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Flexibility in the Market for International Carbon Credits and Price Dynamics Difference with European Allowances

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Abstract

The Paris Agreement establishes a mechanism to allow a Party to benefit from greenhouse gases emissions reductions conducted in a host Party to fulfil its nationally determined contribution. In this context, the objective of this paper is to improve the understanding of carbon offsets price dynamics, in comparison with regular carbon markets allowances. We combine a cointegration approach with risk premium considerations to compare the price dynamics of European Union Allowances (EUA) and Certified Emission Reductions (CER) in the second phase of the European carbon market. By taking account of breaks identified in the series, we find that, while the EUA and CER returns present comparable dynamics, the long-term relationships between the price of these two types of permits and their drivers differ significantly. Given the impact of energy prices (positive for coal and negative for gas) on the CER price, we suggest the existence of a supply-side effect for credits. We find that the price elasticity of allowances with regard to the coal and gas prices is negative in time periods of low economic activity and positive in the rest of the time. We explain the latter by the fact that the market is not tight and the former by the effect of the economic activity on the price of commodities and energy.

Keywords:

European allowances; international credits; emissions trading; power sector; structural breaks; time series analysis.

1 Introduction

The Paris Agreement reached at the 21^{st} Conference of the Parties (COP21) within the United Nations Framework Convention on Climate Change (UNFCCC) establishes a mechanism that aims to contribute to emissions reductions in host Parties and that would allow other Parties to benefit from these reductions to fulfil their nationally determined contribution (Article 6 of the Paris Agreement; UNFCCC, 2016). While there is still a lot of uncertainty on the exact institutional form such a mechanism would take,[1] this suggests that some kind of offsetting mechanism will exist under this new

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[1] It is unclear whether this mechanism will be comparable to currently existing offset mechanisms, extended to a sector level like those suggested by the International Energy Agency (IEA, 2009) and analyzed by Hamdi-Cherif et al.

Agreement.

This happens in a context of development of carbon markets around the world and existing offset mechanisms initiated under the Kyoto Protocol. Besides the European Union Emission Trading Scheme (EU ETS), which is the largest carbon market to date, national or sub-national systems operate in China, Japan, New Zealand, Switzerland, and the United States, and are being developed in Canada and South Korea. Under the Clean Development Mechanism (CDM), Certified Emission Reduction (CER) credits issued for approved projects in developing countries can be used by industrialized countries to meet their emission reduction target under the Kyoto Protocol (UNFCCC, 1998). Under the Joint Implementation, Emission Reduction Units (ERU) from projects in Annex B countries[2] can be used by other Annex B countries to meet their targets. Carbon markets such as the EU ETS have been extensively analyzed, but offset mechanisms have been paid less attention.

The objective of the paper is to improve the understanding of carbon offsets price dynamics, in comparison with regular carbon markets. We take advantage of the coexistence of th European carbon market and the Clean Development Mechanism established under the Kyoto Protocol to examine this question on the case of European Union Allowances (EUA) and CER. While EUA are either freely allocated to installations or bought on auctions, CER are issued by the CDM board for projects undertaken in developing countries.[3] The total amount of EUA available in the market is function of the European cap and they can only be used for compliance in the EU ETS.[4] On the contrary, there is no worldwide limit on the amount of credits issued annually. They can be used for compliance in several carbon markets in the world but the EU ETS is the largest one to accept them, under a certain limit.[5]

Installations covered by the EU ETS have to use permits to cover their emissions. At the microeonomic level, each of these installations takes the carbon price as exogenous and makes an abatement decision as a function of it. This leads to the equalization between the marginal abatement cost and the carbon price (Rubin, 1996, and Schennach, 2000). The demand for permits by installations that have to cover

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(2011) or Gavard et al.(2011 and 2016), or of another new form.

[2] Countries included in Annex B to the Kyoto Protocol for the first commitment period were Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, the European Union, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, the United Kingdom of Great Britain and Northern Ireland, and the United States of America. Canada withdrew from the Kyoto Protocol in December 2012 and the United States never ratified the Protocol.

[3] A good description of the process through which CER are issued is provided by Lecocq and Ambrosi (2007) and Trotignon and Leguet (2009).

[4] For a comprehensive review of the functioning of the European carbon market, we refer to Ellerman et al. (2016).

[5] The limit of CER and ERU accepted for compliance in the European market in Phase II was 13% of the amount of EUA defined by the European cap.

emissions depends on the general economic activity as well as on the production structure. For example, in the power sector, the demand for permits depends on the switching possibilities between the various technologies available for electricity production. Under the assumption that the power sector is the main source of demand for European allowances, this is used by Hinterman (2010) to develop a model that explains the carbon price fundamental economic drivers. He examines the carbon price short-term variations in the first phase of the EU ETS and shows that, besides the influence of the general economic activity, carbon price variability is well explained by the coal and gas prices variations due to the switching opportunities between coal and gas in the power sector, which are the main short-term abatement opportunities.

Several authors have examined how the carbon price and its market fundamentals are jointly determined. For example, Creti et al. (2012) study long-term cointegration relationships between the carbon price, the oil price, an equity price index and the switching price between gas and coal in Phases I and II of the EU ETS. They find long-term equilibrium relationships in both phases. Peri and Baldi (2011) examine non-linearities in the long-term relationship between the carbon price and the spot brent price. Chevallier (2011a) finds evidence of non-linearities in the long-term relationship between the EUA price and the European industrial production. Lutz et al. (2013) examine non-linearity in the short-term relationship between the EUA price and its fundamentals (energy prices and economic activity).

