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

Claire Gavard[a,*,1], Djamel Kirat[a,2]

[a] Centre d'Economie de la Sorbonne, University Paris 1 Panthéon-Sorbonne, Paris School of Economics, 106-112 Boulevard de l'Hôpital, 75013 Paris, France; E-mail: claire.gavard@polytechnique.edu, djamel.kirat@univ-orleans.fr.

* Corresponding author.

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[1] Present address: Claire Gavard, Fondazione Eni Enrico Mattei (FEEM) and Euro-Mediterranean Center on Climate Change (CMCC), Isola di San Giorgio Maggiore n.8, 30124 Venice, Italy; E-mail: claire.gavard@polytechnique.edu; Fax: +39.041.270.0412; Ph: +32.487.104.971.

[2] Present address: Djamel Kirat, Laboratoire d'Economie d'Orléans (LEO), Université d'Orléans, rue de Blois, BP 26739, 45067 Orléans cedex 2, France; E-mail: djamel.kirat@univ-orleans.fr; Fax: +33.238.417.380; Ph: +33.238.494.988.

Abstract

We analyze the price dynamics of European allowances and international carbon credits in the second phase of the European carbon market. We develop and use a model combining fundamental drivers associated with the demand for quotas by installations and risk-return considerations related to the financial nature of carbon permits. We estimate it with autoregressive conditional heteroskedasticity models. Although carbon permits present some characteristics of financial assets, we find that an increased volatility is not associated with an increased return. The price of allowances and credits are explained by similar factors. However, whereas the corresponding returns present comparable dynamics, the long-term relationships between the price of these two types of permits and their drivers differ significantly. While the price of allowances is demand-driven, we suggest the existence of a supply-side effect for credits, and explain it by the flexibility in the related market. The impact of the European economic activity is less visible on credits than on allowances. The price elasticity of allowances with regards to the coal and gas prices is negative in time periods of low economic activity while it is positive in the rest of the time. We suggest an explanation for this dynamics difference.

Keywords:

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

1 Introduction

1.1 Context

Carbon markets are developing around the world. The European Union Emission Trading Scheme (EU ETS) started in 2005. Besides the EU ETS, national or sub-national systems operate in Australia, 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 (Lecocq and Ambrosi, 2007) can be used by industrialized countries to meet their emission reduction target under the Kyoto Protocol. Under the Joint Implementation, Emission Reduction Units (ERU) from projects in Annex B countries[3] can be used by other Annex B countries to meet their targets. CER and ERU are accepted for compliance in the EU ETS under a specific limit.Although CDM credits can be sold in various carbon markets in the world, the EU ETS is the largest one to accept them.

Within the United Nations Framework Convention on Climate Change (UNFCCC), new market mechanisms such as sectoral trading are also considered to involve developing countries in a global carbon market beyond the CDM. At the 17^{th} Conference of the Parties (COP) in Durban in December 2011, a new deal to commit India and China[4] to cut emissions indicated that, even if the Clean Development Mechanism would continue, new market mechanisms would be created to assist developing countries in meeting part of their targets under the Convention. A review of the existing market-based mechanisms by the UNFCCC was also decided.

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[3] 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.

[4] China and India are the main host countries for CDM projects.

A consequence is that different kinds of carbon permits coexist and interact. Macroeconomic studies using computable general equilibrium models have already been conducted to assess the long-term impacts of such interactions (Hamdi-Cherif *et al.*, 2010; Gavard *et al.*, 2011a; Gavard *et al.,* 2011b). More analysis is needed to examine whether the prices of these permits are driven by similar dynamics.

1.2 Question to address

The purpose of the paper is to examine the price dynamics of carbon permits and to see whether the flexibility in the market for international credits has some impact on it. We focus our analysis on the prices of European Union Allowances (EUA) and CER in the second phase of the EU ETS. While EUA were given to installations covered by the scheme,[5] CER are issued by the CDM board for projects undertaken in developing countries. The total amount of EUA available in the market is function of the European cap and they can be used for compliance in the EU ETS only. On the contrary, there is no worldwide limit on the amount of credits issued annually and they can be traded in several carbon markets in the world. 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.

