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A preliminary version of this paper was presented at the workshop "Energy and carbon markets regulation: what is at stake" held in the European University Institute of Florence on May 2011.

We thank Anna Creti for valuable discussions and Francesco Gulli for helpful comments and suggestions.

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An overview of CO_2 cost pass-through to electricity prices in Europe*

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Abstract

This paper investigates the link between wholesale electricity prices in Europe and the CO_2 cost, i.e. the price of European Union Allowances (EUAs), over the two first phases of the European Union Emissions Trading Scheme (EU ETS). We set up a theoretical framework and an empirical model to estimate to what extent daily fluctuations of CO_2 costs may have impacted electricity prices. Regarding estimation results for the first phase of the EU ETS, about 42% of estimated pass-through rates appear to be statistically significant, while only one third of them are statistically different from zero in the second phase. We try to improve those results by proposing alternative estimates based on the EU ETS compliance periods.

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1 Introduction

The European Union Emissions Trading Scheme (EU ETS) has been in operation since 1 January 2005 and has covered around two billion tonnes of CO_2 emitted by almost 12,000 installations throughout Europe. Among the sectors covered by the EU ETS, the electricity sector is the most important both in terms of European Union allowances (EUAs) received and short net positions (i.e. the gap between the sum of allowances allocated to the electricity sector and its emissions). Since CO_2 allowances can be valued in the markets, power producers add this new cost to their marginal production cost, whether or not CO_2 allowances are distributed free of charge. The pass-through of CO_2 costs increases the electricity equilibrium price in wholesale power markets and creates substantial rents for less carbon-intensive and carbon-free infra-marginal units, i.e. those which generate electricity at a marginal production cost lower than the marginal producer, insofar as the marginal unit is a carbon-emitting power plant. When marginal producers pass through the cost of carbon to their prices they also transmit carbon price signals to the economy, in accordance with the aims of the scheme. Thus, the efficiency of the EU ETS in providing incentives both to power producers and to final consumers depends on whether or not CO_2 costs may be passed through to electricity prices.

The theoretical basis of the CO_2 cost pass-through to electricity prices has been established in the literature, in particular by Sijm et al. (2006b) and Bonacina and Gulli (2007). Sijm et al. (2006b) remind us that under perfect competition, the pass-through rate of carbon cost, i.e. the "add-on rate" should be 100%. However, the effective pass-through rate in electricity markets, known as the "work-on rate", depends on the demand elasticity and the change in merit order due to the CO_2 cost. Thus the "work-on rate" may be lower than the "add-on rate". Bonacina and Gulli (2007), develop a theoretical model of carbon cost pass-through under imperfect competition. They show that in the case of perfect competition, the marginal producer fully integrates the cost of carbon to power prices, while under market power the increase in electricity prices due to carbon pricing is less than 100% unless there is excess capacity and the market share of the greatest polluter is low.

Given this theoretical analysis, there are numerous empirical studies that have evaluated the interactions between energy and carbon markets during the first phase of the EU ETS. Overall, three different approaches have been used in the literature. First, the *price drivers* approach (Hintermann, 2010; Keppler and Mansanet-Bataller, 2010; Alberola et al., 2008) shows that there is a significant relationship between CO_2 and energy prices. Second, the *error-correction model* (Zachman and von Hirschhausen, 2008; Fell, 2008; Bunn and Fezzi, 2007, 2009; Honkatukia et al., 2006) exhibits a long-run cointegrating equilibrium between electricity, energy and carbon prices. The third type of analysis consists in estimating the *pass-through rate of carbon costs* to electricity prices. This path has been historically explored by Sijm et al. (2006a, 2006b, 2008). In Sijm et al. (2006a, 2006b) three econometric models (Ordinary Least Squares, Prais-Winston, and Bootstrap) have been estimated to quantify the percentage of the CO_2 cost which was passed through to forward electricity prices in 2005 in Germany and the Netherlands. Sijm et al. (2008) extend the analysis of the CO_2 costs pass-through to forward and spot markets in nine European countries.