In addition, carbon permits and derivatives are traded on financial markets (e.g. the European Energy Exchange, International Carbon Exchange) and exhibit characteristics of financial assets. This led Paolella and Taschini (2008) to examine how autoregressive models could explain EUA returns, and in particular heteroscedasticity in the series. Chevallier (2009) indicates that carbon derivates validate the Samuelson hypothesis. As he analyzes the relationship between European carbon futures and macroeconomic risk factors related to bond and stock markets, he points out that the futures prices volatilities increase as the futures contracts approach their expiration. EUA returns exhibit patterns of volatility clustering and fat tails, as studied for example by Medina and Pardo (2012), Benz and Trück (2009), Daskalakis et al.(2005). The EUA volatility has been particularly examined by Conrad et al. (2012), Chevallier (2011b), Feng et al. (2011).[6]

Offsets price dynamics have been given less attention. Trotignon (2012) analyses the use of CER in

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[6] We only report here a sample of the existing literature that is of particular relevance for the analysis that follows but, for a comprehensive review of the analyses of price behaviors in the European carbon market, we refer to Hintermann et al. (2016).

the first two years they were accepted in the EU ETS. In terms of time series, many of the studies have focused on the analysis of the spread between the EUA and CER prices. This is for example the case of Mansanet-Bataller et al. (2011) or Nazifi (2013).

Our analysis aims at deepening the understanding of the price dynamics of international offsets, in comparison with regular carbon markets. It builds on the literature presented above (on fundamental economic drivers, cointegration, non-linearities and financial aspects). The originality of our work is that we combine a cointegration approach, including breaks identified in the series, with risk remuneration considerations for application to both EUA and CER prices. This allows including the fundamental economic drivers of the carbon price associated with the demand for quotas by installations covered by the EU ETS (gas price, coal price and economic activity) and risk-return features related to the financial nature of carbon permits. Such an approach takes account of the long-term equilibrium relationship driving the carbon price and the corresponding adjustments in the short-term, which are not captured in analyses that focus on day-to-day variations only: by taking account of breaks in the series, long-term cointegration relationships and corresponding short-term adjustments, our analysis complements the work done by Lutz et al. (2013) on EUA. For the same reasons, it also extends and complements the examination of the price drivers of EUA and CER by Mansanet-Bataller et al. (2011).

Our central contribution is that, by identifying breaks in the series and taking them into account in the cointegration relationships, we find that, while the EUA and CER returns present comparable dynamics, the long-term estimations between the price of these two types of permits and their drivers differ significantly. Given the impacts of energy prices (positive for coal and negative for gas) on the CER price, we suggest the existence of a supply-side effect for credits. For the EUA, we find that price elasticities with regards to the coal or gas prices are positive in time periods of normal or high economic activity, but negative otherwise. We provide an explanation for this. We find that the link between the EUA price and the economic activity is tighter than with the CER price.

The paper is structured as follows. Section 2 and 3 respectively present the materials and methodology used. Section 4 shows the results and section 5 concludes.

2 Materials

We use CER and EUA time series from the Phase II of the EU ETS. Given the fact that the volume of EUA and CER futures contracts is dominant over the volume of spot contracts, we use futures price series. They are constructed by rolling over futures contracts after their expiration date. The source for EUA and CER price series is the Intercontinental Exchange (ICE) database. We use data from February 26^{th}, 2008 to November 12^{th}, 2012 for EUA and data from March 14^{th} 2008 to November 12^{th} 2012 for CER. Natural gas and coal prices[7] are also taken from the ICE. We use month-ahead contracts price series. Exchange rates from the European Central Bank are used to convert the natural gas price from £ to € and the coal price from $ to €. The Euro Stoxx 50 index is used to represent the economic activity.[8]

Table 1 presents the summary statistics of the daily variations of the logarithmic price series.

Table 1: Descriptive statistics.

Variable	Nb. of Obs.	Mean	St. Dev.	Min.	Max.
EUA	1195	-0.00075	0.024	-0.093	0.193
CER	1182	-0.00234	0.031	-0.179	0.195
Gas	1195	0.0001495	0.03297	-0.1220	0.3600
Coal	1195	-0.0002768	0.02031	-0.2248	0.1631
Eurex	1195	-0.0003692	0.01823	-0.08208	0.1044

Note: Descriptive statistics of the daily variations of the logarithmic price series.

The observation of EUA and CER futures price series, displayed in Figure 1, [9] suggests the existence of breaks.[10] Following Kirat and Ahamada (2011), we use the Clemente Montanès and Reyes test, unit root test which allows detecting both mean and trend breaks, with endogenous break dates. The results of the two test procedures (the additive and the innovational outlier procedures, respectively AO and IO) are summarized in Table 2.[11]

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[7] The coal price we use is the API2 CIF (Cost, Insurance, Freight) with delivery in ARA (Amsterdam, Rotterdam and Antwerp).

[8] There are several reasons for the use of this proxy. First, daily data are available while industrial production is only reported monthly. Daily data on the aggregate European electricity production or consumption are hard to find. National level data that are available present some seasonality and do not well reflect the changes in the economic activity. Finally, other authors also use this proxy for analysis of the European trading scheme. That is, for example, the case of Bredin and Muckley (2011), and Creti et al (2012).

[9] Price series are expressed in logarithmic terms, returns are defined as the first difference of logarithmic prices.

[10] Alberola et al.(2008) identified breaks in the EUA price series in the first phase of the EU ETS.

[11] The Additive Outlier (AO) procedure applies a filter to detrend the series before performing the unit root test. It captures sudden changes in the series. The Innovational Outlier (IO) procedure detrends and performs the unit root test at the same time. It captures incremental changes in the mean of the series.

