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Document de Travail
Working Paper
2007-33

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European Carbon Price Fundamentals in 2005-2007: the Effects of Energy Markets, Temperatures and Sectorial Production

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October 17, 2007

Abstract

- This article aims at characterizing the daily price fundamentals of European Union Allowances (EUAs) traded since 2005 as part of the Emissions Trading Scheme (ETS). First, the presence of two structural changes on April, 2006 following the disclosure of 2005 verified emissions and on October, 2006 following the European Commission announcement of stricter Phase II allocation allow to isolate distinct fundamentals evolving overtime. The results extend previous literature by showing that spot prices react not only to other energy markets and temperatures, but also to economic activity within the main sectors covered by the EU ETS such as proxied by sectoral production indices. Besides, the sub-period decomposition of the pilot phase gives a better grasp of institutional and market events that drive allowance price changes.

JEL Codes: Q40, Q48 Q54

Keywords: Carbon Emissions Trading, Market Price Fundamentals, EU ETS.

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1 Introduction

Since January 1, 2005 each carbon ton emitted in Europe by about 11,500 energy intensive plants has been priced. The European Union Emissions Trading Scheme (EU ETS), which covers up to 46% of European CO_2 emissions, aims at helping Member States to achieve compliance with their commitments under the Kyoto Protocol during 2008-2012. While International Emissions Trading (IET) allows trading between governments starting in 2008, the EU ETS breaks down emissions trading to the company level. Its main objective consists in giving incentives to industrials to reduce emissions and to contribute to the promotion of low carbon technologies and energy efficiency among CO_2 emitting plants. Most important polluting entities manage their compliance between their allocation and annual verified emissions by buying or selling European Union Allowances (EUAs) to emit a ton of carbon. At the end of the first commitment period on December 31, 2007, the European Commission (EC) intends to provide decision makers with an allowance price to lead to emissions abatements.

Yet the first disclosure of 2005 verified emissions on April, 2006 revealing the net short/long position[1] of each plant was accompanied by a sudden allowance price collapse, and tends towards zero thereafter (see Figure 1). This price path therefore suggests that trading was based on heterogenous anticipations prior to information disclosure. Within 2005-2007, different fundamentals seem to co-exist before and after the compliance break. Thus, understanding price formation mechanisms when creating such a market appears of critical importance. In this context, the question we address is the following: which factors contribute to shape the price formation of this newly European Union Allowances market?

This article analyses the EU ETS during its pilot phase (2005-2007) by focusing on the empirical relationship between CO_2 price changes[2] and its main fundamentals. Springer (2003)'s review of theoretical models and Christiansen et al. (2005) lead to the identification of the carbon prices main drivers being economic growth, energy prices, weather condition and policy issues. Their potential impacts are analysed in this paper.

The total number of allowances is determined by Member States negotiating with industrials and after validation by the EC. As soon as the first National Allocation Plans[3] (NAPs) were drafted, there was a concern of allowance oversupply during the EU ETS pilot phase. Academic and market agents usually agree that the information revelation by simultaneous countries of lower than expected 2005 verified emissions is the main reason behind the fall of CO_2 prices by more than 50% that occurred on April, 2006.

As pointed out by Ellerman and Buchner (2007), this allowances oversupply argument shall be balanced by the analysis of net short/long positions at the installation level. To the best of our knowledge, empirical studies have not yet studied the effects of sectoral economic activity covered by the EU ETS on CO_2 prices. As industrials are able to influence the market price by their abatement decisions, we intend to include their potential effects in our analysis. The inclusion of the sectors production variables is all the more important as the April, 2006 break in the EUA spot price may be explained by wrong projections at the sectoral level (Grubb and Ferrario, 2006).

Compared to previous literature, our contribution is threefold. First, we show statistical evidence of structural changes following the disclosure of new information about the net short/long position at the installation level during Phase I and the EC decision to enforce stricter NAPs during Phase II. Second, the role played by sectoral economic activity in the EU ETS is highlighted. By doing so, this article extends, among other contributions, Mansanet-Bataller et al. (2007) by emphasising other determinants of carbon prices than energy prices and climatic events. Third, we find that those fundamentals vary between periods, and that EUA spot prices react to energy and weather variables during some time periods whereas during other periods, institutional decisions seem to have more influence than the expected drivers. This evidence leads us to the conclusion that allowance prices react to distinct fundamentals within this first commitment period.

The remainder of the paper is organized as follows. Section 2 reviews the main drivers of EUA prices. Section 3 estimates the relationship between the daily carbon price changes and energy commodities, meteorological factors and industrial production. Section 4 presents the results. Section 5 concludes.

2 Main drivers of EUA prices

New commodity markets generally need time to achieve real price discovery. As shown in Figure 1, the EUA price pattern experienced a strong volatility during the first two years. Beginning at 8 € on January 1, 2005 EUA prices increased to around 30 € on July 2005, fluctuated during the following six months in the range of 20-25 €, then rose to 30 € until the end of April. On the last week of April, 2006, prices collapsed when operators disclosed 2005 verified emissions data and showed the scheme was oversupplied. After this considerable adjustment by 54% in four days, EUA prices moved in the range from 15 to 20 € until October, 2006. From this date, the EU ETS is sending two price signals responding to different dynamics. Phase I prices are declining towards zero whereas Phase II prices are increasing to 20 € primarily due to the EC which has reaffirmed its will to enforce tighter targets. On April, 2007, verified emissions were again below the 2006 yearly allocation. The EUA spot price seems to react to this new information by moving towards zero. Phase I EUA futures and spot prices are strong correlated whereas EUA Futures prices for delivery in the Phase II are totally disconnected since October, 2006.

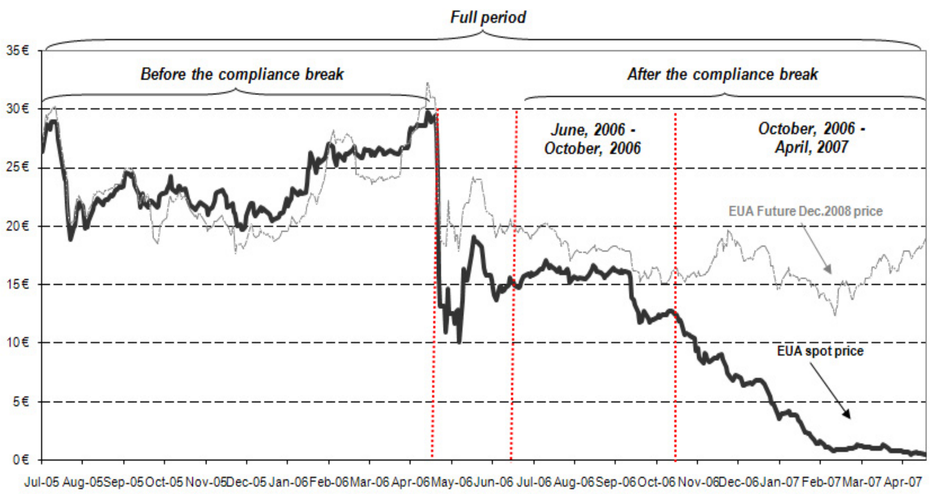

Figure 1: EUA spot prices from July 1, 2005 to April 30, 2007
Source: Powernext carbon

While allowance supply is fixed by each Member States through NAPs, allowance demand is function of the level of CO_2 emissions whose production depends on a large number of factors such as fuel (brent, coal and natural gas) and power (electricity) prices, weather conditions (temperatures, rainfall and wind speed) and economic growth. Until now, the empirical literature focused only on the first two factors.

According to previous literature, energy prices are the most important drivers of carbon prices due to the ability of power generators to switch between their fuel inputs (Kanen, 2006; Christiansen et al., 2005; Bunn and Fezzi, 2007; Convery and Redmond, 2007). This option to switch from natural gas to coal in their inputs represents an abatement opportunity to reduce CO_2 emissions in the short term. High (low) energy prices contribute to an increase (decrease) of carbon prices. This logic is described by Kanen (2006) who identifies brent prices as the main driver of natural gas prices which, in turn, affect power prices and ultimately carbon prices. Power operators also pay close attention to dark and spark spreads and the difference between them. The dark spread is the theoretical profit that a coal-fired power plant makes from selling a unit of electricity having purchased the fuel required to produce that unit of electricity. The spark spread refers to the equivalent for natural gas-fired power plants. With the introduction of carbon costs, dark and spark spreads need to be corrected by EUA prices and thus become respectively clean dark and clean spark spreads. The equilibrium between these clean spreads represents the carbon price above which it becomes profitable for an electric power producer to switch from coal to natural gas, and below which it is beneficial to switch from natural gas to coal. As long as the market carbon price is below this switching price, coal plants are more profitable than gas plants - even after taking carbon costs into account. This switching price is most sensitive to changes in natural gas prices than to coal prices changes (Kanen, 2006). These three profitability indicators are used to determine the preferred fuel in power generation.

By influencing energy demand, weather conditions may have an impact on EUA prices. To the best of our knowledge, only Mansanet-Bataller et al. (2007) show empirical evidence of the impact of weather variables on CO_2 price changes. Yet numerous studies have already highlighted the effect of climate on energy prices[4]. These studies indicate the relationship between temperature and electricity demand is non-linear. Indeed, only both temperature increases and decreases, beyond certain thresholds, can lead to increases in power demand. Warmer summers increase the demand for air conditioning, electricity, and the derived demand for coal. Colder winters increase the demand for natural gas and heating fuel. As a result of increasing (decreasing) their output, power generators will see their CO_2 emissions increase (decrease) which should in return increase (decrease) the demand for allowances.

Some factors are missing in the recent empirical literature of carbon price fundamentals. The overall cap stringency is function of initial allocation but also of economic activity within sectors covered by the EU ETS (Reinaud, 2007). First, political and institutional features impact on the carbon price discovery. As explained above, the gap between initial allocation to industrials and their business-as-usual emission forecasts was problematic. On April, 2006, first disclosures of some EU Member States revealing longs positions caused a sharp fall in the carbon prices. Second, the toughness of the emissions cap depends on the industrial growth in the sectors covered by the EU ETS. These sectors covered by the EU ETS include combustion plants, oil refineries, coke ovens, iron and steel plants, and factories producing cement, gass, lime, brick, ceramics, pulp and paper[5]. More precisely, the emissions net short/long position needs to be balanced with the yearly compliance and the activity trend. If a sector combines a net short (long) position and an increasing (declining) activity trend, then firms in this sector are net buyers (sellers) of allowances and the impact on the allowance price shall be positive (negative). The net position of each sector for the 2005 and 2006 compliance is drawn from the CITL administered by the

EC, according to Trotignon (2007) who computed verified emissions data by sectors and countries.