To our knowledge, there are no empirical studies examining the pass-through of CO_2 cost over the second phase of the EU ETS (2008-12) based on a significant sample of countries. Using the third approach, we propose a simple theoretical model, which in particular allows the possibility of negative pass-through rates. We then develop an econometric model of CO_2 cost pass-through to electricity spot prices based on Sijm et al. (2008). Our sample period covers the first phase of the EU ETS and the first three years of the second phase, February 2008 to April 2011. Our estimates cover ten European countries, accounting for almost 80% of the electricity generation from fossil fuels in Europe. We show that while the impact of the CO_2 cost on electricity spot prices was relatively strong during the first phase of the EU ETS (2005-07), the economic crisis, and the resulting greater market instability, perturbed the estimates of the carbon cost pass-through over the second phase (2008-11). However, with regard to the forward electricity market, which is less driven by short-term events than the spot market, there is clear evidence of carbon cost pass-through to electricity prices over the second phase. Next, taking the compliance periods of the EU ETS instead of calendar years, we can improve the robustness of the regression and thus enhance the accuracy of estimation results. Finally, when we control for exogenous volatility, we show that in some countries at least, power producers passed on the cost of carbon to electricity spot prices in 2008 and 2010 but not in 2009.

The paper is organized as follows. Section 2 expounds the theoretical framework as well as the empirical model of the CO_2 cost pass-through to wholesale electricity prices. Section 3 details the set of data used in the econometric estimations. Section 4 discusses the main results of the empirical estimates of CO_2 costs pass-through. Section 5 provides alternative estimates and in Section 6 we present our conclusions.

2 Models

We here introduce the theoretical and empirical bases supporting the pass-through of the CO_2 cost to electricity prices under perfect competition.

2.1 Theoretical framework: the marginal abatement cost function

Consider a power producer, i, defined by a given technology in a given country, generating an amount of electricity Y_i. The electricity price is denoted by p_i. Emissions E_i result from electricity production and total production can be also defined as a function of emissions, $Y_i \equiv Y_i(E_i)$. Under perfect competition on all markets the firm's program involves maximizing its profit given by $\pi_i(Y_i(E_i)) = p_i Y_i(E_i) - C(Y_i(E_i))$, where $C(Y_i(E_i))$ is the cost of production.[1] Following McKitrick (1999) and Bréchet and Jouvet (2009), we define the marginal abatement cost function (MAC function, hereafter) as the loss of profit when pollution is reduced by one unit,

$$MAC(E)_i \equiv \frac{d\pi_i}{dE_i} = p_i \frac{dY_i}{dE_i} - C_m(Y_i(E_i)) \frac{dY_i}{dE_i} \tag{1}$$

where $C_m(Y_i(E_i)) > 0$ is the marginal cost of production Y_i.

We can now introduce a permits market covering a representative firm i. Denoting the price of permit by q, the profit function can be now defined by

$$\pi_i(Y_i(E_i)) = p_i Y_i(E_i) - C(Y_i(E_i)) - (E_i - \bar{E}_i)q \tag{2}$$

where $\bar{E}_i$ represents the allowance allocation of the representative firm i. Thus, for each firm i, we can deduce the demand for permits, i.e. $E_i \equiv E_i(q)$. It is then easy to determine which firm is a net supplier and which is a net demander of permits by comparing $E_i(q)$ to $\bar{E}_i$. Therefore the equilibrium price of permits is a function of emissions, $q \equiv q(E_i, E_{-i})$. Consequently, the profit function can be written as,

$$\pi_i(Y_i(E_i)) = p_i Y_i(E_i) - C(Y_i(E_i)) - (E_i - \bar{E}_i)q(E_i, E_{-i}) \tag{3}$$

where E_{-i} represents the emissions of other firms. Then (1) is now written as,

$$\frac{d\pi_i}{dE_i} = p_i \frac{dY_i}{dE_i} - C_m(Y_i(E_i)) \frac{dY_i}{dE_i} - q(E_i, E_{-i}) - (E_i - \bar{E}_i) \frac{\partial q}{\partial E_i} \tag{4}$$

[1] See Chernyavs'ka and Gulli (2008) for a detailed representation of the electricity sector under imperfect competition with multiple technologies.

where $\partial q/\partial E_i$ is the marginal effect of permits used on the carbon market. A perfect competition framework means that the producer exhibits non-strategic behaviour. However, studying CO_2 cost pass-through would imply taking into account the effect of permits use on carbon prices even if we assume non-strategic behaviour. The classical marginal spread is given by the difference between the price and the marginal cost for a variation of production. We obtain

$$Spread_i = (p_i - C_m(Y_i(E_i))\frac{dY_i}{dE_i} \tag{5}$$

Following Sijm et al. (2008) and using equation (4), the pass-through analysis is given by

$$Spread_i = (1 + \frac{E_i - \bar{E}_i}{E_i}\sigma)q(E_i, E_{-i}) = \beta q(E_i, E_{-i}) \tag{6}$$