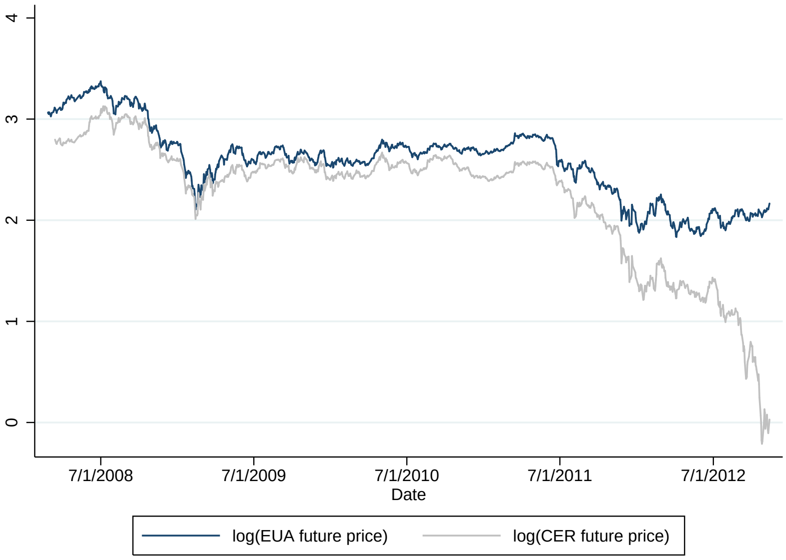

Figure 1: Logarithmic EUA and CER futures prices.

Table 2: Results of the Clemente Montanès and Reyes tests on EUA et CER permit prices (in logarithms).

	EUA future price				CER future price			
Test procedure	IO		AO		IO		AO	
Series	Level	Variation	Level	Variation	Level	Variation	Level	Variation
DU_1	-0.016	0.002	-0.546	0.0036	-0.006	-0.005	-0.471	-0.021
	(-4.67)	(1.47)	(-49.46)	(1.955)	(-1.90)	(-0.669)	(-22.90)	(-2.79)
	{0.000}	{0.141}	{0.000}	{0.052	{0.058}	{0.504}	{0.000}	{0.005}
DU_2	-0.016	0.0005	-0.606	0.0011	-0.006	-0.0003	-1.298	0.016
	(-4.82)	(0.287)	(-63.43)	(0.608)	(-1.39)	(-0.038)	(-72.74)	(2.08)
	{0.000}	{0.774}	{0.000}	{0.543}	{0.163}	{0.970}	{0.000}	{0.037}
$\rho - 1$	-0.028	0.925	-0.034	-0.895	-0.005	-0.899	-0.014	-0.904
	(-5.36)	(-25.43)	(-4.67)	(-10.66)	(-1.427)	(-24.34)	(-2.473)	(-10.12)
	[-5.49]	[-5.49]	[-5.49]	[-5.49]	[-5.49]	[-5.49]	[-5.49]	[-5.49]
Conclusion	$I(1)$	$I(0)$	$I(1)$	$I(0)$	$I(1)$	$I(0)$	$I(1)$	$I(0)$
Significant	13/10/08		03/11/08				21/11/08	23/11/11
dates of breaks	15/09/11		28/11/11				28/11/11	16/12/11

Note: The values in () and [] are respectively the t-statistics and the critical values at the 5% significance level tabulated by Clemente Montanès and Reyes. Values in {} are p-values.The null hypothesis of the unit root test is rejected when the t-statistic is smaller than the critical value.

Both test procedures show that the EUA and CER futures price series are integrated of order 1 and presents two break dates. These are slightly different depending on the test procedure but they are very close, which reveals the robustness of the results. EUA and CER futures price series present breaks in November 2008 and November 2011.

The first break date corresponds to the sharp drop in the carbon price to below 15 € per ton. The emission permit loses over half of its value in less than five months. This collapse in the carbon spot price is due to a low demand of emission permits, which in turn can be attributed to several factors. First, the financial crisis and the declining global equity prices followed by the economic crisis caused a reduction in the economic activity of electricity producers and of the major industrial emitters. This was inevitably followed by a drop in real emissions. Emissions of greenhouse gases from installations covered by the EU ETS fell by 11.6% in 2009 compared with 2008. Second, the low level of gas prices throughout 2009 made it much more attractive than coal for power generation.

The second date corresponds to a significant decline in the EUA price to below 7 € per ton in January 2012. Despite an annual economic growth in Europe of 1.8% in 2011,[12] there was a recession in the third quarter of 2011. Consequently, total verified emissions fell by 1.75% in 2011 compared with 2010.[13] The end of the year 2011 also coincides with the 17th Conference of the Parties organized in Durban. One conclusion of this Conference was to review existing market-based mechanisms and to develop a new one to help developing countries to achieve their mitigation objectives (KPMG, 2011).

For the explanatory variables, the Augmented Dicky-Fuller, Phillips-Perron and Kwiatkowski-Phillips-Schmidt-Shin tests show that the coal and gas prices as well as the European equity index are not stationnary, but that their returns are (results reported in Table 3).

The existence of a co-integration relationship (Johansen, 1991 and 1995) between the carbon price, the coal price, the gas price and the economic activity is tested with the Johansen cointegration test, taking into account the two structural breaks identified previously. Results are reported in Section 4. For each type of permit, they confirm the existence of one cointegration relationship between the carbon price, the coal and gas prices, and the economic activity.

The EUA and CER price variations (or returns) are displayed in Figure 2 (figures for the other variables in appendix). They exhibit patterns of volatility clustering, which are in line with previous observations on the European allowance series by Paolella and Taschini (2008) and Medina and Pardo

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[12] Data source: Eurostat, Real GDP growth rate - volume, Percentage change on previous year.

[13] Data source: European Environment Agency.

Table 3: Unit root tests for the explanatory variables.

	Augmented Dickey-Fuller (ADF)		Philipps-Perron (PP)		Kwiatkowski-Phillips -Schmidt-Shin (KPSS)	
Series (in logarithm)	Level	Variation	Level	Variation	Level	Variation
Gas	0.060(1)	-20.140(1)***	0.013(1)	-33.762(1)***	1.220(2)	0.175(2)
Coal	-0.625(1)	-14.828(1)***	-0.653(1)	-33.401(1)***	0.646(2)	0.154(2)
Eurex	-2.419(2)	-17.195(1)***	-2.753(2)*	-35.348(1)***	1.290(2)	0.142(2)

Note: (1) model without constant or trend; (2) model with constant; (3) model with constant and trend; For ADF and PP tests, *, ** and *** respectively represent the rejection of the null hypothesis of unit-root at 10, 5 and 1% significance levels. The model choice in ADF and PP tests is made according to a strategy of sequential tests from the most general to the most restricted one. For the KPSS test, with Bartlett kernel and automatic selection of the number of lags, the critical values are 0.463 for 5%, 0.739 for 1% in the case without trend, 0.146 for 5%, 0.216 for 1% in the case with trend.