Section 3 details how to capture those relevant determinants in our models.

3 Data and Econometric Specification

We present first data for carbon and energy prices, weather events and sectoral production used to determine EUA price fundamentals and sub-periods on which fundamentals seem to change. Second, econometric specifications are detailed.

3.1 Data

Since we are mostly interested in the institutional features of the EU ETS pilot phase[6], we conduct an analysis of the EUA spot price which is related to daily transactions. Moreover, installations have not, *a priori*, a daily or hourly need of emission allowances, but they only need to hold allowances matching their emissions levels to their allocation once a year (Reinaud, 2007). Therefore, we do not use intraday or day ahead energy prices but futures Month Ahead prices to provide a better analysis of the EUA spot price due to changes of industrial expectations[7].

3.1.1 The carbon price

The EUA price is determined on several markets, *i.e.* the over-the-counter (OTC), spot and futures markets. The most liquid market is the OTC market. Transactions on this OTC market are usually operated by industrials or brokers. Consequently price data is confidential or available through commercial energy consultancies. The most liquid futures market is the European Climate Exchange and the most liquid spot market is Powernext Carbon. We use the daily EUA spot price (P_t in €/tonne of CO_2) negotiated from July 1^{st}, 2005 to April 30, 2007 on Powernext carbon. The sample period starts at the launch of the Powernext market place and ends at a time when the EUA price path tends towards zero.

3.1.2 Structural breaks

As explained above, the EUA price break occurred on April, 2006 following the report of 2005 verified emissions. The dataset is split in subsamples to get rid of the influence of these extreme price changes.

First, the unit root test by Lee and Strazicich (2003)[8] with two structural breaks has been run on the EUA first natural logarithm price series. Their procedure characterizes the "compliance break" period as going from April 25 to June 23, 2006. This period is excluded from our regressions, except for the whole sample. We therefore statistically identify two main periods in our dataset: "before the compliance break" and "after the compliance break". In April, first disclosures of the Netherlands, Czech Republic, France, and Spain revealing longs positions cause the sharp price break. On May 15th 2006, the official communication by the EC confirmed verified emissions were about 80 million tons or 4% lower than the yearly allocation (Ellerman and Buchner, 2007).

Second, the unit root test by Lee and Strazicich (2001) with one structural break[9] has been run. It proofs statistically the EUA price adjustment when the EC announces the stricter validation of NAPs II[10]. That is why we also identify two sub-periods: "June, 2006 - October, 2006" and "October, 2006 - April, 2007". These breaks are included in our regressions using two dummy variables. $break_1$ is a dummy referring to the period after the structural break on April, 2006 and $break_2$ is a dummy reflecting the period after the EUA price adjustment on October, 2006.

These breakdowns by main periods on the one hand and sub-periods on the other hand are summarized in Figure 1.

3.1.3 Energy prices

On energy markets, the following price series are used. The oil price (*brent* in \$/baril) is the daily brent crude futures Month Ahead price negotiated on the Intercontinental Futures Exchange. To ensure that all energy price series are traded with the same currency, the oil price series is converted to euro using the daily exchange rate provided by the European Central Bank. The natural gas (*ngas* in €/Mwh) is the daily futures Month Ahead natural gas price negotiated on Zeebrugge Hub. The price of coal (*coal* in €/t) is the daily coal futures Month Ahead price CIF ARA.

During 2005-07, natural gas prices exhibit strong volatility compared to coal prices. During the winter 2005, natural gas prices soared to 50€/Mwh and steadily declined afterwards to 20€/Mwh during 2006 and to 10€/Mwh during the first quarter 2007. The competitiveness of natural gas compared to coal therefore improved during 2006 and the first quarter 2007 compared to the winter 2005.

The price of electricity Powernext (*elec* in €/Mwh) is the contract of futures Month Ahead Base. To take account of abatement options for energy industrials and relative fuel prices, three specific spreads are included[11]. First, the Clean dark spread, *clean dark spread* expressed in €/MWh, represents the difference

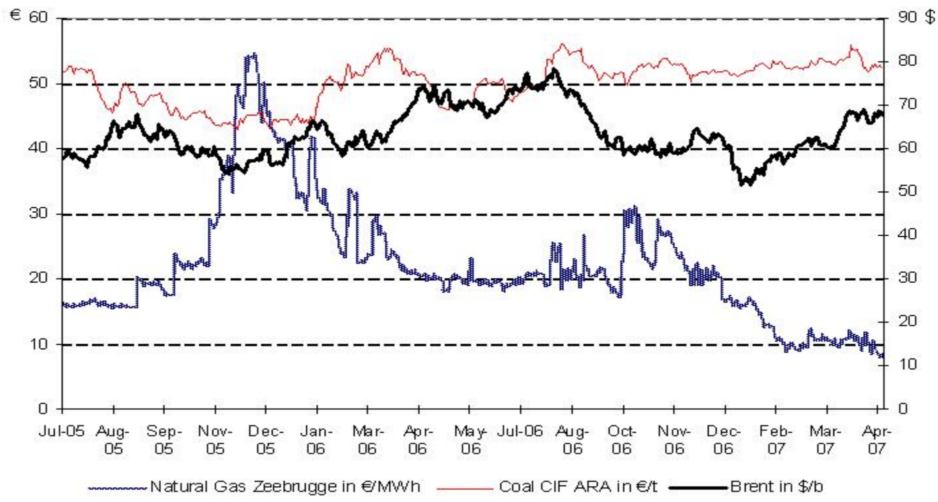

Figure 2: ICE Brent Month Ahead prices, Zeebrugge Natural gas Month Ahead, CIF ARA coal Month Ahead prices from July 1, 2005 to April 30, 2007
Source: Reuters

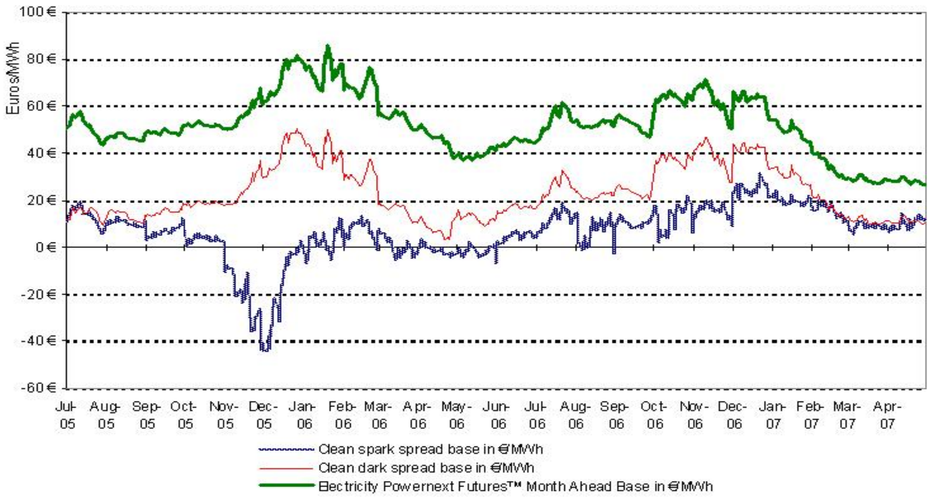

Figure 3: Powernext Futures Month Ahead Base prices, Clean spark spread, Clean dark spread from July 1, 2005 to April 30, 2007
Source: Powernext, Tendances carbone from Caisse des Dépôts

between the price of electricity at peak hours and the price of coal used to generate that electricity, corrected for the energy output of the coal plant. Second, the Clean Spark Spread, *clean spark spread* expressed in €/MWh, represents the difference between the price of electricity at peak hours and the price of natural gas used to generate that electricity, corrected for the energy output of the gas-fired plant. During 2005-06, the use of coal appeared more profitable than gas. Since the beginning of 2007, the difference between clean dark and spark spreads has been narrowing. This situation encourages consequently electric companies to decrease the use of coal to the profit of natural gas.

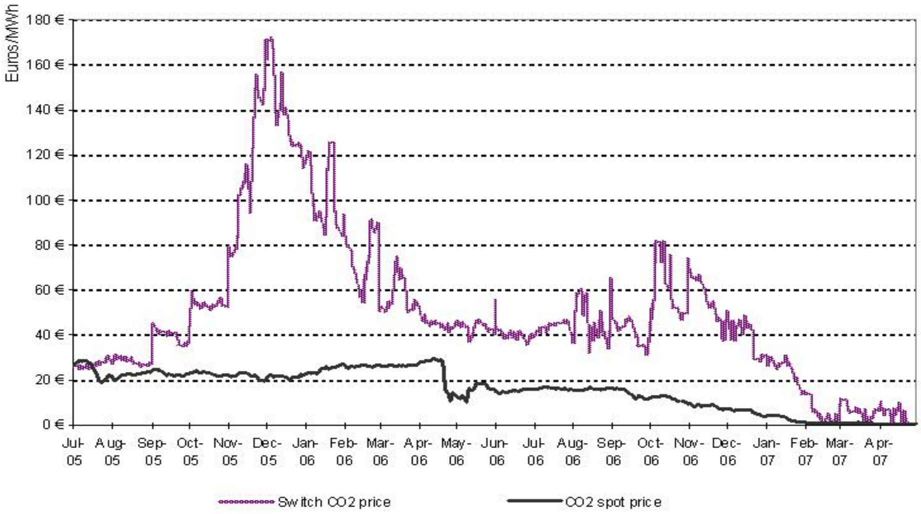

Figure 4: CO_2 spot prices and Switch CO_2 prices from July 1, 2005 to April 30, 2007
Source: Powernext, Tendances carbone from Caisse des Dépôts

Third, the *switch* price of CO_2, expressed in €/MWh, is used as a proxy of the abatement cost. Figure 4 shows on July 2005 and since February 2007, CO_2 spot prices and the *switch* price of CO_2 were very closed suggesting at this carbon price level Emissions abatements may have occurred.

Usual unit root tests (ADF, PP, KPSS) are performed for all price series. All of them are characterized by a unit root and then converted to stationary taking first natural logarithm differences. When tests are applied on series in first differences, they are found to be stationary. In other words, all prices series are integrated of order 1 (I(1))[12].