where $\sigma = (\partial q/\partial E_i)/(q/E_i)$ is the elasticity of prices with respect to the emissions of the individual firm i. Thus all pass-through values are possible and depend on the elasticity and the gap between the initial allocation and the permits used. With a positive price elasticity, if the power sector emissions exceed the allowance allocations, $E_i > \bar{E}_i$, the pass-through rate will be greater than one. Conversely, if the allowance allocations exceed the power sector emissions, $\bar{E}_i > E_i$, the pass-through will be less than one. Moreover, it may be theoretically possible to try out a negative pass-through rate if positive elasticity is high and if there is a very large gap between the initial allocation $\bar{E}_i$ and emissions E_i, i.e. $\beta < 0$.

2.2 Empirical model: CO_2 cost pass-through

We here develop an econometric model with the aim of empirically estimating the CO_2 cost pass-through rate to wholesale electricity spot prices.[2] The basic equation representing the relation between the price of electricity in the spot market and the cost of fuel and EUA can be expressed as follows,

$$Elec_{l,t} = \alpha + \gamma Fuel_{l,t}^{o,g,c} + \beta CO2_t^{o,g,c} + \epsilon_t \tag{7}$$

where $Elec$ represents the price of electricity, α is a constant term capturing stable influences on electricity spreads, $Fuel$ is the cost of energy, including thermal efficiency, $CO2$ the emission cost associated with the production of one MWh of electricity and

[2]The model does not account for the influence of economic activity on electricity prices since it aims at determining the level of cost pass-through and not the drivers of power prices. Thanks to anonymous reviewer.

ϵ is an error term. The subscripts l and t represent respectively the load duration period and the observation time, with l=[peak, off-peak], while the superscripts o, c and g represent the marginal combustible used to produce electricity over the load period considered (respectively for oil, coal and gas).

Following the methodology developed by Sijm et al. (2008), we define a single marginal fuel for each country and load period (see Appendix A). We then assume that power producers fully integrate the fuel cost into electricity prices (see Sijm et al., 2006b). Subsequently, in accordance with equation 6, we explain the variations of the power spread by the underlying changes in CO_2 costs,

$$Spread_{l,t}^{o,g,c} = Elec_{l,t} - Fuel_{l,t}^{o,g,c} = \alpha + \beta CO2_t^{o,g,c} + \epsilon_t \tag{8}$$

Although in spot markets the equilibrium price results from a complex set of technological interactions, for simplicity's sake, we here assume a single marginal technology setting the price throughout the load period considered. This assumption allows us to consider several technologies when estimating pass-through rates. Furthermore, it implies that all other costs and influences are constant over the estimation period (including operation and maintenance costs, demand and capacity scarcity).

In order to account for non-stationarity in price series, we conduct a series of unit root tests. The results show that all spread series are stationary, while CO_2 and energy prices are mostly non-stationary.[3] Finally, given these results and using equation (8), we construct a first-order autoregressive model, which can be written as follows,

$$Spread_{l,t}^{o,g,c} = \alpha + \beta CO2_t^{o,g,c} + \mu_t \tag{9}$$

$$\mu_t = \rho\mu_{t-1} + \epsilon_t, \quad \text{with} \quad |\rho| < 1, \quad \epsilon_t \sim N(0, \sigma^2)$$

where $\mu_t = \rho\mu_{t-1} + \epsilon_t$. To empirically estimate CO_2 costs pass-through rates to electricity prices involves estimating the coefficient β by ordinary least squares (OLS).

3 Data

Because the development of spot markets was one of the first steps towards electricity liberalization in Europe, overall spot prices present sufficiently long and significant times series. Furthermore, as many operations take place every day in physical markets, spot prices serve mainly to assure market balance and are likely to integrate more closely the

[3]Results of unit root tests are available upon request to the authors.

CO_2 cost into electricity prices. In some countries, however, including Spain, Italy and most of the new European member states, electricity forward contracts were launched only a few years ago. Since this paper aims at identifying the changes in patterns of pass-through of the cost of carbon to power prices between Phase 1 and Phase 2 of the EU ETS, in a first approach we decided to base our estimations on spot markets. Subsequently, an estimation of the CO_2 cost pass-through on forward or futures markets over Phase 2 will complement the spot market analysis.