(2012). We may note that the volatility is particularly high after November 2008 and November 2011, that is the time periods folllowing the breaks identified in the series. The events causing breaks in the series seem to increase the volatility in these series. The volatility features identified here require using autoregressive conditionally heteroskedatic (ARCH) models in the following analysis.

3 Method

Our methodology combines a cointegration approach and risk-return considerations. The reason is that, on the one hand, the data confirm the existence of a cointegration relationship between the carbon price and its drivers (see Johansen test results in the previous section) and, on the other hand, the carbon price series present characteristics of financial assets, such as the volatility clustering shown in the previous section. Previous studies, for example Creti et al. (2012), have used a cointegration approach to analyze the European carbon price. Other studies have focused on the short-term dynamics, for example the works by Chevallier (2009), Lutz et al.(2013), Medina and Pardo (2012) or Paolella and Taschini (2008). In our approach, we allow the carbon price volatility to impact its return, and, at the same time, we account for day-to day adjustments around the long-term equilibrium[14] in the short-term estimations, which analyses that only focus on the short-term dynamics cannot do.

For the analysis of the long-term dynamics, we consider the carbon price fundamental economic drivers identified by Hintermann (2010). We adopt a general to specific approach and extend the work done by Kirat (2013) on EUA to CER. The general relationship includes the gas price, the coal price, the

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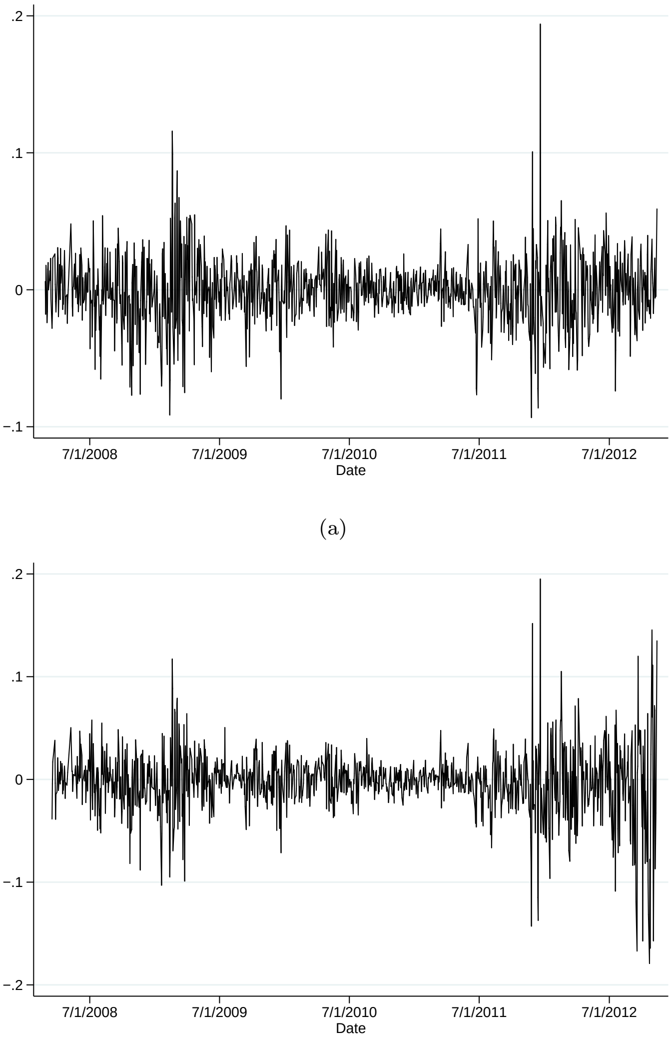
[14] In the econometric analysis presented in this paper, "long-term equation" refers to the equation between the variables in absolute levels, while "short-term equation" refers to the equation between the day-to-day variables variations.



(a)

(b)

Figure 2: (a) EUA and (b) CER price variations.

economic activity and non-linear terms as follows:

$$P_t^{CO_2} = \alpha_0 + \alpha_1 P_t^{gas} + \alpha_2 P_t^{coal} + \alpha_3 G_t + \alpha_4 (P_t^{gas})^2 + \alpha_5 (P_t^{coal})^2 + \alpha_6 P_t^{coal} P_t^{gas} + v_t \tag{1}$$

where $P_t^{CO_2}$, P_t^{gas}, P_t^{coal} are respectively the logarithms of the carbon price, the gas price and the coal price in period t, and G_t is the economic activity (also in logarithm). Given that the power sector represents 60% of emissions permits, the trade-off between gas and coal for producing electricity requires introducting squared terms and an interaction term to account for potential non-linearities in the relationship between energy and carbon prices (Hintermann, 2010; Kirat, 2013).[15] v_t is the error term.

The short-term equation of the cointegration relationship (equation 2) includes the differentials of the variables included in the long-term equation (equation 1): coal and gas prices and economic activity. Under the assumption that the power sector is the main source of demand for carbon permits, the short-term variations in the carbon price are related to the economic activity and the short-term abatement opportunities in this sector. The addition of the error correction term v_{t-1} reflects the cointegration: if the associated coefficient is significant and negative, the return to the long-term equilibrium is confirmed. This Error Correction Model allows representing the fact that the short-term equation tends to bring carbon price back to the equilibrium defined in the long-term equation.

$$\Delta P_t^{CO_2} = \beta_0 + f(\Delta P_t^{gas}, \Delta P_t^{coal}, \Delta G_t) + \beta_v v_{t-1} + \varepsilon_t \tag{2}$$

where ΔP_t is the first log difference of the permit price P_t.