Following Helfand et al. (2006), energy variables are constructed by computing "one-step ahead" forecast errors for all price series. By doing so, we aim at capturing the role of market uncertainty and modelling new information from unexpected changes in markets and conditions that might affect the CO_2 market.

3.1.4 Temperatures variables

According to previous literature, our investigation focuses on the most important dimension of weather: extremely hot and cold degree-days. The influence of precipitation, wind speed, and other climatic conditions on energy demand is left for further research due to a lack of data availability at the European level. Weather variables are constructed by using the daily data of Powernext Weather indices, expressed in $^{\circ}C$, for four countries: Spain, France, Germany and United Kingdom. These indices are computed as the temperature average at the representative regional weather station weighted by regional population. The Tendances Carbone European temperature index is also used. It is equal to the average of national temperature indices provided by Powernext weighted by the share of each NAP in the previous four countries.

For each of these five temperature series, the deviation from their seasonal average[13] is computed . Two kinds of quantitative weather variables are then obtained: the temperature value and the deviation from their seasonal average expressed in absolute value.

To take into account extreme weather conditions, two kinds of dummy variables are computed. First, following Mansanet-Bataller et al. (2007), we calculate the quintiles from the temperature series and use the lower and upper quintiles to construct two dummy variables representing extremely cold and hot days, termed as respectively $Tempext5$ and $Tempext95$. Second, we depart from previous literature by constructing dummy variables representing some monthly extreme weather events which could have an impact on CO_2 price changes.

After computing and comparing for each country the monthly temperatures average on the full period and its deviation from their seasonal average, the following extreme weather events are selected as dummy variables : July, 2005 (abnormal hot season in Spain), January and February, 2006 (a relatively cold winter in Europe), July, 2006 (relatively hot in Europe), September and October, 2006 (hotter than seasonal averages) and January and February, 2007 (winter hotter than seasonal averages). We want to test the non-linearity of the relationship between temperatures and carbon price changes highlighted in previous literature. Thus, these latter extreme events dummies, the temperature series and the absolute value of their deviation from their seasonal average are used to specify the effect of temperatures during extreme events. In particular, two interaction variables are computed: the cross products between our five extreme weather events dummy variables and either temperature or the absolute value of their deviation from their seasonal average. For instance $Win06 = winter2006 * Temp\_AbsDeviation$ is the product of the dummy variable characteristic of January and February, 2006 ($winter2006$) and the absolute

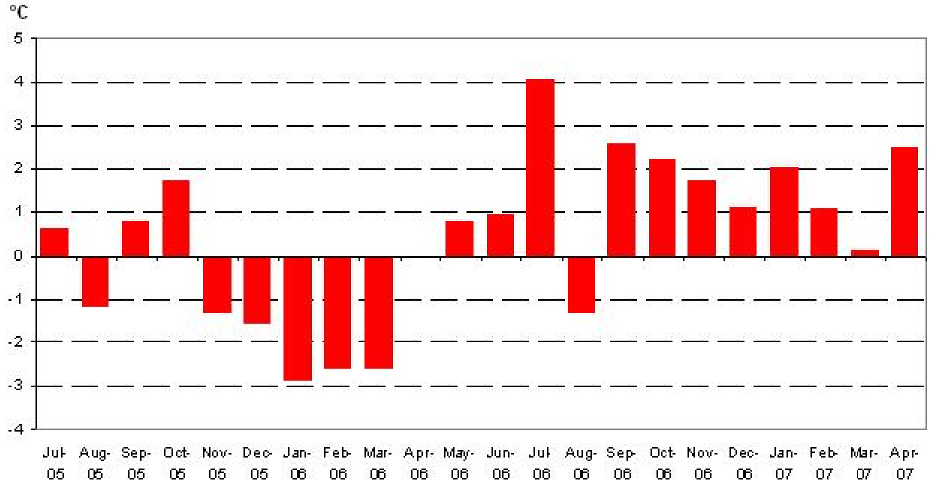

Figure 5: European temperature index: its deviation from their seasonal average
Source: Powernext Weather indices, Tendances carbone from Caisse des Dépôts.

value of the deviation from its mean value of the European temperature index ($Temp\_AbsDeviation$).

3.1.5 Sector indices

EUA prices may be affected by the economic activity of the various sectors covered by the EU ETS. Indeed, economic growth has a major impact on CO_2 emissions and therefore on allowances demand and supply from covered installations. Industrial sectors which result in higher production growth over 2005-07 than their baseline projections are expected to be net buyers of allowances. Conversely, industrial sectors which result in lower production growth than their baseline projections are expected to be net sellers of allowances. Graphs of sectoral net short/long positions during the compliance periods 2005 and 2006 are given in Figures 6 and 7. The data covers Member States which account for three quarters of allowances distributed during the first phase of the EU ETS: France, Germany, Italy, Spain and the United-Kingdom.

Monthly industrial production indices are collected from Eurostat[14] for the paper and board, iron and steel, coke ovens, chemical, glass, cement and combustion[15] industries. At the aggregated level, data are obtained for the EU 27 and the Eurozone. At the country level, data are gathered for most industrial sectors in France, Germany, Italy, Poland, Spain and the UK which account for three quarters of allowances distributed during the first phase of the EU ETS. These data are then resampled to convert monthly indices to daily frequency[16].

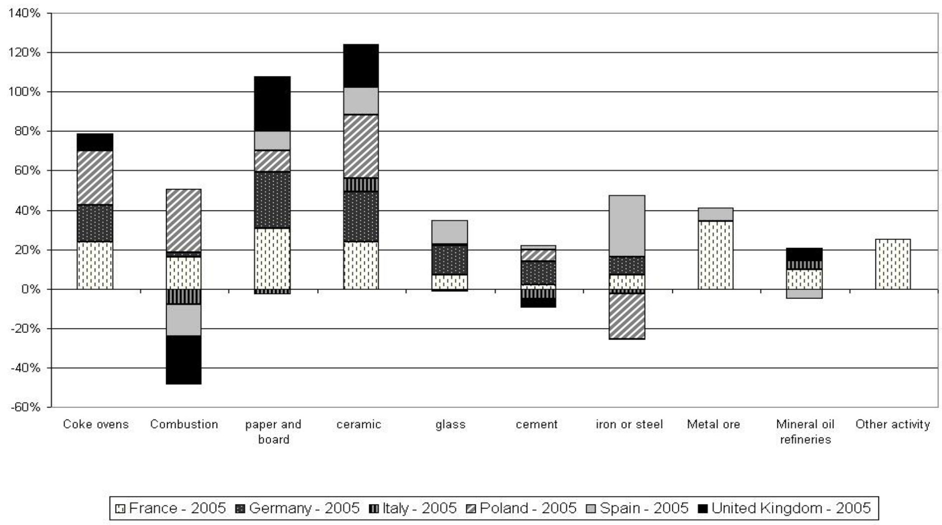

Figure 6: Sectoral Short/Long Positions during 2005 compliance by Member State
Source: Trotignon (2007)

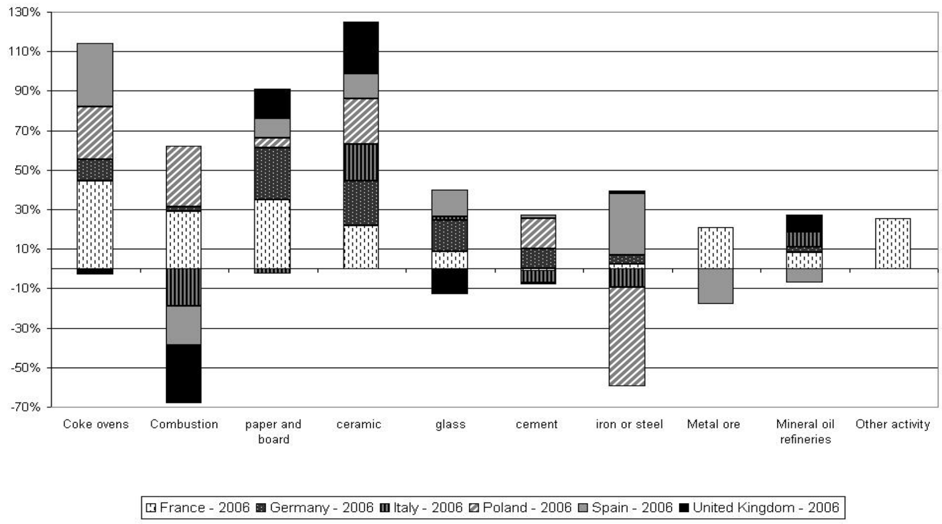

Figure 7: Sectoral Short/Long Positions during 2006 compliance by Member State
Source: Trotignon (2007)

3.2 Econometric specification

We progress incrementally by first verifying in an "Energy model" the role played by energy variables on EUA price changes. Second, temperature variables are added to this "Energy model" . Third, sectoral production indices are included in the ”Energy and temperatures model” . Note that adding step-by-step temperature variables and production indices to the ”base model” also serves as a robustness check for estimates. This estimation strategy is repeated for the full period, the two main periods and the two sub-periods statistically identified in section 3.1.2.

3.2.1 The relationship between carbon prices and energy variables

Equation (1) (eq.(1)) summarizes the ”energy model”:

$$\begin{aligned} p_t = \alpha_i + \beta_i(L)p_t + \chi_i break_1 + \delta_i break_2 + \phi_i(L)brent_t + \varphi_i(L)ngas_t \\ + \gamma_i(L)coal_t + \eta_i(L)switch_t + \iota_i(L)elec_t + \kappa_i(L)clean\ dark_t \\ + \lambda_i(L)clean\ spark_t + \epsilon_{i,t} \end{aligned} \quad (1)$$

where t is the time period under consideration and $i = \{$full period, "before the compliance break", "after the compliance break", "June, 2006 - October, 2006", "October, 2006 - April, 2007"$\}$ corresponding either to the full period or the two main periods or the two sub-periods, p_t is the first log-differenced EUA price series, $break_1$ is a dummy characteristic of the period after the structural break on April, 2006, $break_2$ is a dummy related to the period after October, 2006, $brent_t$ the Brent price series, $ngas_t$ is the Natural gas price series, $coal_t$ is the Coal price series, $switch_t$ is the Switch price series, $elec_t$ is the Electricity price series, $clean\ dark_t$ is the Clean Dark price series, $clean\ spark_t$ is the Clean Spark price series and $\epsilon_{i,t}$ is the error term. All energy price series have been transformed to ”one-step ahead” forecast errors as explained above. L is the lag operator such that $L\ X_t = X_{t-n}$ where n is an integer and polynomes such as $(L)X$ are lag polynomials.

