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The EU emissions trading scheme: The effects of industrial production and CO_2 emissions on carbon prices

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Abstract. This article critically examines the impact of industrial production for sectors covered by the EU Emissions Trading Scheme (EU ETS) on emissions allowance spot prices during Phase I (2005-2007). First, sector production indices are used as a proxy of economic activity in sectors covered by the EU ETS. Second, a ratio of allowance allocation relative to baseline CO_2 emissions is used to measure the extent to which installations are constrained by the EU ETS. We show that carbon price changes react not only to energy prices forecast errors and extreme temperatures events, but also to industrial production in three sectors covered by the EU ETS: combustion, paper and iron.

JEL Classification: L11; L16; Q48; Q54.
Keywords: EU ETS; Emissions Trading; Carbon Pricing; CO_2; Emissions; Industrial Production.

Résumé. Cet article examine les impacts de la production industrielle dans les secteurs couverts par le Système d'Echange des Quotas Européens (*European Union Emissions Trading Scheme*, EU ETS) sur les changements de prix au comptant du CO_2 durant la Phase I (2005-2007). À partir d'indices de production sectorielle et de la position de conformité des installations, nous montrons que les changements de prix du CO_2 ne réagissent pas uniquement aux erreurs de prévisions sur les prix des énergies et aux évènements climatiques extrêmes, mais également à la variation de la production industrielle dans trois secteurs couverts par l'EU ETS : ceux de la combustion, de la production de fer et d'acier, et de la production de pulpe et de papier.

Classification *JEL* : L11 ; L16 ; Q48 ; Q54.
Mots-clefs : EU ETS ; marché de permis ; prix du carbone ; émissions de CO_2 ; production industrielle.

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1. Introduction

In the current global fight against climate change, the European Union took the lead of environmental policy making by implementing the world's largest emissions trading scheme for CO_2 emissions, which came into operation on January 1, 2005. This article analyses the EU Emissions Trading Scheme (EU ETS) during its Pilot Phase (2005-2007) by focusing on the empirical relationship between CO_2 allowance price changes[2] and economic activity in sectors included in the scheme. Springer (2003) and Christiansen *et al.* (2005) identify the main carbon price drivers as being economic activity, energy prices, weather conditions and policy issues. Besides the effects of energy prices, temperatures and institutional events on EU carbon prices, this article opens the "black box" of economic activity, with a particular emphasis on disentangling econometrically potential impacts ranging from the production to the environmental spheres on carbon price changes.

In theory, the carbon price is function of marginal abatement costs that vary depending not only on industrials' emissions abatement options, but also on the relation between emissions caps[3] and counterfactual CO_2 emissions resulting from business-as-usual production growth forecasts. Thus, EUA price changes may be affected by economic activity[4] of various sectors covered by the EU ETS for two main reasons. First, industrials are able to influence the market price through their choice of emissions abatements options.[5] Second, according to many market observers, industrials have hedged their allowances based on actual production during 2005-2007. Indeed, CO_2 emissions are measured at the installation level. Thus, installations know at every moment their CO_2 emissions level from which they decide their purchases/sales of allowances by comparing with their allowances endowment. Note that only installations know their CO_2 emissions level until this private information is revealed on a yearly basis by the European Commission (EC). This particular feature of the allowances market sharply departs from usual commodity markets. To our best knowledge, none empirical study has yet explored the expected impacts of the variation of industrial production in EU ETS sectors on carbon price changes. Although, several studies detail the impacts of EU carbon prices on competitiveness in the power sector (Reinaud, 2007) and for the iron and steel industry (Demailly and Quirion, 2007). In this paper, we analyze *ex post* the impacts of industrial production variation on carbon price changes for all sectors at the EU 27 level.

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2. EU CO_2 allowance 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 EU allowance spot price at time t.

3. Emissions caps place a quantitative limit on the number of CO_2 emissions in tons released in the atmosphere for firms concerned by the scheme.

4. Due to the frequency of the data, the potential effects of economic activity on EUA price changes are analyzed using industrial production indices instead of GDP. Thus, in the remainder of the paper, we refer to the variation of industrial production.

5. Industrials face a choice between different abatement possibilities ranging from investment in simple end-of-pipe technologies reducing emissions at the end of the production line, to heavy investments in complex clean technology systems that necessitate production process changes. Information on marginal abatement costs is however very diffuse and hardly disclosed by covered installations.