1.3 Approach taken

We successively examine the long-term and short-term drivers of CER and EUA prices with time series econometric techniques.[6] The factors identified in the long-term estimations (coal and gas prices, and economic activity) are used for the short-term analysis. The model developed in the latter combines the financial asset characteristic of risk remuneration and the fundamental carbon price dynamics explicited by Hintermann (2010).

Carbon price is the result of equilibrium between the demand and supply for carbon permits. In this paper, we consider two kinds of demand. On the one hand, installations covered by the EU ETS have to buy permits for compliance with their emissions contraints. 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 emissions depends on the general economic activity as well as on the energy 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. His analysis focuses on the carbon price short-term variations in the first phase of the EU ETS. Hintermann finds 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.

On the other hand, there might be a demand for carbon permits by investors who would use them as financial assets. Carbon derivatives are traded on financial markets (e.g. the European Carbon Exchange, and the European Energy Exchange) and present characteristics of financial products. For exemple, carbon price presents patterns of volatility clustering, that is to say periods of high volatility followed by periods of low variability. Carbon derivates also validate the Samuelson hypothesis, as reported by Chevallier (2009). As he analyzes the relationship between European carbon futures

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[5] We focus on the time period before auctions were introduced in the EU ETS.

[6] In the econometric analysis presented in this paper, “long-term relationships” refers to relationships between the variables in absolute levels, while “short-term relationships” refers to relationships between the day-to-day variables variations.

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, which is a characteristic of financial assets. He also finds that the European carbon market is only remotely connected to macroeconomic variables related to stock and bond markets. Another characteristic of a financial asset is that the volatility is related to the return: the higher the volatility of an asset, the riskier this asset, the higher the return expected by agents who could hold it. If carbon price presents this characteristic, there should be an interest for agents in holding some carbon permits even if they do not have to cover carbon emissions. On the contrary, if the risk is not remunerated, there should not be any interest for agents in buying carbon permits if they do not have to cover emissions.

Some research works already developed models combining the fundamental economic dynamics and the financial nature of some commodities to test the respective impact of each on a commodity price. For example, Slade and Thille (1997) confront the Capital Asset Pricing Model (CAPM) and the Hotelling rule (Hotelling, 1931) on the case of copper price, based on the cost function of copper mines. They find that the Hotelling rule is not easily verified while the impact of the return on the price volatility is easily observed, in line with the CAPM. Slade and Thille use detailed installation level data on extraction costs. These data are provided by Denise Young (1992). It is not possible to conduct a similar analysis here without access to the abatement cost for individual installations.

2 Data

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]

Figure 1 and 2 respectively show the EUA and CER futures price series and their variations (or returns). Table 1 presents the summary statistics of their returns.

Table 1: Summary statistics of the EUA and CER futures returns.

Variable	Nb. of Obs.	Mean	St. Dev.	Min.	Max.
EUA futures return	1195	-0.00075	0.024	-0.093	0.193
CER futures return	1182	-0.00234	0.031	-0.179	0.195

As can be seen in Figure 1, CER and EUA price series present two breaks. Following Kirat and Ahamada (2011), we use the Clemente Montanès and Reyes test to detect them. In this test, break dates are endogenous. It includes two test procedures: the additive and the innovational outlier procedures (respectively AO and IO).[9] The results of the test are summarized in Table 2.

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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 quarterly. 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. Thas is, for example, the case of Bredin and Muckley (2010).