We turn to the next step of our empirical analysis by taking account of temperatures besides the ”energy model”.

3.2.2 The inclusion of temperatures

First, methodology followed by Mansanet-Bataller et al. (2007) is applied by including extreme temperature dummy variables using upper and lower quintiles:

$$\begin{aligned} p_t = \alpha_i + \beta_i(L)p_t + \chi_i break_1 + \delta_i break_2 + \phi_i(L)brent_t + \varphi_i(L)ngas_t \\ + \gamma_i(L)coal_t + \eta_i(L)switch_t + \iota_i(L)elec_t + \kappa_i(L)clean\ dark_t \\ + \lambda_i(L)clean\ spark_t + \Theta_i Temp + \mu_i Tempext5 + \nu_i Tempex95 + \epsilon_{i,t} \end{aligned} \quad (2)$$

where $Temp$ is the European temperature index published by Tendances Carbone, $Tempext5$ and $Tempext95$ are dummy variables characteristic of respectively the lower and the upper quintile drawn from this index. Other variables are explained in eq.(1).

Second, we depart from previous literature by introducing interaction variables explained in section 3.1.4. Consequently, the following equation is introduced:

$$
\begin{aligned}
p_t = {} & \alpha_i + \beta_i(L)p_t + \chi_i break_1 + \delta_i break_2 + \phi_i(L)brent_t + \varphi_i(L)ngas_t \\
& + \gamma_i(L)coal_t + \eta_i(L)switch_t + \iota_i(L)elec_t + \kappa_i(L)clean\ dark_t \\
& + \lambda_i(L)clean\ spark_t + o_i Jul05 + \theta_i Win06 + \vartheta_i Jul06 \\
& + \rho_i Sepoct06 + \sigma_i Win07 + \epsilon_{i,t}
\end{aligned} \tag{3}
$$

where $Jul05$ is the cross product of the dummy variable characteristic of July, 2005 and the absolute value of the deviation from its seasonal average of the Spain national temperatures index ; $Win06$ is the cross product of the dummy variable characteristic of January and February, 2006 and the absolute value of the deviation from its seasonal average of the European temperature index; $Jul06$ is the cross product of the dummy variable characteristic of July, 2006 and the absolute value of the deviation from its seasonal average of the European temperature index; $Sepoct06$ is the cross product of the dummy variable characteristic of September and October, 2006 and the absolute value of the deviation from its seasonal average of the European temperature index; $Win07$ is the cross product of the dummy variable characteristic of January and February, 2007 and the absolute value of the deviation from its seasonal average of the European temperature index. Other variables are explained in eq.(1).

3.2.3 The inclusion of sectoral production indices

The third step consists in adding sectoral production indices to the "energy and temperatures model" (eq.(2) and (3)). Since we depart from the previous literature concerning the inclusion of weather variables, we choose to add our sectoral production indices variables not in eq.(2) but in eq.(3):

$$
\begin{aligned}
p_t = {} & \alpha_i + \beta_i(L)p_t + \chi_i break_1 + \delta_i break_2 + \phi_i(L)brent_t + \varphi_i(L)ngas_t \\
& + \gamma_i(L)coal_t + \eta_i(L)switch_t + \iota_i(L)elec_t + \kappa_i(L)clean\ dark_t \\
& + \lambda_i(L)clean\ spark_t + o_i Jul05 + \theta_i Win06 + \vartheta_i Jul06 + \rho_i Sepoct06 \\
& + \sigma_i Win07 + \varsigma_i cement_{t,j} + \tau_i chem_{t,j} + \upsilon_i coke_{t,j} + \omega_i elecgas_{t,j} \\
& + \xi_i glass_{t,j} + \psi_i metal_{t,j} + \zeta_i paper_{t,j} + \epsilon_{i,t}
\end{aligned} \tag{4}
$$

where $cement_{t,j}$ is the cement production index in country $j =$ {EU27, Germany, Spain, France, Italy, Poland, UK} which applies for all sectors; $chem_{t,j}$

is the production index in the chemicals sector; $coke_{t,j}$ is the production index in the coke ovens sector; $elecgas_{t,j}$ is the production index in the combustion sector (i.e. heating from electricity and gas); $glass_{t,j}$ is the glass production index; $metal_{t,j}$ is the production index in the iron and steel sector and $paper_{t,j}$ is the paper production index.

The next section presents results of these different sets of regressions.

4 Results and Interpretation

Full period results for eq.(1), (2), (3) and (4) are first presented in section 4.1 followed by subsequent main periods (sections 4.2 and 4.3) and sub-periods (sections 4.3.1 and 4.3.2) results. Descriptive statistics may be found in the Appendix (Table 1). The quality of regressions is verified through the following diagnostic tests: the simple R-squared, the adjusted R-squared, the p-value of the F-test statistic ($F - Stat$), the Durbin-Watson statistic ($D.W$), the p-value of the Breush-Godfrey Serial Correlation Lagrange Multiplier test (LM), the p-value of the White heteroskedasticity test ($Whitetest$), the Akaike Information Criterion (AIC) and the Schwartz Criterion (SC). Despite heteroskedasticity as shown by the White test, we comment coefficient estimates obtained by OLS estimator with a Newey-West procedure (NW OLS) rather than GARCH(1,1) estimates since they yield similar results. When there is evidence of heteroskedasticity, the same choice applies in the remainder of the paper to simplify the exposition[17].

4.1 Full period

Energy model

Table 3, row (1) shows results for eq.(1). Both the adjusted R-squared and the R-squared are included between 34% and 35.5%, and, as judged by the F-test P-value, the joint significance of results is accepted at the 1% significance level.

Brent and *switch* variables are not statistically significant at 10% level. The former result is consistent with Kanen (2006) who stated that brent might affect EUA price changes through the natural gas price. The latter result is counter-intuitive since the *switch* variable does not affect EUA prices unlike coal and natural gas and may be explained by a multicollinearity problem.

First, among significant fuel variables, *natural gas* and *spark* impact positively EUA price changes, whereas *coal* and *dark* have negative coefficients. The EU ETS was launched at a time where energy prices were at high levels. The *natural gas* coefficient is positive and significant at 1%. High levels of natural gas lead power operators to realise a switching of their fuel from gas to coal. Natural gas price got higher from October 2005 to April 2006 and thereby influenced positively the EUA price. *Spark* affects EUA price changes with a positive coefficient significant at 10%. During the two years, *dark* stays above *spark* indicating burning coal is more profitable than natural gas, which increases allowances demand. As the most CO_2-intensive variable, *coal* plays a negative role on carbon price changes at 5%. The rationale behind this analysis is that when confronted to a rise of the price of coal relative to other energy markets, firms have an incentive to adapt their energy mix towards less CO_2-intensive energy sources, which conducts to less need of EUAs. Carbon price changes are positively affected by the *electricity* variable. Notwithstanding the power sector was endowed with more than 50% of EUAs, it must be stressed it also was the most constrained sector during the allocation process.

Second, concerning structural change dummies, only the April, 2006 structural break (*break1*) is statistically significant at 10%. The institutional break that occurred following the first report of 2005 verified emissions is far more important than the October, 2006 break. In the first case, a sudden price collapse occurs with most of the adjustment being made in four days, while in the second case a lengthy downward carbon price adjustment is observed. This situation may explain why only *break1* is statistically significant on the full period. This analysis is confirmed by the Chow's test of structural change (Table 2 in the Appendix) which indicates statistical evidence for the two breakpoints.

Energy and temperatures model

Table 3, row (2a) shows results for eq.(2). Note the stability of energy variables coefficients between the two models proofs the robustness of our results. This comment applies in the remainder of the paper. Neither *Tempext5* nor *Tempext95* are statistically significant at 10%. It seems to indicate there is no effect of extremely cold or hot days on CO_2 price changes, which is surprising when compared with previous literature. Still more counter-intuitive is the negative sign of *Tempext95*. When there is extremely cold weather, the use of heating is larger, leading to an increase in energy consumption that should provoke allowance price raising as a result of larger CO_2 emissions (Mansanet-Bataller et al., 2007).

Equation (3) estimates (row (2b)) provide first elements of explanation. Only *win07* is significant and its coefficient is negative. Notice that the coefficient of *win06* is positive, even if this variable is not significant at 10%. In relation to eq.(1) (row (1)), the adjusted R-sqared increases from 34.17% to 35.58%; the AIC and the SC both decrease. Therefore, the "Base model and weather" is more relevant to explain CO_2 price changes. Other weather variables are not significant at 10%: extremely hot days do not seem to impact allowance price levels. Moreover, each of the five temperature series have been included as likely regressors and none of them were statistically significant. We also tried to replace the $win06$ variable (the $win07$ variable) by the cross product of the dummy variable characteristic of January and February, 2006 (January and February, 2007) and the European temperature index, instead of its deviation from its seasonal average expressed in absolute value, but these latter variables were not significant at 10%.

By combining these two results, we deduce two main conclusions. First, we retrieve previous literature results which show the non-linearity of the relationship between temperatures and carbon price changes. Second, we take this analysis one step further by showing that deviations from seasonal average matter more than temperature themselves on CO_2 price changes during extreme weather events. Note that these concluding remarks apply for for extremely cold days but not for extremely hot days.

Energy and temperatures with sectoral production model

As explained in Section 2, the arbitrage between economic activity and the net short/long position within each sector serves as a guide for the comments of Table 6 with energy variables, temperatures and sectoral production indices. When confronted with multicollinearity, results are presented in separate models. As the main comment, losing significance on the structural break dummy *break1* at both aggregated and country levels indicates sectoral analysis contributes to a sharper explanation of the April, 2006 break.

Similar results are obtained for the electricity production sector at the aggregated $Elecgaseu27$ and country levels obtained in France ($Elecgasfr$), Italy ($Elecgasit$) and the UK ($Elecgasuk$). At the aggregated level (Table 6, row (10a)), $Elecgaseu27$ is significant at 5% and positive which may be explained by a declining economic activity trend[18]. In France, the stable combustion economic activity, despite a sharp downturn toward the end of the period, combined with a net long position contribute to explain its positive sign (row (13)) at 1%. In the UK, the positive coefficient reveals the combustion net short position has more effect than its decreasing activity trend at 5% (row (16a)). In Italy, the combustion net short position creates an allowance scarcity explaining the positive coefficient found at 10% despite a relatively declining activity trend (row (14)).