A wide range of data has been gathered on the trading of electricity, energy and CO_2 allowances in the main marketplaces in Europe over the period June 2005 to April 2011. For electricity spot prices, hourly settlement data of day-ahead exchanges were taken from European power exchanges. For each country, peak and off-peak prices were obtained by taking the average of the settlement price over the country-specific hours. Overall, peak load hours correspond to the day period from 8 a.m. to 8 p.m., while off-peak periods concern the trading hours from 9 p.m. to 7 a.m.[4] (see Appendix A for a detailed description of country specifications).

Energy prices for oil, gas and coal result from daily spot trades in European marketplaces. In particular, oil prices refer to the spot exchanges of Brent crude barrels on the IntercontinentalExchange (ICE), while coal prices refer to the standard API 2 for the delivered area ARA (Antwerp, Rotterdam, and Amsterdam). Prices for gas are those of the National Balancing Point of the United Kingdom, the Zeebrugge hub of Belgium and the Tile Transfer Facility hub of the Netherlands. All fuel prices have been converted into euros per MWh by taking the daily current exchange rate published by the European Central Bank (ECB), the standard conversion factors of the International Energy Agency (IEA), and fuel efficiency factors used by Sijm et al. (2008). For the latter, we assume a net thermal efficiency of 35% for coal and oil, 40% for gas-fired steam cycle plants and 55% for combined cycle gas turbine (CCGT) power plants.

Finally, we take the daily settlement prices for CO_2 allowances traded on BlueNext, the largest spot exchange market in terms of volumes traded. CO_2 prices have been converted into euros per MWh using standard emission factors of the Intergovernmental Panel on Climate Change (IPCC) and fuel efficiency factors as described above.

To facilitate the interpretation of the results and cross-country comparisons, we have identified four subgroups of countries depending mainly on the degree of market coupling between them, as well as the marginal fuel considered (Table 1).

[4] It should be noted that the choice of a period influences the corresponding demand level and marginal producer on the electricity market. Thus assumptions regarding a load period may impact the resulting estimated pass-through.

Table 1: Subsets of countries grouped by market coupling and marginal fuels

Group 1	**Group 2**	**Group 3**	**Group 4**
Austria (AT)	United Kingdom (UK)	Poland (PL)	Italy (IT)
France (FR)	Netherlands (NL)	Czech Republic (CZ)	Spain (ES)
Germany (DE)			
Nord Pool (NP)			

4 The CO_2 cost pass-through

We conducted a first set of estimates of coefficients β based on equation (9), with a sample running from 24 June 2005 to 31 December 2010. The sample period was divided into five subsamples following the calendar years.[5] In addition, estimates were made over two additional subsamples representing both the first phase (from 24 June 2005 to 31 December 2006) and the second phase (from 1 January 2008 to 31 December 2010) of the EU ETS. However, since these sample periods are quite long, some parameters, which are not taken into account but can be considered as stable in the short term, including operation and maintenance costs, electricity mix and capacity scarcity, could have changed over the period and therefore biased the estimates of the CO_2 cost pass-through. Thus, estimated pass-through rates obtained for each phase of the EU ETS have to be viewed with caution.

4.1 Results overview

Overall, we observe that the percentage of CO_2 costs which had been passed on to electricity spreads is almost always higher during peak load periods than off-peak ones. This result is consistent with those of Sijm et al. (2006, 2008) and Honkatukia et al. (2006) and suggests that the higher the electricity demand and the utilization rate of generation capacity, the greater the CO_2 cost pass-through. However, given the associated R^2 values, which indicate the proportion of the variance of the dependent variable explained by the fits, it seems that the CO_2 cost explains off-peak periods better than peak ones. This result holds for the two phases of the EU ETS. The principal reason for this unexpected result is that during peak load periods, electricity prices can reach high levels that may be only partially explained by a CO_2 price of 20 euros per tonne. This result suggests also that during peak load periods these price spikes are mainly due

[5] In a first approach, 2007 was excluded from the sample since during this year the price of CO_2 was close to zero.

Table 2: Summary of estimation results over Phase 1 and Phase 2

	2005	**2006**	**2008**	**2009**	**2010**	**Phase1**	**Phase 2**
Significant coefficients	0/20	14/20	5/20	8/20	7/20	11/20	6/20
Negative coefficients	-	2/20	2/20	7/20	4/20	2/20	0/20
Min	-	-3.56	-1.23	-6.39	-5.43	-2.82	0.64
Max	-	1.75	3.69	4.56	4.24	1.70	6.17

to an increase in generation capacity scarcity.