At the EU-wide level, the total number of allowances allocated is determined by Member States (MS) negotiating with industrials and after the validation of the EC. As soon as the first National Allocation Plans[6] (NAPs) were drafted, there was a concern of allowance oversupply during 2005-2007. Although this situation was common knowledge among market participants, the EUA price pattern increased to around 30€ on July 2005 and then experienced a high level of volatility on late April 2006, when EUA prices collapsed by 54% within four days. Academic and market agents usually agree that the information disclosure of lower than expected 2005 verified emissions by simultaneous MS is the main reason behind this fall.

As pointed out by Ellerman and Buchner (2008), allowance oversupply and early abatement concerns need to be balanced against the analysis of verified emissions relative to allowances allocated at the installation level. Thus, we examine the relationship between economic activity, as measured by industrial production indices, and carbon price changes based on two kinds of dummy variables. First, we use an indicator of allocation stringency, defined as the actual allocation relative to baseline emissions to capture the extent to which each sector records a net short/long position.[7] Second, we identify production peaks, defined as the variation of industrial production above a specific threshold, to estimate the effects of economic activity in conjunction with industrial production indices. To fully decompose the net effects on carbon price changes, we also take into account the potential interaction between the two latter dummy variables and the industrial production index for each sector.

Compared to previous literature, this article extends Mansanet Bataller *et al.* (2007) and Alberola *et al.* (2008) by emphasizing other EU carbon price drivers than energy prices, temperatures and institutional events. Our results feature that three sectors may be identified as having a statistically significant effect on carbon price changes: the combustion, iron and paper sectors which total 80% of allowances allocated in the EU ETS. While it has been possible to decompose the analysis between simple dummy variables and the interaction variable only in the case of the combustion sector, this finding is the most interesting one since the combustion sector amounts to approximately 70% of allowances allocated.

The article is organized as follows. Section 2 details the empirical relationship tested between the variation of industrial production in EU ETS sectors, emissions caps and carbon price changes. Section 3 presents the data and the econometric specifications. Section 4 contains the empirical results and a discussion. Section 5 concludes with a summary of the main results.

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6. NAPs determine the total quantity of allowances allocated to installations.

7. For a more comprehensive definition of "net short/long position" term, see Section 2.2.2.

2. Industrial production and emissions compliance: impacts on carbon price changes

The EU ETS, the largest multi-country and multi-sector greenhouse gases emissions trading scheme world-wide, concerns large energy-intensive CO_2 emitting installations from nine industries across its 27 MS. The aim of the EU ETS is to convey appropriate price signals to industrial operators who can select a combination of capital investments, operating practices and emissions releases to minimise the sum of abatements costs and allowance expenses (Noll, 1982). While allowance supply is fixed by each MS through NAPs, allowance demand is function of the level of industrial participants' CO_2 emissions. Thus, the market equilibrium is driven by the transfer from installations with a long allowance position to installations with a short allowance position.

In the short run, a large number of factors may influence industrial CO_2 emissions such as fuel (brent, coal and natural gas) and power (electricity) prices, weather conditions (temperatures, rainfall and wind speed) and economic activity (Springer, 2003; Christiansen *et al.*, 2005). Previous empirical literature focused only on the impacts of the first two factors (Mansanet Bataller *et al.*, 2007; Alberola *et al.*, 2008; Rickels *et al.*, 2007). Some potential factors are missing in recent studies of carbon price drivers, such as the impacts of banking restrictions, other climatic variables (such as wind speed), project mechanisms and economic activity. As developed by Alberola *et al.* (2008), political and institutional decisions concerning allowance allocation and yearly compliance announcements may be identified as driving basically EU carbon price changes during 2005-2007. In what follows, we detail how the achievement of the emissions cap depends on forecasts of industrial growth in the sectors covered by the EU ETS. More precisely, the extent to which verified CO_2 emissions are lower than allowances allocated needs to be balanced against an analysis of yearly compliance objectives that are fixed *ex ante* and the variation of industrial production that occurs *ex post*.

2.1. Industries in the EU ETS

Let us first detail the classification of industries covered by the EU ETS, as well as the variation of their production during 2005-2007.

2.1.1. Classification of industries

Over 2005-2007, the EU ETS covers large CO_2-intensive emitting plants from nine industrial sectors. It does not deal with diffuse emissions from transport and agriculture, in order to keep the system simple and cost efficient. The Directive 2003/87/CE indicates the list of activities qualified by the EU ETS: the combustion sector with a rated thermal input exceeding above 20 MWh, mineral oil refineries, coke ovens, iron and steel and factories producing cement, glass, lime, brick, ceramics, pulp and paper. Table 1 gives details on those sectors which include approximately 10,600 installations.