Cement, whose inputs are highly CO_2-intensive, is only statistically significant for the aggregated level (row (10b)) and France (row (13)). *CementEU27* negatively impacts EUA price changes at 10% following a decreasing activity trend since January, 2007. The same result applies for France where the cement sector is characterized by a balanced net position and a stable activity trend.

The paper and board sector is statistically significant in several countries. In Germany, activity peaks in this sector (*Paperde*)coupled with a net long position negatively impact allowance price changes at 10% (row (11)). In Spain, the paper industry (*Paperes*)has a negative impact at 5% (row (12)): the depriming effect of its net long position overwhelms its increasing activity trend. In Italy, this sector (*Paperit*)is positive and significant at 10% (row (14)). It may be explained by activity fluctuations and its net short position. Economic activity varies between countries which explains why we obtain both positive and negative coefficients for the same sector depending on the country considered.

Other remarkable influences of sectoral economic activity include chemicals and coke ovens. In the UK, the chemicals sector (*Chemuk*)has an especially strong impact since, with an increasing activity trend, it negatively affects EUA price changes at 1% (row (16b)). To a lesser extent, a negative impact of the chemicals sector in Poland (*Chempl*), which has a stable economic activity, is found at 10% (row (15b)). *Cokepl* is negative and significant at 5% due to its net long position despite an increasing activity trend (row (15a)).

The Energy and temperatures with sectoral production model is especially rich in Italy (row (14)): two statistically significant sectors were added to those commented above. *Cokeit* positively impact EUA price changes at 5% and is characterized by activity fluctuations. Finally, *Glassit* is at 10% which may be explained by a relatively net short position and strong economic fluctuations.

As evidence of the April, 2006 structural change has been shown in the Energy model results in Section 4.1, we turn to the analysis of the two main periods in sections 4.2 and 4.3.

4.2 Before the compliance break (July, 2005 - April, 2006)

Energy model

Results of eq.(1) are presented in Table 4 (row (3)). The adjusted R-squared is equal to 11%. All diagnostic tests are validated. *gas*, *coal*, *spark* and *dark* are non significant whereas *brent*, *electricity* and *switch* are significant and positive. Both *brent* price[19] and *electricity* are significant at 5%. The sign of *switch*, significant at 10%, is conform to what has been explained in section 2. During the EU ETS first year, agents needed time to discover real price drivers. Thus, the carbon market was largely influenced by the electricity power market since its participants are the main traders on the carbon market.

Like Mansanet-Bataller et al. (2007), we uncover the positive impact of *brent* lagged one and the lack of significance for *coal* on carbon price changes. Some of their results are opposite since they show a positive coefficient for *gas* and the non significance of their equivalent *switch* variable. Yet, since the coal price is relatively stable over the time period considered, having *switch* significant and not *gas* carries the same information as having *gas* significant only. We find overall the same energy fundamentals as Mansanet-Bataller et al. (2007) during the "before the compliance break" period.

Energy and temperatures model

Results of eq.(2) and (3) are presented in Table 4 (row (4a) and (4b)). Compared to full period results, $Tempext95$ remains not significant at 10%. On the contrary, $Tempext5$ becomes significant at 5% and its sign is positive: the cooler the weather, the higher EUA price changes.

Concerning results of eq.(3) (row (4b)), $Win06$ becomes significant at 10%. Its positive sign is consistent with previous literature concerning extremely cold events.

Energy and temperatures with sectoral production model

Results of eq.(4) are presented in Table 7. At the aggregated level, we do not find significant relationships between EUA price changes and sectoral economic activity. Compared to the full period, we observe similar results for the glass sector in Italy (*Glassit*) in row (18) and add the significance of one sector in Germany. Indeed, in row (17) we observe at 10% a negative coefficient for the cement industry ($Cementde$)which is characterized by a net long position and a rather stable economic cycle. Yet it is not possible to include the $Win06$ temperature dummy variable, maybe due to the fact that these climatic events and the sectoral variable under consideration are collinear. In other countries, we were not able to identify any sectoral influences besides energy variables.

4.3 After the compliance break (June, 2006 - April, 2007)

Energy model

Results of eq.(1) are presented in Table 5 (row (5)). The adjusted R-squared is equal to 22%. Following Section 4.1, the *break 2* dummy is re-introduced to verify the presence of another structural change starting on October 26, 2006 within "the after compliance break" period as revealed by the Chow tests (Table 2). Actually, this dummy variable is now significant at 5% and negative.

Compared to the full period, *gas* and *coal* become not statistically significant, whereas *switch* becomes positive and significant at 10%. Energy fundamentals are similar between these two periods since *switch* may be interpreted as a shadow price of natural gas and coal. Besides, *electricity*, *spark* and *dark* remain significant with the same sign and *brent* becomes a positive determinant of EUA price changes at 1%. On the contrary, Energy fundamentals are more CO_2 prices drivers during the "after compliance break" period than during the "before compliance break" period. The publication of 2005 verified emissions creates a behavioral change among market participants given that they had no clear indication about their net short/long position.

Energy and temperatures model

Results of eq.(2) and (3) are presented in Table 5 (row (6a) and (6b)). Concerning eq.(2) estimates, only $Tempext5$ is significant and its sign is negative. Results of eq.(3) estimates indicate only $Win07$ is significant at 5% and its sign is also negative. Comparing results of eq.(2) during the "before the compliance break" period and the "after the compliance break" period *a priori* leads to conclude to the non-robustness of the sign of extremely cold events. Actually, the analysis of eq.(3) estimates during these two periods explains the $Tempext5$ sign change. The lower quintile of the European temperature index ($Tempext5$) corresponds, for the most part, to January and February, 2006 during the "before the compliance break" period and to January and February, 2007 during the "after the compliance break" period. As explained above, the former winter was a very cold winter whereas the latter winter was hot ter than seasonal averages in Europe. Both interaction variables $Win06$ and $Win07$ are significant during respectively the "before the compliance break" period and the "after the compliance break" period. The sign of $Win06$ is positive whereas the sign of $Win07$ is negative. These results indicate that extreme cooling days do have an impact on CO_2 price changes. The sign of this impact depends on deviations of temperatures from their seasonal average and not on temperatures themselves. When extremely cold events are colder (hotter) than expected, power generators have to produce more (less) than they forecasted which conducts to an increase (decrease) of allowances demand and finally to an increase (decrease) of CO_2 price changes. Forecasting errors on temperatures seem to matter more than temperature themselves during extremely cold events when one tests for the influence of climatic events on CO_2 price changes.

Energy and temperatures with sectoral production model

Results of eq.(4) are presented in Table 7. Compared to the full period, we observe similar results only for the French electricity production sector ($Elecgasfr$)(row (21))[20]. Except for Germany and France, losing significance on *Break 2* strenghthens our analysis with production indices as explained above.

Among new results, the glass industry has a significant impact at 10% in Germany ($Glassde$)and at 5% in France ($Glassfr$). In Germany, the positive coefficient is explained by the net long position and a stable activity trend (row

(20)). In France, an opposite conclusion is reached: *Glassfr* negatively affects EUA price changes due to a net long position and activity peaks (row (21)).

Besides, the coke ovens sector emerges as a significant determinant of EUA price changes in the Eurozone (*Cokeeuro*)and the UK (*Cokeuk*), both at 5%. At the aggregated level, the negative coefficient is explained by a rather stable economic activity with peaks toward the end of the period (row (19)). The UK sector is characterized by strong economic fluctuations and a balanced net position which explains its negative sign (row (23)). Note also that due to colinearity with the *Glassde* and *Cokeuk*, *Win*07 cannot be included but it is significant at 1% in the Eurozone.

In Italy, strong econonomic fluctuations in the cement sector (*Cementit*) negatively affect EUA price changes despite a net short position (row (22)). *Metalit* positively impacts the allowance price due to a net short position and an increasing activity trend.

As evidence of the October, 2006 structural change has been shown in the "Energy model" results in Section 4.3, we turn to the analysis of the two subperiods in sections 4.3.1 and 4.3.2.

4.3.1 June, 2006 - October, 2006

EUA prices are disconnected from almost all types of fundamentals during this specific period. Results of eq.(1), presented in Table 5 (row (7)), highlight market participants' wait-and-see behaviour since no energy variables except *brent* influence EUA price changes. They integrate in their expectations the revelation of the global long position at the installation level. Furthermore, they are expecting the 2008-2012 NAPs validation by the EC. Market agents are sensitive to the diffusion of these new information. Neither temperatures nor sectoral production variables have been EUA price changes drivers.

4.3.2 October, 2006 - April, 2007

Energy model

Results of eq.(1) are presented in Table 5 (row (8)). After the first compliance and EC decisions on 2008-2012 allocation, EUA price changes respond to the same energy variables as during the "after the compliance break" period (row (5)) in a context of fuel prices decrease. This situation reflects a delayed adjustment of the EUA market to the Brent price peak, as explained by market specialists.

Energy and temperatures model

Results of eq.(2) and (3) are presented in Table 5 (row (9a) and (9b)). As during the "after the compliance break " period, results indicate only extremely cold events have a statistically significant and negative impact on carbon price changes. As explained above, the negative sign of $Win07$ highlights it is not temperatures themselves but forecast errors which have an impact on CO_2 price changes during extreme weather events.

Energy and temperatures with sectoral production model

Results of eq.(4) are presented in Table 8. Compared to the full period, similar results are found for *Glassde* (row (25a)), $Elecgasfr$ (row (26a)), $Cokeit$ and *Glassit* (row (27a))[21]. Compared to the "after compliance break" period, similar results are found for *Cokeeuro* (row (24a)) and $Metalit$ (row (27b)).

Among new results, $Metaleuro$ has a positive impact on EUA prices at 5% due to a strong economic activity (row (24b)). Similarly, $Metalde$ with a net long position and a slightly increasing economic activity has a positive coefficient (row (25b)). Finally, $Chemfr$ positively affect EUA prices at 5% despite economic downturns (row (26b)).

As a global conclusion, the effects of sectoral production on EUA price changes are not linear. If the combustion sector appears to be the main driver over the full period sample, this relationship does not hold in first period while in second period the negative impact of the coke ovens sector has been emphasized. At the country level, most relationships hold between the whole period and subsequent sub-periods for the paper and board industry in Germany, the combustion sector in France, the coke ovens and glass sectors in Italy. In the case of France, sectoral production impacts match closely the impacts at the aggregated level. Finally, the sectoral production analysis seems especially relevant in Italy where a wide variety of sectors have been identified as key determinants of EUA prices.