This short-term equation is combined with risk remuneration considerations associated with the financial characteristic of the carbon permit. If the latter were only a financial asset, one would expect a positive impact of the carbon price volatility on its return according to the dynamics described in Equation 3: the higher the volatility of an asset, the riskier this asset, the higher the return expected by agents to hold it.

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[15] Other authors such as Creti et al.(2012) include the switching price between coal and gas but this has been questioned by others such as Delarue et al. (2010) or Rickels et al. (2015). Some studies also include the price of electricity, but this requires restricting the analysis to some part of the area covered by the EU ETS, as in the work by Lo Prete and Norman (2013) or Bunn and Fezzi (2008).

$$E_{t-1}(\Delta P_t^{CO_2}) = r_f + \mu_t \tag{3}$$

where $\Delta P_t^{CO_2}$, the ex-post permit return in period t, depends on the risk free rate r_f, and on the risk premium μ_t, that is itself a function of σ_t^2, the conditional variance of the return:

$$\mu_t = \mu(\sigma_t^2)$$

with $\mu' > 0$.

The combination of the two dimensions leads to:

$$E_{t-1}(\Delta P_t^{CO_2}) = r_f + \mu_t + f(\Delta P_t^{gas}, \Delta P_t^{coal}, \Delta G_t) + \beta_v v_{t-1}. \tag{4}$$

In line with previous literature (Paolella and Taschini, 2008; Chevallier, 2009; Medina and Pardo, 2012; Lutz et al., 2013), we use a GARCH model (Bollerslev, 1986) for the estimations as it is appropriate for time series that exhibit time-varying volatility clustering (see observation on Figure 2). We use a GARCH-in-Mean (GARCH-M) model (Engle *et al.*, 1987), that allows taking account of the risk premium μ_t.[16] It is an extension of the GARCH model in which the mean of the dependent variable depends on the conditional variance. GARCH-M is most commonly used in evaluating financial time series when a theory supports a trade-off between asset risk and return.

Following the model developed in equations 2 to 4 and a GARCH-M(1,1) process, the mean equation is written as follows:

$$\begin{aligned}\Delta P_t^{CO_2} = {} & \beta_0 + \beta_1 \Delta P_t^{gas} + \beta_2 \Delta P_t^{coal} + \beta_3 \Delta G_t + \beta_4 (\Delta P_t^{gas})^2 + \beta_5 (\Delta P_t^{coal})^2 \\ & + \beta_6 \Delta P_t^{gas} \Delta P_t^{coal} + \beta_v v_{t-1} + \beta_h h_t^2 + \varepsilon_t \end{aligned} \tag{5}$$

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[16] Engle, Lilien, and Robins (1987) assume that the risk premium is an increasing function of the conditional variance of returns: the greater the conditional variance, the greater the risk premium needed to compensate for the asset to be held by an agent for portfolio diversification.

Table 4: Results of the Johansen's cointegration tests with two structural breaks (EUA).

Null hypothesis	Trace statistic	Critical value (1%)	Critical value (5%)	P-value
None	177.73	178.88	167.21	0.011**
At most 1	110.58	142.62	132.15	0.452
At most 2	72.67	110.18	100.92	0.767
At most 3	42.46	81.67	73.61	0.944
At most 4	24.44	57.16	50.32	0.955
At most 5	10.48	35.50	30.89	0.974
At most 6	1.84	19.74	15.34	0.988

Note: *** and ** respectively refer to the rejection of the null hypothesis at the 1 and 5% significance levels. The critical values are tabulated by Giles and Godwin (2012). They also provide code that generates corresponding p-values.

and the variance equation is

$$h_t^2 = \omega + \gamma_1 \varepsilon_{t-1}^2 + \gamma_2 h_{t-1}^2 \tag{6}$$

where h_t^2, the conditional variance of the error term, reflects the fact that the price volatility may impact the carbon permit return. If β_h, the associated coefficient, is significantly different from zero, it will reflect the risk premium, *i.e.* the increased return to compensate for the increased volatility and increased risk. If β_h is not significantly different from zero, it will mean that the increased volatility does not influence the price differential.

4 Results and Discussion

Before estimating these relationships on the EUA and CER price series, we report the results of the Johansen cointegration tests in tables 4 and 5. They indicate that, for each type of permit, one cointegration relationship exists between the carbon price, the coal and gas prices, and the economic activity at the 5% significance level.

In the following estimations, the structural breaks identified in Section 2 are taken into account through the use of dummy variables.

Table 6 and 7 respectively present the results for EUA and CER prices. For EUA, regression (C) is the general specification including non-linear terms. Regressions (A), (B) and (D) are restrictions. Restrictions (B) and (A) are better than restriction (D) as the likelihood ratio test allows to reject the null hypothesis for regression (D) (the null hypothesis assumes that both α_1 and α_4 are equal to zero). The Akaike and the Bayesian information criteria allow favoring regression (B) to regressions

Table 5: Results of the Johansen's cointegration tests with two structural breaks (CER).

Null hypothesis	Trace statistic	Critical value (1%)	Critical value (5%)	P-value
None	178.28	178.92	167.24	0.011**
At most 1	111.04	142.66	132.19	0.439
At most 2	73.57	110.22	100.96	0.742
At most 3	42.25	81.71	73.66	0.947
At most 4	24.39	57.21	50.36	0.956
At most 5	10.03	36.54	30.93	0.980
At most 6	3.16	19.77	15.37	0.934

Note: *** and ** respectively refer to rejection of the null hypothesis at the 1% and 5% significance levels. The critical values are tabulated by Giles and Godwin (2012). They also provide code that generates the corresponding p-values.

(A) and (C).

As regression (B) includes non-linear terms, the interpretation of the coefficients associated with the coal and gas prices requires computing the corresponding elasticities. The results are presented in Figure 3. We observe that both elasticities are positive most of the time, while they are negative in 2009, when general economic activity and energy prices were low.