[9] The Additive Outlier (AO) procedure applies a filter to detrend the series before performing the unit root test. It

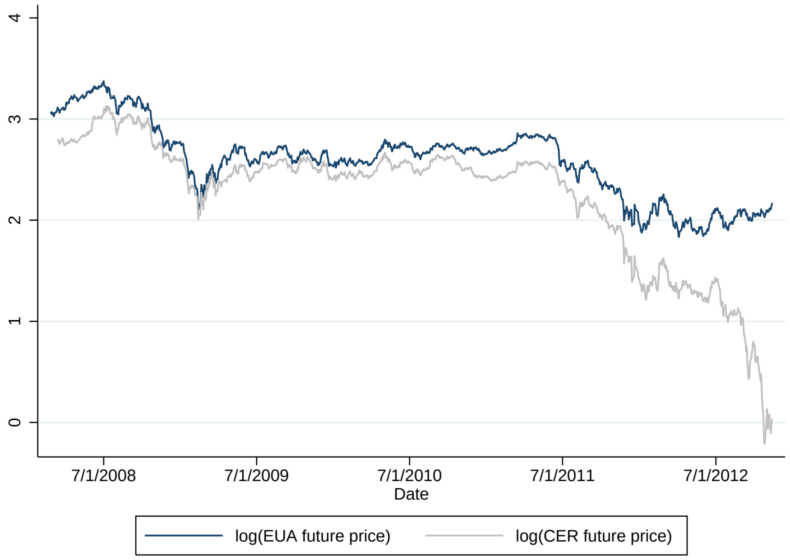
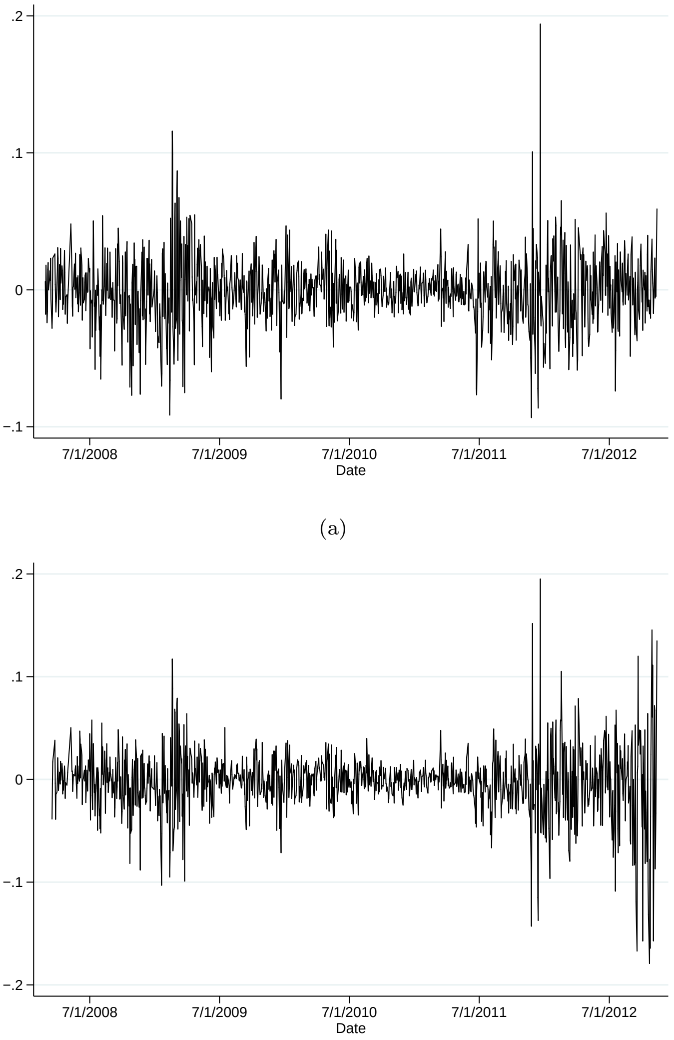


Figure 1: Logarithmic EUA and CER futures prices.

Both test procedures show that the EUA and CER futures price series presents two break dates. They 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 breaks in 2011 can be attributed to announcements made by the EU of its intention to reduce the volume of CER credits accepted for compliance in the EU-ETS. In July 2011, at the launch of the Sandbag's report *Buckle Up! 2011 Environmental Outlook for the EU ETS*, the Climate Action Commissioner's speech to the European Parliament stated that the use of international offsets would be limited from 2013 onwards, and that it would increasingly focus on projects in least developed countries. It was also indicated that credits from some controversial gas projects would be banned and that the EU would push for a reform of the Clean Development Mechanism.