5 Summary and concluding remarks

The EUA price collapse that occurred on April, 2006 after the first compliance of highlights the necessity to understand the underlying mechanisms of carbon price changes. Theoretical studies identified three types of fundamentals: energy prices, weather influences and economic growth. The empirical analysis of the daily spot carbon price conducted in this article clearly identifies these fundamentals during the EU ETS pilot phase (2005-2007) and besides the influence of the institutional context.

The main result features drivers of carbon price changes vary before and after two structural breaks on April, 2006 following the disclosure of 2005 verified emissions and on October, 2006 following the European Commission announcement of stricter Phase II allocation. It emphasizes the existence of different fundamentals as a consequence of the revelation of institutional information. These results suggest before the revelation of the net short/long emission position by country on April, 2006, allowance trading was based on heterogenous anticipations prior to information disclosure since EUA prices do react to some, but not all, mechanisms that has been highlighted for the full period.

First, our results point out that energy drivers change over 2005-2007. Brent, Natural gas, Coal, Electricity, Clean Dark, Clean Spark and Switch prices all impact significantly carbon spot prices, but their influence vary following the structural breaks and the sub-periods under consideration.

Second compared to previous literature, the analysis on temperatures influences is extended by considering not only extreme temperatures, but also unanticipated temperature changes by market agents. First, we retrieve previous literature results showing the non-linearity of the relationship between temperatures and carbon price changes. Second, we show that forecasting errors on temperatures matter more than temperature themselves on CO_2 price changes during extreme weather. Note that these concluding remarks only hold for extremely cold days and not for extremely hot days.

Finally, this article brings in a new line of research by showing that EUA price changes also react to economic activity of the main sectors covered by the EU ETS as influenced by their emissions net short/long position. Other areas for future research include the effects of precipitation and wind speed on energy demand and EUA price changes.

On April, 2007 the second compliance disclosed that verified emissions were about 30 million tons or 1.45% lower than the 2006 allocation. In a context of the impossible transfers of allowances from Phase I to Phase II, the EUA spot price seems to react to this new information by moving towards zero. The Phase II spot price now serves as a guide for investors on the medium and long term to conduct to less CO_2-intensive production processes.

Acknowledgements The authors are grateful to the Climate Task Force of the Caisse des Dépôts for the use of their Tendances Carbone database, to C. de Perthuis for his intuitions of the EU ETS development presented on April, 2007 at the First Workshop "Evaluation of the EU ETS" of the Joint Research Program between the MIT, the UCD, the University Paris-Dauphine and the Caisse des Dépôts. The authors thank Pr. V. Mignon (University Paris-X) for her precious reading on earlier drafts. The usual disclaimer applies.

Notes

[1]See the Community Independent Transaction Log (CITL) available at http://ec.europa.eu/environment/ets/, accessed on August, 2007.

[2]CO_2 price changes are defined as the first log-differenced carbon price series $p_t = ln\,(P_t/P_{t-1})$, with P_t the daily EUA spot price at time t.

[3]NAPs determine the total quantity of allowances allocated to installations.

[4]For an extensive literature review on this topic, see Li and Sailor (1995); Springer (2003); Mansanet-Bataller et al. (2007).

[5]The main sector whose share is the largest in terms of emissions covered by the EU ETS in Phase I is the power sector, which accounts for over 50% of emissions capped by the scheme. Their emissions abatement costs are assumed to be the lowest compared to others sectors, notably through fuel switching from coal to gas (Reinaud, 2007).

[6]*i.e.* all allowances need to be surrendered by the end of December, 2007.

[7]Thereby reflecting the fact that most energy needs are met by forward contracting.

[8]Their GAUSS codes may be found at http://www.cba.ua.edu/ jlee/gauss/, accessed on August, 2007.

[9]The model with one structural change in the intercept or level of the time series provides an estimated breakpoint on October, 26th 2006.

[10]The EU Environment Commissionner, Stavos Dimas, said on October 23, 2006 that according to the EC calculations, allocation plans submitted for Phase II seek to allocate 15% more allowances than the amount that would cover the same countriesâĂŹ2005 emissions.

[11]As calculated by the Caisse des Dépôts–Climate Task Force for Tendances carbone. The methodology is available on the website http://www.caissedesdepots.fr, accessed on August, 2007.

[12]Detailed results of the unit root tests are available upon request to the authors.

[13]Seasonal averages are calculated between 1986 and 2007.

[14]Each industrial production index has a base 100 in 2000 and is seasonally adjusted. Classification NACE Rev.1 C-F, available at http://ec.europa.eu/eurostat, accessed on August, 2007.

[15]Specifically, the index of production and distribution of electricity, gas and heating.

[16]Using the MATLAB interpolation function by L. Shure. See IEEE (1979) for reference.

[17]See "Details on estimation procedures and tables" in Appendix.

[18]Due to the complexity of the analysis for the EU 27, it appears difficult to further comment on the net short/long position of this sector.

[19]This variable is lagged one because it loses its significance without lag.

[20]Note that despite the non-significance of *spark* at 11%, we choose to keep it to preserve coefficients stability. A reduced model without *spark* does not change either the sign or the significance of other coefficient estimates.

[21]Despite the non-significance of *spark* at 11%, it is preserved for the same reasons as explained in Section 4.3.

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6 Appendix

A. Descriptive and Chow Breakpoint Test Statistics

Full period[a]	Mean	Median	Max	Min	Std. Dev.	Skew.	Kurt.	N
p_t	-0.01	0.01	0.30	-0.47	0.06	-1.33	14.71	483
Brent	0.01	0.01	3.76	-2.97	1.07	-0.02	2.80	483
Natural Gas	0.01	-0.15	11.54	-10.57	1.67	0.99	14.81	483
Coal	0.01	-0.00	0.55	-0.24	0.07	1.29	13.61	483
Switch	0.01	-0.54	42.37	-38.60	6.16	0.97	14.73	483
Electricity	0.01	-0.23	24.99	-19.40	3.78	0.90	15.51	483
Dark	0.01	-0.07	16.05	-11.70	2.09	1.09	19.83	483
Spark	0.01	0.15	13.56	-19.34	3.18	-0.99	10.89	483

Table 1: Descriptive Statistics

[a]for the full period sample with p_t the first log-differenced EUA price series, all energy variables transformed in forecast errors, *StdDev.* the standard deviation, *Skew.* the skewness, *Kurt.* the kurtosis and *N* the number of observations.

Full period	Probability	F-statistic
Base model[a]	0.0000	112.1917

"After the compliance break" period	Probability	F-statistic
Base model[b]	0.0316	16.8623

Table 2: Chow Breakpoint Test statistics

[a]Results for breakpoints on June 20, 2006 and October 25, 2006.
[b]Results for breakpoint on October 25, 2006.

6.1 B. Details on estimation procedures and tables

In all tables, the dependent variable is the first log-differenced EUA price series with $p_t(-1)$ and $p_t(-2)$ its lagged 1 and 2 values respectively. Other variables are explained in Section 3. As usual, *** indicates significance at 1%, ** at 5% and * at 10%.
Ordinary least squares estimator with a Newey-West Heteroscedastic-Consistent Covariance Matrix (HCCM) is used (NW OLS), which corrects residuals to adjust for both heteroskedasticity and autocorrelation. Unless otherwise indicated, all regression results are presented in reduced form. Different lags

were included for energy variables which yield similar results. To simplify the exposition, we generally present the results without lag except for specific cases. As is standard the simple R-squared, the adjusted R-squared, the p-value of the F-test statistic ($F - Stat$), the Durbin-Watson statistic ($D.W.$), the Akaike Information Criterion (AIC) and the Schwartz Criterion (SC) are reported. We also report three additional diagnostic tests for the quality of the regressions: the p-value of the the Breusch-Godfrey Serial Correlation Lagrange Multiplier test (LM) and the p-value of the White heteroskedasticity test ($White\ test$).

Note the White test shows evidence of heteroskedasticity in some NW OLS estimates, which is a standard result when using daily time-series. When necessary, we capture this heteroskedasticity by calibrating the data with a GARCH(p, q) model. For the mean equation we choose the same AR process from the corresponding equation estimated by NW OLS, while for the variance equation we test different GARCH specifications. Parameter estimates for higher orders of p or q are not significant for all equations. Thus, we perform the most commonly used GARCH(1,1) model using Bollerslev-Wooldrige robust standard errors and covariance. As shown in Table 9, the two estimation procedures yield similar results in the mean equation with positive coefficient estimates in the variance equation (*ARCH(1)* and *GARCH(1)*). Thus and to simplify the exposition, our comments are only based on coefficient estimates obtained from NW OLS.

	Full Period		
	Energy	Energy & temp	
	(1)	(2a)	(2b)
Pt(-1)	0.2129***	0.2118***	0.1979***
	(0.0754)	(0.0755)	(0.0747)
Pt(-2)	-0.0980*	-0.0989*	-0.1123*
	(0.0579)	(0.0583)	(0.0588)
Constant	0.0006	0.0013	0.0005
	(0.0023)	(0.0026)	(0.0024)
Break 1	-0.0165***	-0.0175***	-0.0125***
	(0.0054)	(0.0057)	(0.0049)
Break 2	-	-	-
Brent	-	-	-
Brent(-1)			
Natural Gas	0.0730***	0.0732**	0.0736**
	(0.0300)	(0.0305)	(0.0306)
Coal	-0.0999**	-0.0978**	-0.1018**
	(-0.0471)	(0.0470)	(0.0471)
Switch	-	-	-
Electricity	0.0083***	0.0082***	0.0079***
	(0.0027)	(0.0027)	(0.0027)
Clean Dark	-0.0525***	-0.0527***	-0.0526***
	(0.0146)	(0.0148)	(0.0148)
Clean Spark	0.0394**	0.0396**	0.0398**
	(0.0167)	(0.0169)	(0.0170)
Tempext5		-0.0097	
		(0.0068)	
Tempext95		0.0056	
		(0.0663)	
Win06			-
Win07			-0.0074**
			(0.0035)
R-squ.	0.3543	0.3560	0.3694
Adj. R-squ.	0.3417	0.3407	0.3558
F-Stat	0.0000	0.0000	0.0000
D.W.	1.8892	1.8944	1.8900
LM test	0.1155	0.1277	0.1472
White test	0.0001	0.0002	0.0000
AIC	-3.3030	-3.2974	-3.3226
SC	-3.2153	-3.1920	-3.2260
Procedure	NW OLS	NW OLS	NW OLS

Table 3: Results of eq.(1),(2),(3)