Based on NAPs, which provide the list of installations, and the Community Independent Transactions Log (CITL), which is the European central administrator registry that oversees all national registries, it is possible to identify installations and the classification of their manufacturing activities. The CITL keeps track of yearly allocation, yearly verified emissions, the ownership of allowances and records transactions between industrial accounts. The analysis of CITL data provides the number of plants, their geographical and sector breakdown. To our best knowledge, Trotignon and McGuiness (2007) and Trotignon *et al.* (2008) first provide an in-depth analysis on the number of installations and compliance positions in the EU ETS based on CITL data from which we derive the insights developed in the next section.

Table 1 - The decomposition of industrial sectors in the EU ETS

UNFCCC sectors	CITL activities
Energy	1. Combustion installations with a rated thermal input exceeding 20 MW
	2. Mineral oil refineries
	3. Coke ovens
Production and processing of ferrous metals	4. Metal ore (including surphide ore) roasting or sintering installations
	5. Installations for the production of pig iron or steel
Mineral industry	6. Installations for the production of cement clincker in rotary kilns with a production capacity exceeding 500 tonnes per day or lime in rotary kilns with a production capacity exceeding 50 tonnes per day
	7. Installations for the manufacture of glass including glass fiber with a melting capacity exceeding 20 tonnes per day
	8. Installations for the manufacture of ceramic products by firing, in particular roofing tiles, bricks, refractory bricks, tiles, stoneware or porcelain, with a production capacity exceeding 75 tonnes per day
Other activities	9. Industrial plants for the production of (a) pulp from timber or other fibrous materials (b) paper and board with a production capacity exceeding 20 tonnes per day

Source: EU Directive 2003/87/CE, Annex 1.

2.1.2. Variation of industrial production in 2005-2006

Since the launch of the EU ETS in 2005, economic activity in Europe has been relatively robust: GDP in the EU 25 has grown by 1.9% in 2005 and 3.0% in 2006 according to Eurostat. Industrial production, seasonally adjusted by Eurostat, rose by 2.8% in 2005 and by 4.4 % in 2006. Table 2 details industrial production growth rates for those sectors in 2005 and 2006.

Table 2 - Industrial production growth for EU ETS sectors

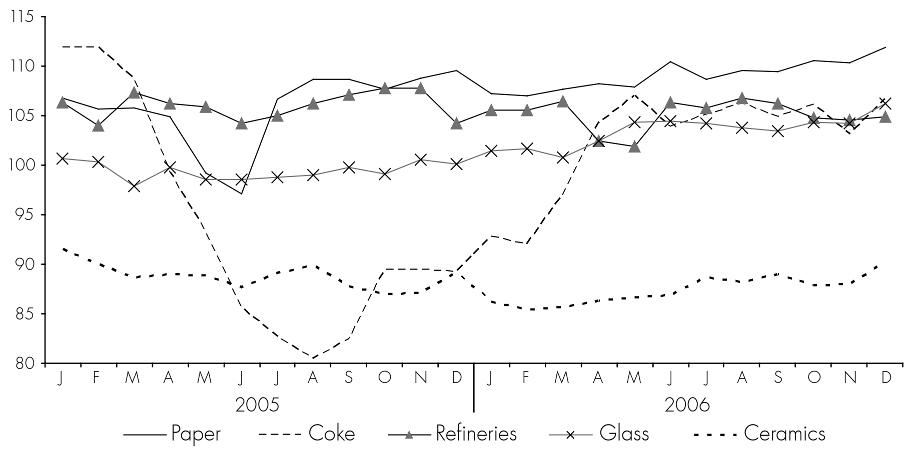
Annual growth rate, %

CITI activities	2005	2006
1. Combustion	5.87	–4.83
2. Mineral oil refineries	–2.03	–0.64
3. Coke ovens	–20.32	12.94
4. Metal ore	1.46	7.90
5. Iron and steel	0.62	6.64
6. Cement	2.05	10.77
7. Glass	–0.59	4.70
8. Ceramic	–2.66	4.59
9. Pulp and paper	2.61	4.31

Source : Eurostat.

Figures 1 and 2 display the evolution of monthly industrial production by sector at the EU 27 level. In figure 1, we observe a stable – almost increasing – evolution of economic activity in the glass, ceramics and refineries sectors. The evolution of economic activity has been more chaotic in the paper and coke sectors with a strong decrease during the 2nd and 3rd quarters 2005 and a strong recovery until the end of 2006.