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.



(a)

(b)

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

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.

3 Long-term dynamics

For the analysis of the long-term dynamics, we extend the work already done by Kirat (2013) on EUA to CER. We include the estimations results regarding the EUA price to allow for comparison with those for the CER price. Following Kirat (2013), we adopt a general to specific approach. The general relationship includes the gas price, the coal price, the 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). v_t is the error term. 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. Table 3 presents the results of the test when including linear terms only. Table 4 presents the results of the test when including non-linear terms as well. Tables 5 and 6 present the results of the test when taking into account the two structural breaks. These tests indicate that, for each type of permit, one cointegration relationship exists between the permit price, the coal and gas prices, and the economic activity at the 1% significance level.

Table 3: Results of the Johansen's cointegration tests (p-value).

Dependent variable	EUA price		CER price	
Null hypothesis	Trace test	Max. eigenvalue test	Trace test	Max. eigenvalue test
None	0.012**	0.047**	0.005***	0.015**
At most 1	0.124	0.190	0.137	0.226
At most 2	0.320	0.425	0.299	0.544
At most 3	0.162	0.162	0.072	0.072

Note: *** and ** respectively refer to the rejection of the null hypothesis at the 1 and 5% significance levels.

Table 4: Results of the Johansen's cointegration tests (p-value) with nonlinear terms.

Dependent variable	EUA price		CER price	
Null hypothesis	Trace test	Max. eigenvalue test	Trace test	Max. eigenvalue test
None	0.000***	0.000***	0.000***	0.000***
At most 1	0.024**	0.293	0.036**	0.344
At most 2	0.071	0.267	0.091	0.149
At most 3	0.191	0.570	0.357	0.542
At most 4	0.208	0.303	0.468	0.625
At most 5	0.363	0.455	0.451	0.619
At most 6	0.188	0.188	0.140	0.140

Note: *** and ** respectively refer to the rejection of the null hypothesis at the 1 and 5% significance levels.

We now estimate these relationships on the EUA and CER price series. The structural breaks identified in Section 2 are taken into account through the use of dummy variables. Table 7 and 8 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 to favour regression (B) to regressions (A) and (C).

Table 5: 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.

Table 6: 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.

Table 7: 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)
$Break1$	-0.208***	-0.209***	-0.209***	-0.216***
	(0.024)	(0.023)	(0.023)	(0.025)
$Break2$	-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.

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. 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 price, while the elasticity with regard to the gas price depends on the coal price. The higher the coal price, the stronger the effect of the gas price on the carbon price, and symetrically, the higher the gas price, the stronger the effect of the coal price on the carbon price. This is understandable as an increase in either the coal or gas price creates a tension in the market, which enhances the effect of the other factor. We observe that both elasticities are positive most of the time (results consistent with Hintermann's expectations), while they are negative in 2009, when general economic activity and energy prices were low. We suggest the existence of two corresponding different dynamics. During time periods of low level of economic activity, the power industry may switch part of its production to renewable energy installations when the coal and gas prices increase. This would reduce emissions and the demand for carbon permits, which would induce a carbon price drop. During time periods of normal or high economic activity, an increase in energy price is correlated with an increase in the general economic activity, the use of renewable energy installation remain possible when coal and gas prices increase, but most other fossil energy installations remain needed to insure power supply. The dominant effect is the general increase in the demand for carbon permits correlated with the rise in the economic activity and energy prices. This results in a higher carbon price.

The EUA price increases by $0,45\%$ when the economic activity rises by 1%. The structural breaks