Regarding estimation results for the three subsamples of the first phase, about 42% of estimated pass-through coefficients appear to be statistically significant, while only 33% of them are statistically different from zero in the second phase. Over the first phase, significant coefficients vary between -3.56 for peak load hours in Italy and 1.75 in France over the peak load periods of the year 2006. In the second phase, the range of significant pass-through is greater and fluctuates between -6.39 in Italy and 4.56 in the Netherlands in 2009.

In the first phase, we observe that half of estimated pass-through rates are negative in 2005, but all of them prove to be not significant (Table 2). This result could be firstly attributed to the fact that our estimation sample starts in mid-2005, when the first EUA exchanges took place on the spot market, while electricity operators were already able to account for the CO_2 cost, since bilateral trades started a few months earlier. Then, in some countries, these negative pass-through rates may suggest the allowance allocations effect, in addition to the existence of a transition period (Sijm et al., 2006b). In 2006, the first complete year of the sample, 12 out of 20 coefficients are statistically significant and positive, except for the Italian market where similarly to 2005 both peak and off-peak prices seem to be inversely correlated with emission costs.[6] Results for Phase 2 show a high degree of negative but almost never significant pass-through rates, which represent approximately half of the estimated coefficients. 2009 is an exception as almost all the significant coefficients are negative.

[6] As explained by Chernyavs'ka and Gulli (2008), this seems to be due to the fact that Italian power producers only received their CO_2 allowances in 2006 and hence did not pass through the cost of carbon to electricity prices before the allocation process was complete.

4.2 What happened between Phase 1 and Phase 2

While the empirical model provides a relative good and stable outcome in Phase 1, such a relation between electricity prices and CO_2 costs appear to be less evident in the second phase. In particular, a high frequency of negative pass-through combined with a low level of significance indicates a conjectural break in the correlation between prices of power and EUAs as well as in the explanatory power of the CO_2 cost in Phase 2.

There is no doubt that the financial crisis has greatly impacted energy markets.[7] Fuel prices, and consequently electricity prices in wholesale spot markets, have crashed, along with emerging countries' demand for oil. In the meantime, the economic downturn has depressed the activity of energy-intensive industries and thus their electricity demand. This could lead to a decrease in the scarcity of generation capacity in spot markets and a disruption of the CO_2 cost pass-through in three ways. First, since estimates of carbon cost pass-through assume that all other costs and influences are stable over time, a decline in the rate of capacity utilization may result in a mis-estimation of the pass-through coefficients. Second, in a period of turmoil, the opportunities for power producers to passed on the cost of CO_2 may have been weaker. This appears to be particularly true, since the demand for electricity followed a downward trend, suggesting that power producers were less likely to increase demand depression by adding the opportunity cost of freely allocated allowances. Subsequently, electricity prices over Phase 2 seem to have been driven more by the decrease in the scarcity of generation capacity. Thirdly, the decrease in CO_2 emissions of the European power sector subsequent to the economic crisis may have induced some allowance effect. Indeed, according to our theoretical framework (equation 6), a situation where allowances exceed emissions ($E_i - \bar{E}_i < 0$) could in some countries lead to negative pass-through rates.

5 Alternative estimates of CO_2 cost pass-through

In this section, we first provide an estimation of the carbon cost pass-through on electricity forward markets with the aim of emphasizing to what extent they have been impacted by the economic crisis. We then propose alternative ways of estimating CO_2 cost pass-through rates to electricity spot prices and accounting for the incidence of both the compliance periods and exogenous volatility on the estimation outputs.

[7]Even in a period of economic downturn, there is no direct incidence of economic activity on carbon costs pass-through. See Declercq et al. (2011) for a detailed discussion of the impact of the economic downturn on the power sector.

5.1 CO_2 cost pass-through to forward electricity prices

The analysis of the link between EUA prices and wholesale electricity spot prices showed that in the second phase, the estimation of the CO_2 cost pass-through was perturbed by variations in the electricity demand and capacity scarcity, as well as by the volatility of energy prices. In order to test this hypothesis, we estimated the CO_2 cost pass-through on forward markets given different maturities.[8] As forward price series prove to be non-stationary, we estimate the CO_2 cost pass-through on forward markets by taking the first differences of the series:

$$\Delta Spread_{l,t}^{o,c,g} = \Delta CO2_t^{o,g,c} + \epsilon_t \tag{10}$$

First, taking the front calendar price, we observe that all the coefficients are statistically significant and positive over each year of the second phase, except for the peak load period of the United Kingdom in 2009. For most countries, the estimated pass-through rates are greater than one. This tends to confirm that the CO_2 costs were still passed on to electricity prices in Phase 2, at least regarding forward markets. Nonetheless, results for 2009 display lower levels of pass-through rates, confirming that the economic crisis lowered the impact of the CO_2 cost on power prices. In addition, in order to test whether or not the effect of the crisis is viewed as a transitional effect by power producers, we estimate a second set of pass-through coefficients based on a longer-term maturity, i.e. the 2011 Calendar, for countries where such contracts are available and sufficiently liquid. Results show that all the estimated pass-through rates are greater than one in 2008 and 2010, except for the peak load contract of the Netherlands, while they are close to one in 2009.