	"Before the compliance break"		
	Energy	Energy & temp	
	(3)	(4a)	(4b)
Pt(-1)	0.0850*	0.0874*	0.0851*
	(0.0502)	(0.0489)	(0.0481)
Constant	0.0001	-0.0004	-0.0005
	(0.0016)	(0.0018)	(0.0018)
Brent(-1)	0.0033**	0.0030**	0.0030**
	(0.0015)	(0.0015)	(0.0015)
Natural Gas	-	-	-
Coal	-	-	-
Switch	0.0004*	0.0004**	0.0004**
	(0.0002)	(0.0002)	(0.0002)
Electricity	0.0012**	0.0013**	0.0013**
	(0.0005)	(0.0005)	(0.0005)
Clean Dark	-	-	-
Clean Spark	-	-	-
Tempext5		0.0073**	
		(0.0037)	
Tempext95		-0.0018	
		(0.0064)	
Win06			0.0018*
			(0.0011)
Win07			
R-squ.	0.1311	0.1346	0.1327
Adj. R-squ.	0.1100	0.1047	0.1072
F-Stat	0.0000	0.0000	0.0000
D.W.	1.9038	1.9404	1.9257
LM test	0.2306	0.4861	0.2906
White test	0.1113	0.1635	0.1513
AIC	-4.6690	-4.6703	-4.6777
SC	-4.5740	-4.5433	-4.5665
Procedure	NW OLS	NW OLS	NW OLS

Table 4: Results of eq.(1),(2),(3) continued

	"After the compliance break"			*Jun06-Oct06*	*Oct06-Apr07*		
	Energy	Energy & temp		Energy	Energy	Energy & temp	
	(5)	(6a)	(6b)	(7)	(8)	(9a)	(9b)
Pt(-1)	0.3485***	0.3444***	0.3321***	0.2776***	0.3573***	0.3532***	0.3362***
	(0.0788)	(0.0792)	(0.0805)	(0.0985)	(0.0859)	(0.0863)	(0.0889)
Pt(-2)	-0.1940**	-0.1934**	0.2157**		-0.2007**	-0.2003**	-0.2255**
	(0.0931)	(0.0933)	(0.0934)		(0.1009)	(0.1010)	(0.1015)
Constant	-0.0046*	-0.0040	-0.0094**	-0.0021	-0.0158**	-0.0149**	-0.0117*
	(0.0028)	(0.0031)	(0.0038)	(0.0021)	(0.0069)	(0.0070)	(0.0070)
Break 2	-0.0132**	-0.0129*	-				
	(0.0066)	(0.0068)					
Brent	0.0107***	0.0107***	0.0106***	0.0072**	0.0139**	0.0139**	0.0137**
	(0.0035)	(0.0035)	(0.0034)	(0.0033)	(0.0057)	(0.0058)	(0.0056)
Natural Gas	-	-	-	-	-	-	-
Coal	-	-	-	-	-	-	-
Switch	0.0088*	0.0089*	0.0090*	-	0.0101**	0.0100**	0.0097*
	(0.0049)	(0.0051)	(0.0054)		(0.0050)	(0.0051)	(0.0053)
Electricity	0.0093*	0.0089***	0.0079***	-	0.0116***	0.0110***	0.0095***
	(0.0024)	(0.0024)	(0.0022)		(0.0031)	(0.0030)	(0.0029)
Clean Dark	-0.0297*	-0.0293***	-0.0283***	-	-0.0310***	-0.0300***	-0.0279***
	(0.0101)	(0.0103)	(0.0108)		(0.0101)	(0.0103)	(0.0106)
Clean Spark	0.0167*	0.0169*	0.0173	-	0.0150*	0.0144*	0.0144
	(0.0099)	(0.0103)	(0.0110)		(0.0083)	(0.0085)	(0.0090)
Tempext5		-0.0302***		-		-0.0269***	
		(0.0090)				(0.0096)	
Tempext95		-0.0031		-		-	
		(0.0060)					
Win06		-	-				
Win07			-0.0042**	-			-0.0035*
			(0.0017)				(0.0018)
R-squ.	0.2541	0.2586	0.2673	0.1532	0.2506	0.2544	0.2656
Adj. R-squ.	0.2216	0.2188	0.2353	0.1336	0.2003	0.1975	0.2096
F-Stat	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
D.W.	1.9606	1.9829	1.9735	1.9745	1.9456	1.9641	1.9604
LM test	0.7865	0.9962	0.9570	0.2951	0.8367	0.9600	0.7492
White test	0.0002	0.0005	0.0003	0.0358	0.4744	0.4850	0.4262
AIC	-2.9796	-2.9672	-2.9975	-4.7598	-2.5074	-2.4968	-2.5119
SC	-2.8239	-2.7803	-2.8418	-4.6759	-2.3068	-2.2734	-2.2891
Procedure	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS

Table 5: Results of eq.(1),(2),(3) continued

Full Period	Aggregated level		Germany	Spain	France	Italy	Poland		UK	
	(10a)	(10b)	(11)	(12)	(13)	(14)	(15a)	(15b)	(16a)	(16b)
Pt(-1)	0.1929***	0.1999***	0.1985***	0.1998***	0.1864***	0.1840**	0.2000***	0.2000***	0.1979***	0.1973***
	(0.0749)	(0.0747)	(0.0743)	(0.0743)	0.0739	(0.0757)	(0.0739)	(0.0743)	(0.0742)	(0.0741)
Pt(-2)	-0.1193**	-0.1120**	-0.1151**	-0.1110*	-0.1250**	-0.1251**	-0.1121*	-0.1124**	-0.1123**	-0.1134**
	(0.0577)	(0.0579)	(0.0593)	(0.0589)	(0.0573)	(0.0569)	(0.0582)	(0.0587)	(0.0580)	(0.0573)
Constant	-0.3561***	-0.1385*	0.1747	0.2624**	-0.1530*	-0.7033**	0.0243*	0.0620	-0.2110**	0.3010***
	(0.1259)	(0.0766)	(0.1096)	(0.1217)	(0.0916)	(0.2778)	(0.0141)	(0.0400)	(0.0849)	(0.0932)
Break 1	-	-	-	-	-	-	-	-	-	-
Natural Gas	0.0735**	0.0728**	0.0717**	0.0714**	0.0734**	0.0794**	0.0702**	0.0707**	0.0716**	0.0711**
	(0.0303)	(0.0299)	(0.0295)	(0.0296)	(0.0300)	(0.0338)	(0.0290)	(0.0291)	(0.0295)	(0.0292)
Coal	-0.1092**	-0.1013**	-0.0982**	-0.0974**	-0.1110**	-0.1203**	-0.0982**	-0.0986**	-0.1029**	-0.1015**
	(0.0479)	(0.0464)	(0.0459)	(0.0462)	(0.0476)	(0.0535)	(0.0462)	(0.0460)	(0.0467)	(0.0463)
Electricity	0.0078***	0.0080***	0.0081***	0.0082***	0.0079***	0.0074***	0.0083***	0.0082***	0.0081***	0.0082***
	(0.0027)	(0.0027)	(0.0026)	(0.0026)	(0.0027)	(0.0028)	(0.0026)	(0.0026)	(0.0026)	(0.0026)
Clean Dark	-0.0524***	-0.0522***	-0.0518***	-0.0518***	-0.0524***	-0.0555***	-0.0514***	-0.0514***	-0.0517***	-0.0516***
	(0.0146)	(0.0145)	(0.0144)	(0.0145)	(0.0145)	(0.0160)	(0.0142)	(0.0143)	(0.0144)	(0.0142)
Clean Spark	0.0398**	0.0393**	0.0387**	0.0385**	0.0398**	0.0434**	0.0379**	0.0382**	0.0388**	0.0384**
	(0.0168)	(0.0167)	(0.0164)	(0.0164)	(0.0167)	(0.0189)	(0.0161)	(0.0162)	(0.0164)	(0.0162)
Win07	-0.0071**	-0.0060*	-0.0061*	-0.0086**	-0.0076**	-0.0063*	-0.0086**	-0.0071**	-0.0089**	-0.0084**
	(0.0035)	(0.0035)	(0.0037)	(0.0036)	(0.0035)	(0.0034)	(0.0036)	(0.0036)	(0.0036)	(0.0036)
Elecgaseu27	0.0032***									
	(0.0011)									
Cementeu27		-0.0013*								
		(0.0007)								
Paperde			-0.0016*							
			(0.0010)							
Paperes				-0.0024**						
				(0.0011)						
Elecgasfr					0.0021***					
					(0.0007)					
Cementfr					-0.0007*					
					(0.0004)					
Elecgasit						0.0012*				
						(0.0007)				
Paperit						0.0028*				
						(0.0016)				
Cokeit						0.0050**				
						(0.0021)				
Glassit						-0.0017*				
						(0.0009)				
Cokepl							-0.0003**			
							(0.0001)			
Chempl								-0.0004*		
								(0.0002)		
Elecgasuk									0.0020**	
									(0.0008)	
Chemuk										-0.0029***
										0.0009
R-squ.	0.3736	0.3653	0.3666	0.3647	0.3818	0.3924	0.3638	0.3638	0.3660	0.3660
Adj. R-squ.	0.3601	0.3516	0.3529	0.3510	0.3671	0.3753	0.3501	0.3500	0.3523	0.3523
F-Stat	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
D.W.	1.8902	1.8832	1.8843	1.8845	1.9011	1.9269	1.8809	1.8806	1.8830	1.8821
LM test	0.1489	0.1310	0.1238	0.1176	0.1946	0.3281	0.1030	0.1054	0.1122	0.1121
White test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AIC	-3.3293	-3.3161	-3.3181	-3.3152	-3.3382	-3.3471	-3.3138	-3.3137	-3.3173	-3.3172
SC	-3.2327	-3.2195	-3.2215	-3.2186	-3.2329	-3.2242	-3.2173	-3.2171	-3.2207	-3.2206
Procedure	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS

Table 6: Results of eq.(4) - Energy and temperatures with sectoral production model