In this specification that best captures the complexity of the interactions between the coal, gas and carbon prices, the elasticity of the EUA price with regard to the coal price depends on the gas and coal prices, while the elasticity with regard to the gas price depends on the coal price only. The higher the coal price, the stronger the effect of the gas price on the carbon price, and symmetrically, the higher the gas price, the stronger the effect of the coal price on the carbon price. An increase in either the coal or gas price creates a tension in the market, which enhances the effect of the other factor.

In time periods of normal or high economic activity, the positive elasticity observed with regard to the gas price is in line with results from the existing literature. The positive elasticity with regard to the coal price is less intuitive. We suggest that the sign of these two elasticities is explained by the impact of the economic activity on the price of commodities in general, and of energy prices and emissions in particular: a rise in the economic activity is associated with an increase in energy and carbon prices. This effect would dominate the potential impact of switching between coal and gas in the power sector,[17] which would be consistent with the observation by Rickels et al.(2015) of a small influence of fuel switching on the EUA price. In time periods of low economic activity, the negative elasticities can be explained by the fact that the market is not tight.

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[17] If the switching between generation from coal and gas in the power sector were the dominating effect, a coal price increase would result in a switch to gas, emissions reductions and a drop in the EUA price, resulting in a negative elasticity of the EUA price with regard to coal.

Table 6: Estimation results of the long-run equation for the EUA price.

Equation	(A)	(B)	(C)	(D)
P_t^{gas}		-1.770***	-4.805	
		(0.251)	(3.621)	
$(P_t^{gas})^2$	-2.379***		4.106	
	(0.348)		(5.075)	
P_t^{coal}	-1.009***	-1.048***	-1.126***	-1.941***
	(0.311)	(0.307)	(0.349)	(0.309)
$(P_t^{coal})^2$	-0.310***	-0.313***	-0.309***	0.407***
	(0.106)	(0.103)	(0.104)	(0.059)
$P_t^{gas}P_t^{coal}$	0.867***	0.883***	0.900***	0.071***
	(0.118)	(0.117)	(0.107)	(0.019)
$Eurex_t$	0.451***	0.451***	0.453***	0.490***
	(0.060)	(0.060)	(0.060)	(0.062)
$AfterBreak1$	-0.208***	-0.209***	-0.209***	-0.216***
	(0.024)	(0.023)	(0.023)	(0.025)
$AfterBreak2$	-0.582***	-0.583***	-0.585***	-0.573***
	(0.017)	(0.017)	(0.018)	(0.018)
$Cons$	0.175	2.607***	6.783	0.084**
	(0.398)	(0.488)	(5.039)	(0.416)
$Likelihood$	977.61	978.29	978.73	923.25
$R - squared$	0.9140	0.9140	0.9141	0.9058
AIC	-1939.23	-1940.58	-1939.47	-1832.50
BIC	-1898.54	-1899.88	-1893.69	-1796.89
LR tests	$\chi^2_{(1)}$= 2.24 [0.13]	$\chi^2_{(1)}$= 0.90 [0.34]		$\chi^2_{(2)}$= 110.98 [0.00]

Note: Standard errors are in (); *, ** and *** respectively refer to the 10%, 5% and 1% significance levels of estimated coefficients.

All things being equal, the EUA price increases by $0,45\%$ when the economic activity rises by 1%. The structural breaks identified above are confirmed and indicate a decrease in the EUA price level after each break.

For the CER price, regression (G) is the general form, while regressions (E) and (F) are restrictions. According to the likelihood ratio tests associated with these restrictions, regressions (E) and (F) are better specifications than (G), and according to the Bayesian information criterion, restriction (E) is the specification that best captures the CER price long-term dynamics.

The long term relationship between CER and energy prices is significantly different from what is observed for the EUA: it is linear at the standard 5% significance level and the gas price elasticity of CER price is -0.54 while the coal price elasticity is 0.51. These signs are opposite to what one would expect from switching between coal and gas generation in the power sector. This could be explained by a supply-side effect. The CER market offers some flexibility. Generating offsets is a relatively

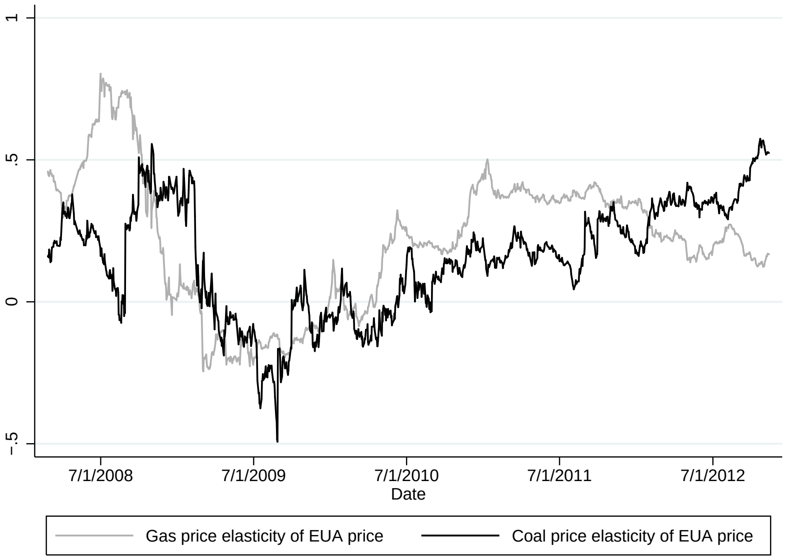

Figure 3: The EUA price elasticities with regard to the coal and gas prices.

long procedure but organisations, including installations covered by the EU ETS, that manage CDM projects and credits do not have to use their CER as soon as these credits are issued. They may keep them until the conditions for using or selling them improve. When the demand for carbon permits rises, some agents may increase the CER supply. For example, when the gas price increases, power companies covered by the scheme may switch part of their power production to coal installations, which tends to increase their need of permits to cover emissions. Organisations holding CER may then decide to supply them to the market, which would reduce the CER price. On the contrary, when the coal price increases, power generation may switch to gas plants. The demand for permits to cover emissions then decreases and the incentive to increase the supply of CER to the market would disappear.