Since there is clear evidence of carbon cost pass-through on forward markets, one question is whether the non-correlation between EUAs and spot prices in 2009 is specific to the carbon market or, on the contrary, lies in the functioning of the electricity spot markets. In order to test the latter assumption, we estimate the extent to which electricity spot prices are linked to the corresponding forward prices over the second phase (Table 3). In comparison to 2008, the correlation between spot and forward prices proves to be very weak in 2009, except for Poland and the United Kingdom. These correlations continue to decline in 2010 in almost all the coal countries belonging to groups 1 and 3. Thus, the results of estimates of carbon cost pass-through rates to spot prices in Phase 2 seem to be more likely due to the underlying dynamics of the electricity markets and to the behaviour of energy prices on international markets rather than to the CO_2 market.

[8] Results of forward estimates are available upon request to the authors.

Table 3: Correlation between forward and spot electricity prices over Phase 2

Country (Forward)	2008	2009	2010	$\Delta_{2009-2008}$	$\Delta_{2010-2009}$
AT_Base	0.33	-0.02	0.09	-0.35	0.11
AT_Peak	0.28	0.14	-0.12	-0.14	-0.26
CZ_Base	0.39	0.08	0.17	-0.30	0.08
CZ_Peak	0.29	0.14	-0.07	-0.15	-0.21
DE_Base	0.35	0.01	0.12	-0.34	0.11
DE_Peak	0.24	0.14	-0.12	-0.10	-0.26
FR_Base	0.27	0.01	-0.16	-0.26	-0.17
FR_Peak	0.25	0.19	-0.26	-0.06	-0.45
NL_Base	0.33	0.10	0.26	-0.23	0.16
NL_Peak	0.28	0.09	0.07	-0.19	-0.02
NP_Base	0.24	0.22	0.39	-0.03	0.18
PL_Base	0.67	0.74	0.05	0.07	-0.69
PL_Peak	0.43	0.72	-0.25	0.29	-0.97
UK_Summer_Base	0.61	0.32	0.54	-0.29	0.22
UK_Winter_Base	0.66	0.58	0.61	-0.09	0.03
UK_Summer_Peak	0.51	0.32	0.41	-0.18	0.08
UK_Winter_Peak	0.54	0.52	0.48	-0.02	-0.04

5.2 Compliance periods

As far as the estimates concern spot markets, there is in principle no reason to consider calendar years when estimating the pass-through of carbon costs, since there is no maturity effect. In addition, calendar years are not very appropriate to the analysis of the carbon market, since in the EU ETS the institutional calendar plays a great role in market functioning. In particular, allocation and compliance periods, which occur respectively at end-February and end-April of each year, strongly impact the EUA price. In order to empirically test this assumption, we perform unit root tests with structural breaks based on Zivot and Andrews (1992). Figure 1 shows that the EUA price for 2009 has an estimated break point on 31 March. Similar results were found for the other years of the sample, which tends to support the view that compliance periods play a significant role in EUA price patterns. Therefore we resample the data based on "compliance periods" (Figure 2) and provide a second set of pass-through estimates given these new subsamples.

The sample period goes from 22 June 2005 to 30 April 2007 for the first phase and from 28 February 2008 to 30 April 2011 for the second phase.[9] Over the first phase, about

[9]Following the theft of carbon allowances in the EU ETS, the European Commission decided on 19

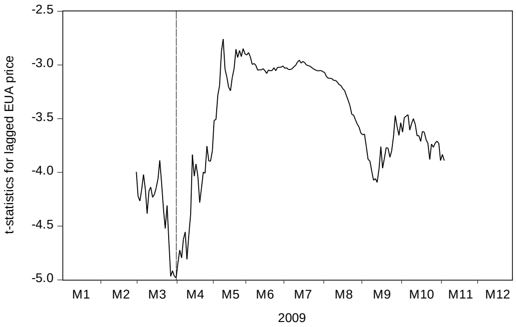

Figure 1: Zivot-Andrews (1992) unit root test statistic for the CO_2 price in 2009