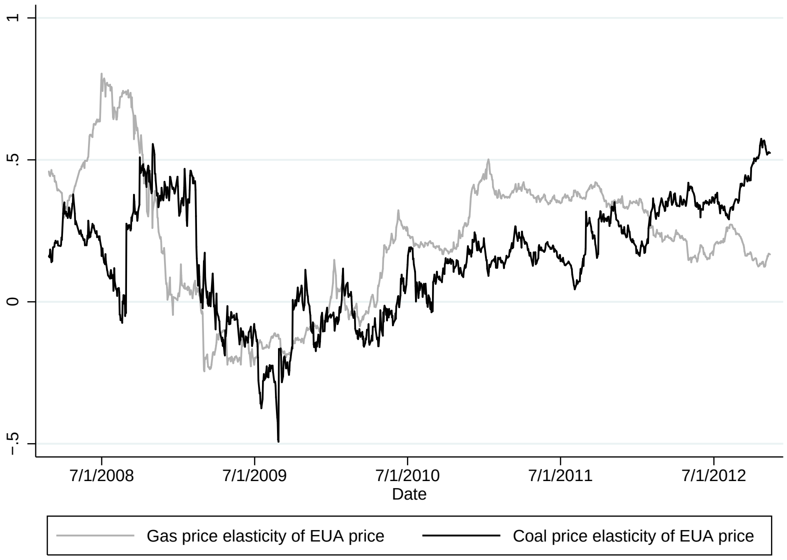


Figure 3: The EUA price elasticities with regard to the coal and gas prices.

indentified above are confirmed (the coefficients associated with Break1 and Break2 dummy variables are significant).

For the CER price, regression (G) is the general form, while regressions (E) and (F) are restrictions. We find that restriction (E) is the specification that best captures the CER price long-term dynamics. The gas price elasticity of CER price is -0.54 while the coal price elasticity is 0.51. This could be explained by a supply-side effect. Indeed, the CER market offers some flexibility. Many CDM projects registered in the CDM pipeline have actually not yet been used to issue permits. Some agents possess CER but do not use them. In addition, some companies covered by the EU ETS also manage a large number of CDM projects and credits. Hence, 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. They may then decide to supply CER 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 much lower 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.

Table 8: 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)
$Break1$	-0.471***	-0.504***	-0.516***
	(0.022)	(0.031)	(0.041)
$Break2$	-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	$\chi^2_{(1)}$= 7.80 [0.05]	$\chi^2_{(1)}$= 1.15 [0.56]	

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

4 Short-term drivers

4.1 Model

For the short-term analysis, we develop a model combining the fundamental carbon price drivers identified by Hintermann (2010) and the risk remuneration term associated with the potential demand from agents who would hold carbon permits as financial assets. We consider two kinds of agents: EU ETS installations that have to buy credits to cover their emissions, and agents who do not have to cover emissions, but who can buy and sell carbon credits as financial assets. If only EU ETS agents buy carbon permits, carbon price is mainly driven by the short-term abatement opportunities in the power sector, as explained by Hintermann (2010). Carbon price variations then depend on the coal price P_t^{coal}, the gas price P_t^{gas}, and the economic activity G_t:

$$\Delta P_t = f(\Delta P_t^{gas}, \Delta P_t^{coal}, \Delta G_t) \tag{2}$$

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

If only the second type of agents buy carbon permits, r_t, the ex-post permit return in period t, that is equal to ΔP_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:

$$E_{t-1}(r_t) = r_f + \mu_t \tag{3}$$

with $\mu_t = \mu(\sigma_t^2)$ and $\mu' > 0$.

The existence of this second type of agents should be reflected by a positive impact of the carbon price volatility on its return. We assume that the carbon price dynamics is driven by the coexistence of the two kinds of agents, reflected in the combination of the two equations presented above:

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

4.2 ARCH, GARCH, and GARCH-M models

In this section, we remind the characteristics of the time-series models used for the estimation, and we introduce the corresponding notations.

4.2.1 The Autoregressive Conditional Heteroskedasticity (ARCH) model.

The ARCH model (Engle,1982) represents a process for which the error term depends on the error terms in the previous time periods. More precisely, the square of the error term follows an autoregressive process (AR). ARCH models are commonly employed in modeling financial time series that exhibit time-varying volatility clustering, *i.e.* periods of high volatility followed by periods of low variability. This is the case here, as seen in Figure 2.

An ARCH process of order q can be described by a mean and a variance equations (respectively (5) and (6)) to characterize the return of a financial asset as follows:

$$r_t = r_a + \varepsilon_t \tag{5}$$

$$\sigma_t^2 = \omega + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 \tag{6}$$

Where $\omega > 0$, and α_i is a coefficient that depends on i.

