_{t-3}	0.024300	-0.187014*	-	-	-	-
ΔCER_{t-4}	0.004275	-0.148894*	-	-	-	-
ΔCER_{t-5}	-0.014816	-0.134791*	-	-	-	-

Panel B	ΔEUA	ΔCER	ΔEUA	ΔCER	ΔEUA	ΔCER
ω_j	0.51275333	0.48724667	0.6852245	0.314775505	0.5277704	0.472229604

Table VI. Short-run causality test

For each equation in the VEC the output displays χ^2 statistics for the joint significance of each of the other lagged endogenous variables in that equation. *k* indicates the number of lags included in the VEC model.

		Endogenous variables					
		2008 Future Contracts		2009 Future Contracts		2010 Future Contracts	
		ΔEUA_t	ΔCER_t	ΔEUA_t	ΔCER_t	ΔEUA_t	ΔCER_t
$H_0: \beta_1 = \ldots = \beta_k = 0$	X^2		6.5820		19.7714		23.5948
	p-value		0.2536		0.0001		0.0000
$H_0: \gamma_1 = \ldots = \gamma_k = 0$	X^2	10.7552		2.7351		58.1116	
	p-value	0.0565		0.2547		0.0000	
	K	5	5	2	2	1	1

Figure I. Illiquidity

From left to right the upper division exhibits the figures for the daily illiquidity approach proposed in Amihud (2002), for 2008, 2009 and 2010 EUAs futures contracts. Similarly, the figures in the bottom division show the figures for the daily illiquidity approach for 2008, 2009 and 2010 CERs futures contracts.