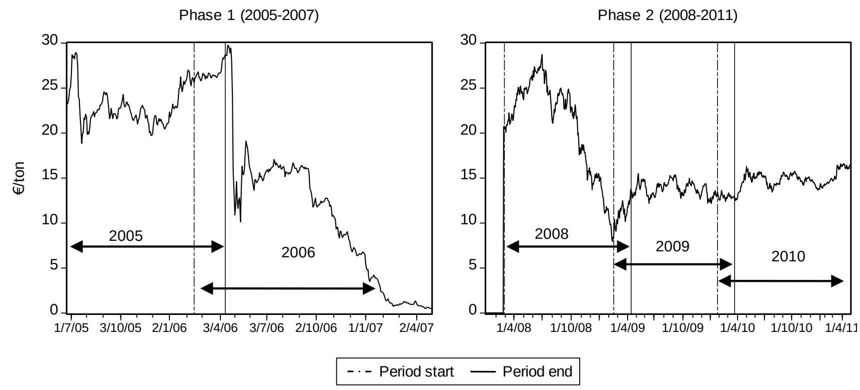

Figure 2: Decomposition of the EUA price curve following compliance periods of the EU ETS

two-thirds of the estimated coefficients are statistically significant, which is significantly higher than the results obtained with the calendar samples (Table 4). In Phase 2, the number of significant coefficients is still progressing relative to those obtained with the calendar samples and represents almost half of the pass-through rates. In addition, the R^2 values associated with the compliance samples are higher than those of the calendar samples, which suggests a greater robustness of the estimation. This result holds for both phases of the EU ETS. Regarding the presence of negative pass-through coefficients, it appears that there are fewer in the case of the compliance samples, for all the years considered.

January 2011 to close all national registries until 26 January 2011. Since all carbon transactions had been suspended, there were no carbon prices in spot markets and consequently, we did not take this period into account in our estimations.

Table 4: Summary of country estimates in Phase 1 and Phase 2 (in brackets) based on the compliance samples

Country groups	Significant coefficients	Min	Max
Group 1	17/24 (10/32)	0.35 (-1.29)	1.73 (1.70)
Group 2	8/12 (10/16)	0.79 (-4.40)	2.28 (11.29)
Group 3	6/12 (6/16)	0.10 (-0.35)	0.80 (1.98)
Group 4	5/12 (10/16)	-2.54 (-5.65)	1.32 (3.98)
Total	36/60 (36/80)	0.10 (-5.65)	2.28 (11.29)

5.3 Compliance periods with adjusted samples

Electricity spot prices in Phase 2 prove to be highly volatile. For instance, on the French spot market, on 19 October 2009, the electricity price was higher than several thousand euros in most of the trading hours. It is clear that such price levels cannot be explained solely by the costs of fuel and carbon. Thus these erratic movements disturb the estimates of the carbon cost pass-through on spot markets. As pointed out by Sijm et al. (2008), if the variance of the electricity price is fully explained by the underlying changes in fuel and carbon costs, the clean spread should be a horizontal straight line. In order to control for extreme values and get the most suitable set of data, we drop 5% of the observations from both sides of the clean spread distribution and estimate the pass-through rate of the carbon cost over the remaining 90% (Figure 3).

Combining the compliance effect with the sample adjustment allows us to improve the estimates of the carbon cost pass-through over the second phase (Table 5). For all the countries considered, this last set of estimates presents a higher degree of statistical significance overall, a lower range of pass-through values and a smaller share of significant negative coefficients. Hence, over the second period as a whole, almost all the estimated coefficients of carbon costs pass-through are positive and statistically significant. Major exceptions concern the Nordic area and Italy, both during peak load and off-peak load periods, and Spain and Poland respectively during peak load and off-peak load hours. In these countries, we can reasonably conclude that carbon costs were not yet passed through on spot markets over the second phase of the EU ETS.