	"Before the compliance break"		"After the compliance break"				
	Germany (17)	Italy (18)	Aggregated level (19)	Germany (20)	France (21)	Italy (22)	UK (23)
Pt(-1)	0.0873*	0.0856*	0.3157***	0.2086***	0.3026***	0.3093***	0.3439***
	(0.0502)	(0.0497)	(0.0813)	(0.0810)	0.0828	(0.0841)	(0.0843)
Pt(-2)			-0.2301**	-0.2092**	-0.2412***	-0.2363***	-0.2001**
			(0.0904)	(0.0897)	(0.0885)	(0.0892)	(0.0871)
Constant	0.0243*	-0.1053*	-0.2597**	-0.1210*	0.2963	-0.03547*	-0.0698*
	(0.0142)	(0.0569)	(0.1333)	(0.0677)	(0.3389)	(0.2126)	(0.0380)
Break 2			-	-0.0300***	-0.0122**	-	-
				(0.0097)	(0.0063)		
Brent			0.0114***	0.0096***	0.0115***	0.0106***	0.0096***
			(0.0034)	(0.0032)	(0.0034)	(0.0034)	(0.0033)
Brent (-1)	0.0030**	0.0028*					
	(0.0015)	(0.0015)					
Switch	0.0004**	0.0004**	0.0075*	0.0104*	0.0082*	0.0083*	0.0097*
	(0.0002)	(0.0002)	(0.0047)	(0.0065)	(0.0050)	(0.0051)	(0.0056)
Electricity	0.0012**	0.0013**	0.0076***	0.0091***	0.0078***	0.0076***	0.0093***
	(0.0005)	(0.0005)	(0.0022)	(0.0025)	(0.0023)	(0.0022)	(0.0023)
Clean Dark			-0.0252***	-0.0325***	-0.0264***	-0.0267***	-0.0315***
			(0.0096)	(0.0125)	(0.0101)	(0.0104)	(0.0110)
Clean Spark			0.0144	0.0202	0.0157	0.0161	0.0188*
			(0.0094)	(0.0131)	(0.0100)	(0.0103)	(0.0113)
Win06	-	-					
Win07			-0.0044***	-	-0.0031*	-0.0030*	-
			(0.0017)		(0.0019)	(0.0018)	
Cementde	-0.0003*						
	(0.0002)						
Glassit		-0.0010*					
		(0.0005)					
Cokeeuro			-0.0029**				
			(0.0014)				
Glassde				0.0012*			
				(0.0007)			
Elecgasfr					0.0038**		
					(0.0016)		
Glassfr					-0.0073**		
					(0.0036)		
Cementit						-0.0057**	
						(0.0024)	
Metalit						0.0096**	
						(0.0040)	
Cokeuk							-0.0011**
							(0.0005)
R-squ.	0.1339	0.1365	0.2840	0.2670	0.2992	0.2895	0.2604
Adj. R-squ.	0.1079	0.1111	0.2493	0.2361	0.2628	0.2513	0.2329
F-Stat	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
D.W.	1.9236	1.9246	1.9901	1.9787	2.0084	1.9874	1.9656
LM test	0.2676	0.2627	0.9903	0.9900	0.9113	0.9766	0.9083
White test	0.1452	0.0480	0.0001	0.0000	0.0002	0.0004	0.0005
AIC	-4.6785	-4.6820	-3.0114	-3.0245	-3.0520	-3.0098	-3.0250
SC	-4.5673	-4.5708	-2.8401	-2.9726	-2.8692	-2.8229	-2.8879
Procedure	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS

Table 7: Results of eq.(4) continued

Oct06-Apr07	Aggregated level		Germany		France		Italy	
	(24a)	(24b)	(25a)	(25b)	(26a)	(26b)	(27a)	(27b)
Pt(-1)	0.3206***	0.3174***	0.3290***	0.3217***	0.3171***	0.3202***	0.3108***	0.3149***
	(0.0897)	(0.0906)	0.0898	(0.0903)	(0.0924)	(0.0901)	(0.0930)	(0.0901)
Pt(-2)	-0.2383**	-0.2422***	-0.2335**	-0.2396**	-0.2433***	-0.2405**	-0.2506***	-0.2444***
	(0.0979)	(0.0968)	(0.0989)	(0.0972)	(0.0962)	(0.0971)	(0.0945)	(0.0952)
Constant	0.2733*	-1.0998**	-0.5518*	-0.8041**	-0.4034**	-1.0570**	-1.118	-0.5224*
	(0.1603)	(0.5576)	(0.3287)	(0.4111)	(0.1990)	(0.5190)	(0.9024)	(0.2709)
Brent	0.0148***	0.0147***	0.0137**	0.0142***	0.0139**	0.0143***	0.0143***	0.0157***
	(0.0057)	(0.0056)	(0.0056)	(0.0056)	(0.0057)	(0.0056)	(0.0052)	(0.0053)
Switch	0.0081*	0.0085*	0.0104*	0.0092**	0.0090*	0.0091*	0.0088*	0.0074*
	(0.0047)	(0.0049)	(0.0058)	(0.0050)	(0.0050)	(0.0051)	(0.0049)	(0.0042)
Electricity	0.0090***	0.0093***	0.0097***	0.0094***	0.0092***	0.0093***	0.0086***	0.0085***
	(0.0028)	(0.0028)	(0.0029)	(0.0028)	(0.0028)	(0.0028)	(0.0027)	(0.0027)
Clean Dark	-0.0245***	-0.0258***	-0.0294***	-0.0267***	-0.0265***	-0.0266***	-0.0260***	-0.0236***
	(0.0095)	(0.0099)	(0.0116)	(0.0103)	(0.0101)	(0.0103)	(0.0103)	(0.0092)
Clean Spark	0.0114	0.0123	0.0161	0.0136	0.0133	0.0136	0.0138	0.0111
	(0.0076)	(0.0081)	(0.0103)	(0.0086)	(0.0085)	(0.0087)	(0.0090)	(0.0075)
Win07	-0.0041**	-0.0042**	-0.0058***	-0.0058***	-0.0038**	-0.0057***	-0.0036*	-0.0037*
	(0.0018)	(0.0018)	(0.0023)	(0.0021)	(0.0019)	(0.0021)	(0.0021)	(0.0019)
Cokeeuro	-0.0030*							
	(0.0017)							
Metaleuro		0.0100**						
		(0.0051)						
Paperde			0.0047*					
			(0.0029)					
Metalde				0.0068*				
				(0.0035)				
Elecgasfr					0.0038**			
					(0.0019)			
Chemfr						0.0091**		
						(0.0045)		
Cokeit							0.0180*	
							(0.0110)	
Glassit							-0.0042**	
							(0.0020)	
Metalit								0.0046*
								(0.0025)
R-squ.	0.2816	0.2853	0.2776	0.2844	0.2866	0.2858	0.2924	0.2854
Adj. R-squ.	0.2202	0.2242	0.2158	0.2232	0.2257	0.2247	0.2354	0.2339
F-Stat	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
D.W.	1.9829	1.9850	1.9930	1.9977	1.9843	1.9999	1.9889	1.9816
LM test	0.9954	0.9961	0.9795	0.9787	0.9948	0.9712	0.9970	0.9919
White test	0.3430	0.3515	0.3285	0.3332	0.3077	0.3534	0.3183	0.3393
AIC	-2.5184	-2.5234	-2.5127	-2.5222	-2.5254	-2.5242	-2.5771	-2.5800
SC	-2.2733	-2.2783	-2.2676	-2.2771	-2.2803	-2.2791	-2.3404	-2.3668
Procedure	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS	NW OLS

Table 8: Results of eq.(4) continued

	Full Period		*"After the compliance break"*			*Jun06-Oct06*
	Energy (1G)	Energy & temp (2bG)	Energy (5G)	Energy & temp (6bG)	Aggregated level (19G)	Energy (7G)
Pt(-1)	0.0232	0.1976	0.2111***	0.2253***	0.3350***	0.2139*
	(0.0253)	(0.0272)	(0.0816)	(0.0799)	(0.0816)	(0.1229)
Pt(-2)	-0.0195	-0.0201	-0.1095	-0.1016	-0.1169	
	(0.0205)	(0.0283)	(0.0716)	(0.0717)	(0.0735)	
Constant	-0.0095***	-0.0095***	-0.0054*	-0.0070***	0.3540*	-0.0017
	(0.0004)	(0.0005)	(0.0029)	(0.0025)	(0.1930)	(0.0024)
Break 1	0.0081***	0.0084***				
	(0.0026)	(0.0010)				
Break 2	-	-	-0.0166***	-	-	
			(0.0053)			
Brent	-	-	0.0053***	0.0056***	0.0059***	0.0063**
			(0.0021)	(0.0019)	(0.0020)	(0.0027)
Natural Gas	0.1345***	0.1349***	-	-	-	-
	(0.0050)	(0.0033)				
Coal	-0.1928***	-0.1929***	-	-	-	-
	(0.0077)	(0.0108)				
Switch	-	-	0.0137***	0.0137***	0.0136***	-
			(0.0010)	(0.0012)	(0.0012)	
Electricity	0.0010***	0.0011***	0.0069***	0.0067***	0.0067***	-
	(0.0004)	(0.0004)	(0.0023)	(0.0021)	(0.0021)	
Clean Dark	-0.0761***	-0.0763***	-0.0377***	-0.0377***	-0.0375***	-
	(0.0025)	(0.0014)	(0.0039)	(0.0039)	(0.0040)	
Clean Spark	0.0748***	0.0750***	0.0281***	0.0283***	0.0281***	-
	(0.0027)	(0.0018)	(0.0021)	(0.0025)	(0.0024)	
Tempext5						
Tempext95						
Win06		-				
Win07		-0.0069**	-0.0083***	-0.0075**	-	
		(0.0030)	(0.0032)	(0.0032)		
Cokeeuro				-0.0040*		
				(0.0021)		
ARCH(1)	0.4216***	0.4302***	0.0515***	0.0542***	0.0531***	-0.0432***
	(0.0727)	(0.0569)	(0.0169)	(0.0190)	(0.0179)	(0.0131)
GARCH(1)	0.7323***	0.7323***	0.9695***	0.9663***	0.9675***	1.0556***
	(0.0185)	(0.0185)	(0.0172)	(0.0178)	(0.0166)	(0.0053)
R-squ.	0.1397	0.1782	0.2026	0.2065	0.2225	0.1477
Adj. R-squ.	0.1173	0.1549	0.1557	0.1598	0.1727	0.0964
F-Stat	0.0000	0.0000	0.0000	0.0000	0.0000	0.0191
D.W.	1.4389	1.4979	1.7129	1.7372	1.7408	1.8659
AIC	-4.2763	-4.2815	-3.4682	-3.4599	-3.4739	-4.8349
SC	-4.1621	-4.1586	-3.2657	-3.2574	-3.2559	-4.6672
Procedure	GARCH	GARCH	GARCH	GARCH	GARCH	GARCH

Table 9: Robustness GARCH Estimates