- r_t is the return of the asset at time t,

- r_a is the average return

- ε_t is the residual return at time t defined as:

$$\varepsilon_t = \sigma_t z_t \tag{7}$$

with z_t the standard residual return (independent and identically distributed random variable with a zero mean and a unity variance), and σ_t^2 the conditional variance. The return is a function of a constant term and an error term (5). The conditional variance of the residual returns depends on the residual returns in past periods (6).

4.2.2 The Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model.

The GARCH model (Bollerslev, 1986) is a generalization of the ARCH model in which the conditional variance also depends on its own lags.

The GARCH(p,q) model can be represented by the following set of equations:

$$r_t = r_a + \varepsilon_t \tag{8}$$

$$\sigma_t^2 = \omega + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \beta_j \sigma_{t-j}^2 \tag{9}$$

Where $\omega > 0$, and α_i and β_j are coefficients that respectively depend on i and j.

- r_t is the return of the asset at time t,

- r_a is the average return

- ε_t is the residual return at time t defined as:

$$\varepsilon_t = \sigma_t z_t \tag{10}$$

with z_t is a standard residual return (independant and identically distributed random variable with a zero mean and a unity variance), and σ_t^2 is the conditional variance.

4.2.3 The GARCH in the Mean model (GARCH-M).

The return of a financial asset may depend on its volatility. The GARCH in the Mean model (GARCH-M) developed by Engle, Lilien and Robins (1987) describes this phenomenon. It is an extension of the GARCH model in which the mean 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. For a simple GARCH-M(1,1) model, the mean and variance equations are the following:

$$r_t = r_a + \lambda \sigma_t^2 + \varepsilon_t \tag{11}$$

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2 \tag{12}$$

where λ is a parameter called the risk premium parameter. If λ is positive, the return is positively related to its volatility. In other words, the higher the risk, the higher the covariance, the higher the asset return to compensate for the risk.[10]

4.3 Estimation

The short-term relationship (equation 13) includes the differentials of the variables identified in the long-term relationship. The addition of the error correction term v_{t-1} reflects the cointegration: if the associated coefficient is negative, the return to the long-term equilibrium is confirmed. This Error Correction Model allows to represent the fact that the short-term relationship tends to bring carbon price back to the equilibrium defined in the long-term relationship.

$$\Delta P_t^{CO_2} = \beta_0 + f(\Delta P_t^{gas}, \Delta P_t^{coal}, \Delta G_t) + \beta_v v_{t-1} + \varepsilon_t \tag{13}$$

The first part of equation (13) is the short-term relationship between carbon permits return and the variations of the main drivers, which are the coal and gas prices and the economic activity, in line with Hintermann's model. 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.

As in the long-term analysis, we test the inclusion of linear and non-linear terms in the relationship. We observe the existence of heteroskedasticity in the series. For this reason, it is appropriate to apply ARCH and GARCH models to the series, and the GARCH-M model to test the impact of the volatility on the price series.

Following the model developed in section 4.1 and a GARCH-M(1,1) process, the mean equation is written as follows:

$$\begin{aligned}\Delta P_t^{CO_2} = \beta_0 &+ \beta_1 \Delta P_t^{gas} + \beta_2 \Delta P_t^{coal} + \beta_3 \Delta G_t + \beta_3 (\Delta P_t^{gas})^2 + \beta_4 (\Delta P_t^{coal})^2 \\ &+ \beta_5 \Delta P_t^{gas} \Delta P_t^{coal} + \beta_v v_{t-1} + \beta_h h_t^2 + \varepsilon_t \end{aligned} \tag{14}$$

The variance equation is

$$h_t^2 = \omega + \gamma_1 \varepsilon_{t-1}^2 + \gamma_2 h_{t-1}^2 \tag{15}$$

Equation 14 includes h_t^2, the conditional variance of the error term, which 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.

Table 9 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 negative.

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

Table 9: 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.