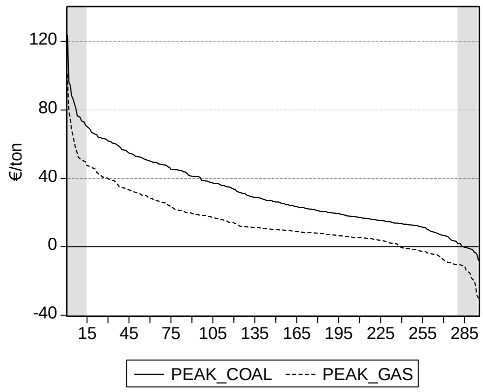

Figure 3: Clean dark spread and clean spark spread in the Netherlands over peak load hours of the conformity year 2008-09 (ranked in descending order)

In the second period, estimation results are mixed. First, we failed to find any evidence of carbon cost pass-through over the year 2009, except for Poland, the Czech Republic, the Netherlands and Italy. This result is consistent with those obtained with the two previous regressions, and thus confirms the hypothesis that over the year 2009 there is no empirical relation between the price of electricity and the price of carbon allowances. Second, the estimated pass-through coefficients for the compliance year 2010 appear to be positive and significant in most of the countries belonging to groups 1, 2 and 3. This finding is consistent with the intuitive result, derived from the analysis of the forward market, which suggests that a conjectural break occurred on the spot market. It tends also to confirm the effect of the economic crisis on the carbon cost pass-through.

6 Conclusion

While the impacts of allowance prices on wholesale electricity spot prices have been well established for the first phase of the EU ETS, the relationship between CO_2 costs and marginal costs of electricity seems to be less evident over the second phase. Due to the global financial downturn in particular, all the countries in the four groups showed no empirical evidence of cost pass-through over 2009.

We have shown that this is mainly due to the shocks that have occurred in energy and electricity spot markets since the beginning of the second phase. First, the financial crisis ended the continuous rise of energy prices, which had started a few years previously in international markets. As energy prices are the main drivers of electricity prices, the

Table 5: Summary of country estimates in Phase 2 based on adjusted compliance samples and calendar samples (in brackets)

Country groups	Significant coefficients	Min	Max
Group 1	14/32 (6/32)	0.60 (-4.94)	1.53 (0.89)
Group 2	12/16 (9/16)	-1.80 (-4.36)	7.01 (6.17)
Group 3	9/16 (2/16)	0.40 (0.90)	1.47 (1.02)
Group 4	7/16 (9/16)	-3.87 (-6.39)	3.07 (4.24)
Total	42/80 (26/80)	-3.87 (-6.39)	7.01 (6.17)

economic crisis also heavily impacted wholesale electricity markets and increased market instability and price volatility. Second, the economic downturn reduced the activity of energy-intensive industries and thus led to lower electricity demand. As a result, power producers were less able to pass through the cost of carbon in the presence of increasing excess of generation capacity. Finally, as suggested by the theoretical framework, the resulting lower level of carbon emissions may make power producers less likely to pass through the cost of freely allocated allowances.

These changes have disrupted the detection of the impact of carbon costs on electricity markets through standard methodologies. The alternative approaches we have developed in this paper have enabled us to enhance the global level of statistical significance as well as the robustness of the carbon cost pass-through estimates. In particular, the compliance effect of the EU ETS combined with the adjustment of the estimation samples indicate that while power producers did not pass on the cost of carbon over 2009, in some countries at least there is clear evidence of CO_2 cost pass-through over the compliance year 2010-11.

One unresolved question is why forward markets seem to have been less impacted by the economic crisis than spot markets and therefore continued to incorporate CO_2 costs over the second phase. Thus a dynamic explanation of the way the economic crisis altered the relationship between spot and forward electricity prices would be an interesting area for further research. In addition, a panel approach, which allows a dynamic representation of carbon costs on electricity markets, could constitute a second way of improving the estimates of carbon cost pass-through to electricity prices.

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A Data description

Table 6: Country data specifications – spot markets

Country	Power market	Load periods	Marginal technology
Austria	EXAA	Peak: 9 to 20	Coal
		Off-Peak: 21 to 8	Coal
Czech Republic	OTE	Peak: 8 to 19	Coal
		Off-Peak: 20 to 7	Coal
France/Germany	EPEX Spot	Peak: 8 to 20	Coal
		Off-Peak: 21 to 7	Coal
Italy	GME	Peak: 8 to 20	Oil (NBP)
		Off-Peak: 21 to 8	CCGT (Zeebrugge)
Netherlands	APX	Peak: 8 to 20	Gas (TTF)
		Off-Peak: 20 to 8	Coal
Nord Pool	ELSPOT	Peak: 9 to 20	Coal
		Off-Peak: 21 to 8	Coal
Poland	POLPX	Peak: 8 to 22	Coal
		Off-Peak: 23 to 7	Coal
Spain	OMEL	Peak: 8 to 20	Oil (NBP)
		Off-Peak: 21 to 8	Coal
United-Kingdom	APX	Peak: 7 to 19	CCGT (NBP)
		Off-Peak: 19 to 7	Coal

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