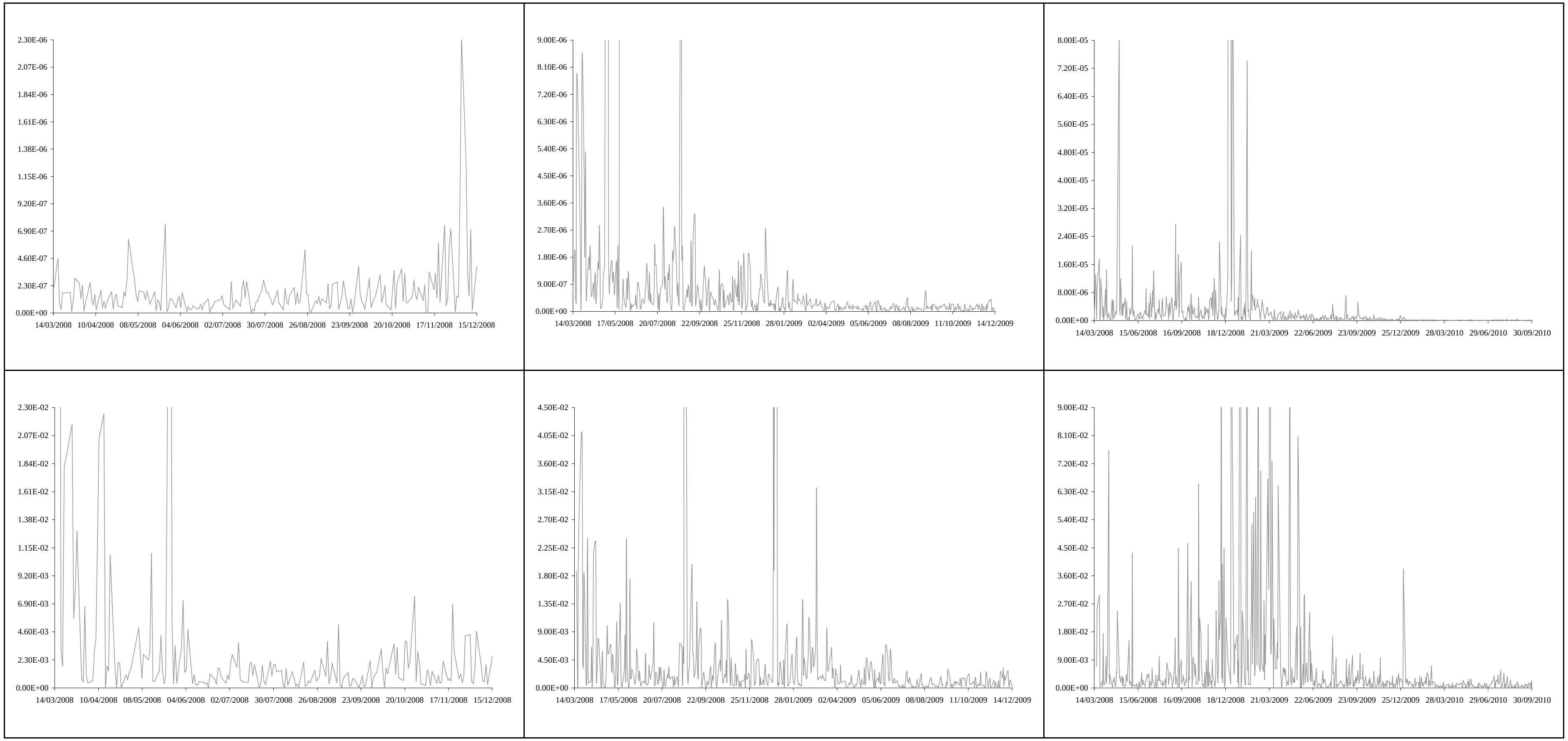
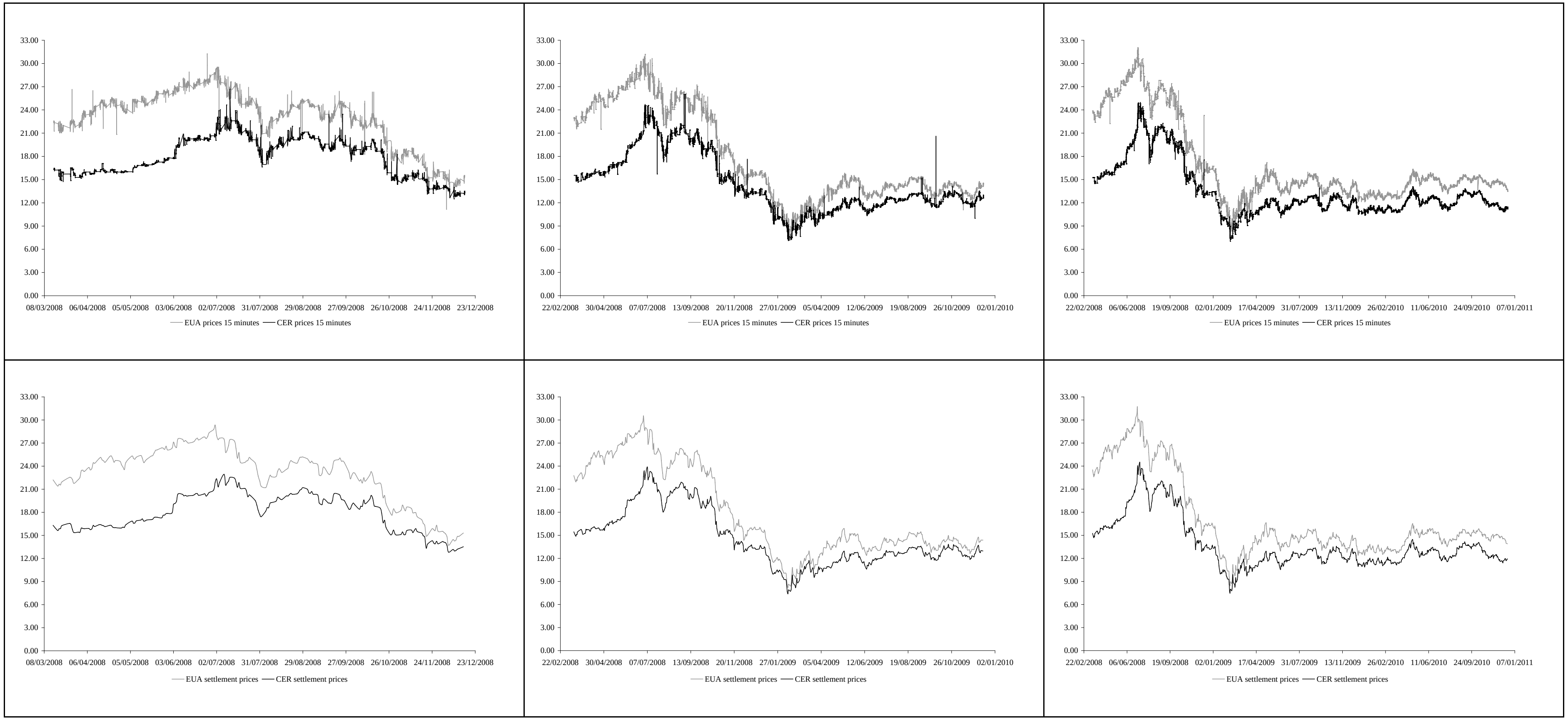


Figure II. Evolution of intraday prices

From left to right the upper division exhibits the figures for the historical intraday prices of the last transaction occurred in intervals of fifteen minutes for 2008, 2009 and 2010 EUAs and CERs futures contracts. Similarly, the figures in the bottom division show the historical daily settlement prices for 2008, 2009 and 2010 EUAs and CERs futures contracts. 2008 EUA and CER futures contracts refers to the futures contracts maturing in December 15, 2008; 2009 EUA and CER Futures Contracts refers to the futures contracts maturing in December 14, 2009; and 2010 EUA and CER Futures Contracts refers to the futures contracts maturing in December 20, 2010.



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