In the short-term relationship, the coefficients associated with the drivers identified by Hintermann are significant: the coal and gas prices impact carbon price in a non linear way. While the long-term relationship between the EUA price and the coal and gas prices was different from the relationship between the CER price and the fossil energy prices, the impact of the gas and coal prices on the EUA and CER prices are very close in the short-term estimation. This can be explained by the fact that the supply-side effect suggested in Section 3 to explain the impact of the coal and gas prices on the CER price in the long-term analysis may not be possible in the short term.

As in the long-term estimations, 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 suggest that the reason for which it is higher for EUA than for CER is the same as in the long-term analysis: there is a tighter link between the EUA price and the European economic activity.

The coefficient associated with the volatility is not significant. This indicates that the volatility of EUA and CER does not influence their price variations. There is no risk premium associated with an increased volatility of the EUA or CER prices. This means that there is no interest for an agent in holding EUA and CER as an asset if this agent does not have to cover carbon emissions: the risk taken would not be remunerated.

5 Conclusion

To conclude, this paper aims at characterizing the price dynamics differences between European allowances and international carbon credits that are issued under the Clean Development Mechanism. We develop a model that combines the risk remuneration associated with the potential financial nature of carbon permits, and the fundamental carbon market dynamics, related to the demand for carbon permits by installations covered by the EU ETS, as explicited by Hinterman. The analysis is done econometrically on EUA and CER price series in the second phase of the EU ETS, when allocations were given for free to installation, before the introduction of auctions. Estimations are conducted with autoregressive conditional heteroskedasticity models.

Although carbon permits present some characteristics of financial assets, such as patterns of volatility clustering, we observe that the volatility does not have a significant impact on their return. In other words, the return of these permits does not compensate for their respective risks. This means that there is no interest in holding carbon permits as assets for an agent who does not have to cover carbon emissions. The permit volatility is mostly associated with policy announcements related to the EU ETS regulation, for example regarding changes in the acceptance of CDM credits in the European market or decisions to couple the ETS with other carbon markets.

The main carbon price drivers remain those identified by Hinterman: the coal price, the gas price and the economic activity. This is explained by the dominance of the power sector in the European carbon market. Contrary to Hinterman, we find that there exists a co-integration phenomenon between the carbon price and these drivers: there is a long-term relationship between the carbon price, the coal and gas prices, and the economic activity. The existence of this long-term relationship is confirmed by the negative impact of the previous period error term in the short-term relationship (error correction model).

But this long-term relationship is not the same for the EUA and CER prices. The long-term dynamics of EUA and CER prices differ significantly. This is consistent with the fact that EUA and CER are two different products, issued and used according to different regulations. EUA are issued at the European level, their volume is defined by the European cap and they can be used for compliance in the EU ETS only. CDM credits are issued by the CDM board, they can be traded worldwide, and there is no limit on the amount of CER produced annually. While the EUA price dynamics is demand-driven, we suggest the existence of a supply-side effect for the CER price: the CER market offers flexibility that may allow some agents to modify the CER supply as a function of the demand for carbon permits, which itself depends on the gas and coal prices.

Such behaviours are not visible in the short-term analysis: the returns of these two types of carbon permits present comparable dynamics. This suggests that it might be less easy to use the flexibility in the CER market from one day to the next.

Both in the long and short-term analyses, we observe that the EUA price is more correlated with the European economic activity than the CER price is. This is explained by the fact that the volume of EUA is set by the European cap and that EUA can only be traded in Europe, while CER can be traded in other markets than the EU ETS and there is no limit on the amount of CER produced annually.

In the long-term estimations, we observe that the elasticity of the EUA price with regards to the coal and gas prices is positive except in 2009, when energy prices were low. We suggest that, in times period of normal or high economic activity, the positive elasticity is simply explained by the fact that a rise in the coal or gas prices is often correlated with a rise in the economic activity and a higher demand for carbon permits. In time periods of low activity, another effect might dominate: the partial swith of electricity generation to renewable energy plants when coal or gas become more expensive. This would reduce the demand for carbon permits and, hence, result in a carbon price drop.

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