The elasticity of the CER price with regard to the economic activity is 0.25. It is nearly twice smaller than the corresponding elasticity for the EUA price, which reflects the looser link between the CER price and the European economic activity: while EUA can only be traded in the European carbon market and the volume of EUA is set by the European cap, the volume of CER in the market is flexible (at the global level, there is no limit on the amount of CER produced annually) and CER can be traded in markets outside Europe. EUA and CER are two different products that coexist in Europe but they are not perfect substitutes. Finally, the structural breaks identified in Section 2 are confirmed, the CER price level being lower after each break.

Table 7: Estimation results of the long-run equation for the CER price.

Equation	(E)	(F)	(G)
P_t^{gas}	-0.538***	-16.830*	-14.922*
	(0.088)	(9.115)	(8.834)
$(P_t^{gas})^2$		22.290*	20.178*
		(12.427)	(12.006)
P_t^{coal}	0.509***	0.467***	0.512
	(0.114)	(0.108)	(0.663)
$(P_t^{coal})^2$			0.105
			(0.220)
$P_t^{gas} P_t^{coal}$			-0.174
			(0.198)
$Eurex_t$	0.255***	0.251***	0.243**
	(0.095)	(0.096)	(0.104)
$AfterBreak1$	-0.471***	-0.504***	-0.516***
	(0.022)	(0.031)	(0.041)
$AfterBreak2$	-1.110***	-1.117***	-1.115***
	(0.035)	(0.017)	(0.036)
$Cons$	1.305*	23.448*	20.894*
	(0.735)	(12.600)	(12.166)
$Likelihood$	103.42	106.74	107.32
$R - squared$	0.8771	0.8778	0.8779
AIC	-194.84	-199.49	-196.64
BIC	-164.38	-163.96	-150.96
LR tests	$\chi^2_{(3)}$= 7.80 [0.05]	$\chi^2_{(2)}$= 1.15 [0.56]	

Note: Standard errors are in ( ), they are computed with the Newey-West methodology to account for correlation in the residuals; *, ** and *** respectively refer to the 10%, 5% and 1% significance levels of estimated coefficients. P-values of the likelihood ratio tests are in [ ].

Table 8: Estimation results of the short-term (error correction) equation.

Short term Model	CER price variations		EUA price variations	
	Mean equation		Mean equation	
v_{t-1}	-0.009**	-0.010***	-0.022***	-0.022***
	(0.003)	(0.003)	(0.005)	(0.005)
ΔP_t^{gas}	-5.567***	-5.513***	-6.645***	-6.643***
	(1.010)	(1.036)	(1.019)	(1.020)
$\Delta(P_t^{gas})^2$	8.077***	8.002***	9.675***	9.671***
	(1.446)	(1.479)	(1.441)	(1.442)
ΔP_t^{coal}	-0.333	-0.330	-0.284	-0.284
	(0.215)	(0.215)	(0.223)	(0.223)
$\Delta(P_t^{coal})^2$	0.141***	0.141***	0.154***	0.154***
	(0.053)	(0.053)	(0.055)	(0.055)
$\Delta(P_t^{gas} P_t^{coal})$	-0.097**	-0.097**	-0.129	-0.129
	(0.047)	(0.047)	(0.042)	(0.042)
$\Delta(Eurex_t)$	0.178***	0.176***	0.210***	0.210***
	(0.031)	(0.031)	(0.030)	(0.030)
$cons$	-0.000	-0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
h_t^2		-1.403		0.035
		(1.162)		(1.868)
	Variance equation		Variance equation	
$ARCH$	0.188***	0.189***	0.140***	0.140***
$GARCH$	0.811***	0.810***	0.855***	0.855***
$cons$	0.000***	0.000***	0.000***	0.000***

Note: Standard errors are in (); *, ** and *** respectively refer to the 10%, 5% and 1% significance levels of estimated coefficients.

Table 8 presents the results of the estimation of the short-term relationship on CER and EUA futures price series. Both for EUA and CER, the existence of the long-term relationship is confirmed as β_v, the coefficient associated with the previous period error term, v_{t-1}, is significant and negative. This confirms the relevance of using a cointegration approach, to take account of the error term in the short-term estimations. The coefficients associated with the energy prices are significant: the coal and gas prices impact carbon price in a non linear way.

Interestingly, while the long-term dynamics of EUA and CER were significantly different, the impact of the gas and coal prices on the EUA and CER prices are very close in the short-term estimations. This seems to indicate that the mechanism dominating the results observed for CER in the long-term (supply-side effect) is not the most important one in the short-term.

As in the long-term estimations, the coefficient associated with the economic activity is higher for EUA than for CER. The economic activity elasticity is 0.18 for the CER price and 0.21 for the EUA price. We also observe that the error correction term is higher for the EUA that for the CER, meaning that, following a shock in the long-term equilibrium, the return to equilibrium is faster for EUA than for CER.[18] We explain these two results by the tighter link between the EUA price and the European economic activity.

The coefficient associated with the volatility is not significant. One explanation could be the existence of two regimes, as shown by Lutz et al.(2013). Using a Markov regime-switching model, Lutz et al. show that the price of EUA in the second phase of the EU ETS is characterized by two types of regimes: one with a high volatility when the economic activity exhibits negative shocks, and one with a relatively low and constant volatility in time periods of good economic activity. In the second regime, the authors observe insignificant GARCH parameters. Our observation could be caused by the preponderance of the second regime over the first. Our work is complementary to the analysis by Lutz et al. as we capture the error correction term associated with the cointegration relationship between the carbon price and its drivers.

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[18] We find that these error correction terms correspond to half-lives of 69 days for CER and 32 days for EUA.

5 Conclusions

This work is conducted in the context of international climate negotiations in which the further development of an offset mechanism is announced. While several regions of the world have developed carbon markets to reduce their greenhouse gas emissions, Article 6.4 of the Paris Agreement establishes a mechanism that allows a Party to use emissions reductions achieved in another one to fulfil its nationally determined contribution. Whereas the functioning of emissions trading schemes, and in particular the EU ETS, have been extensively analyzed, less attention have been paid to offset mechanisms.

The paper takes advantage of the coexistence of the EU ETS and the Clean Development Mechanism established under the Kyoto Protocol to characterize the price dynamics differences between offset credits and regular allowances. EUA can be used for compliance in the EU ETS only, their total volume equals the European cap. CER are issued by the CDM board, they can be traded worldwide, and there is no limit on the amount of CER produced annually.

The methodology combines a cointegration approach, that takes account of the fundamental carbon market dynamics related to the demand for carbon permits by installations covered by the EU ETS, and risk remuneration considerations associated with the financial nature of carbon permits. The econometric analysis is conducted on both EUA and CER in the second phase of the EU ETS. It takes account of breaks identified in the series in November 2008 and November 2011, in relation with the recessions that then affected the European economy.

We find that, while the day-to-day variations of the price of EUA and CER follow comparable dynamics, their long-term dynamics differ significantly. Whereas the cointegration relationship between the price of European allowances and energy prices can be understood by the general impact of the economic activity on commodity prices, the results we obtain for the CER price suggest the existence of a supply-side effect, which might be linked to the flexibility that companies involved in CDM projects have to release their corresponding credits. Even if the issuance of CER is a long procedure, institutions managing such credits may decide to release them on the market when conditions are more favorable, and, in particular, when demand for permits rises as a consequence of low coal or high gas prices.

In the long-term, the effect of energy prices on the EUA price depends on the economic activity level. In time periods of normal or high economic activitiy, the positive elasticities with regard to both coal and gas prices indicate that the effect one would expect of fuel switching between coal and gas generation in the power sector is dominated by the general impact of the economic activitiy on commodity prices and, in particular, on energy and carbon prices. In time periods of low economic activity, the negative sign of these elasticities is explained by the fact the market is not tight.

Both in the long and short-term estimations, the influence of the European economic activity is larger on the EUA than on the CER price. This is understandable as the issuance mechanism of EUA make them more tighly linked with the activity in the European Union.

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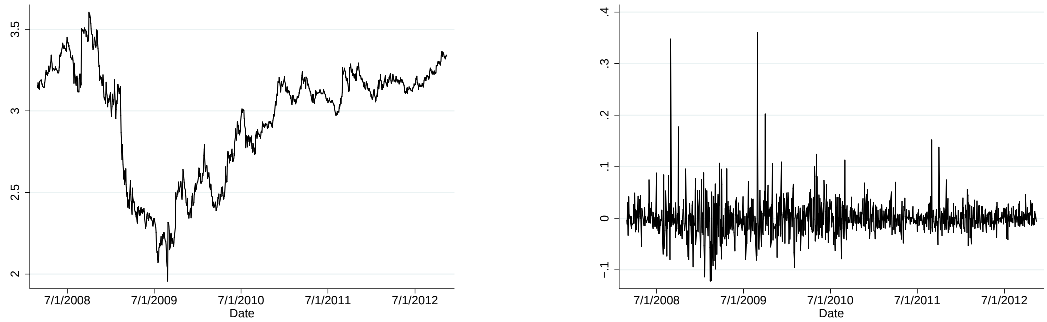
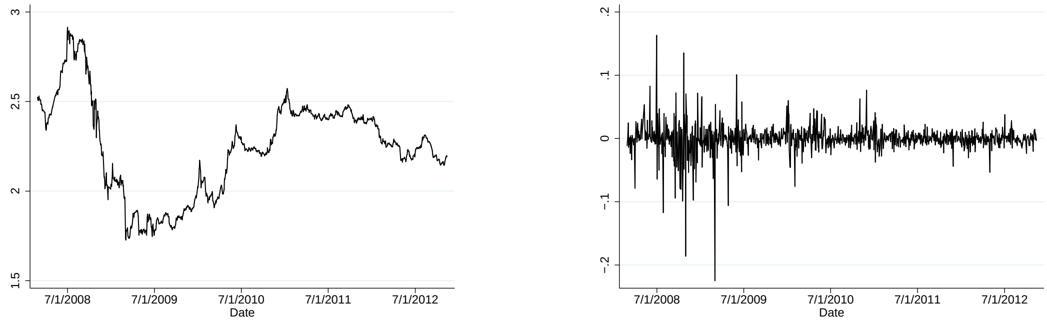
Appendix



(a) Gas price (logarithm)

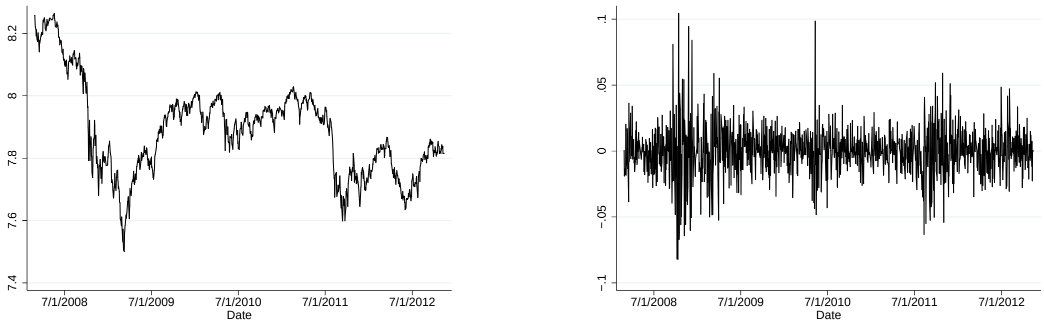
(b) Gas price variations



(c) Coal price (logarithm)

(d) Coal price variations

Figure i: Energy prices (in logarithm terms) and corresponding returns (first difference of logarithmic prices



(a)

(b)

Figure ii: Euro Stoxx 50 index in logarithm terms (a) and corresponding return (b)