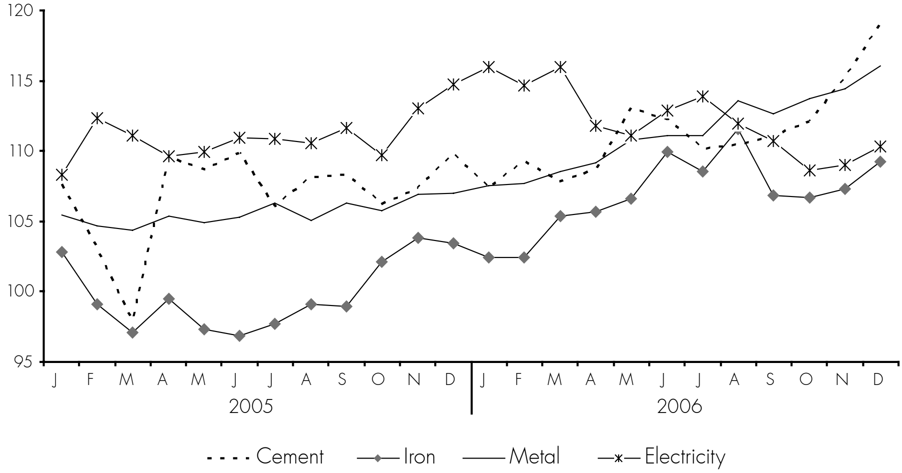
Figure 1 - Monthly industrial production indices in paper, coke, refineries, glass and ceramics sectors, 2005 and 2006*



* Based on the classification NACE Rev.1 C-F.
Source: Eurostat.

In FIGURE 2, we notice that economic activity in the cement, iron and metal sectors has been strictly increasing during 2005-2006. This situation contrasts with the combustion sector, which has encountered a stagnation – almost decreasing – evolution of activity during 2006. We have seen that the evolution of industrial production has been very contrasted during 2005-2006 depending on the sector under consideration. We refer to the evolution specific to each sector in the remainder of the paper for those which have had a statistically significant impact of EUA price changes.

Figure 2 - Monthly industrial production indices in cement, iron, metal and electricity sectors, 2005 and 2006*



* Based on the classification NACE Rev.1 C-F.
Source: Eurostat.

Following this description of production growth rates in sectors covered by the EU ETS during 2005-2006, we describe in the next section the adoption of NAPs and the verification of emissions during compliance periods.

2.2. Emissions cap and compliance of industrial sectors in 2005-2006

This section provides a brief description of the institutional features concerning allowance allocation and emissions monitoring in the EU ETS.

2.2.1. National allocations plans of the phase I (2005-2007)

The overall stringency of the EU emissions cap is fixed by the EC to meet the targets of CO_2 emissions abatement agreed by MS in the Burden Sharing Agreements. During the Pilot phase of the EU ETS, the Directive 2003/87/CE indeed required from each MS to develop a NAP that identifies the installations to be included, to determine the amount of allowances allocated, and to specify reserves for new entrants and installations closures. Although each MS has the responsibility for drafting its own NAP and enacting it, the initial proposal is subject to review and approval by the EC. Before the launch of the EU ETS on January 1, 2005 the NAPs from 25 MS[8] should have been notified by March 31, 2004 to the EC, which should then have been reviewed for approval or rejection within three months. Yet, due to the administrative requirements for the implementation of this new environmental regulation tool, the EU ETS was launched before the validation of all NAPs.[9] Betz and Sato (2006), Leseur and Dufour (2006) and Ellerman and Buchner (2008) provide a detailed analysis of NAPs during 2005-2007.

MS have distributed allowances to installations based on guidelines provided by the EC.[10] The allocation process has thus followed a top-down structure in three layers.

i) Allocation at the *macro* level: the most important allocation decision from a macro perspective concerns the total number of allowances to be created, *i.e.* the setting of the cap. The sum of the 25 NAPs conditions the overall scarcity of emissions allowances and the environmental performance of the European policy. Each MS decides on its total amount of allowances allocated based on the coherence with its commitment under the Burden Sharing Agreements and the validation by the EC.

ii) Allocation at the *sector* level: total allocation is based on emissions forecasts for sectors covered/not covered by the scheme, efforts to reduce past emissions during 1990-2002 and potential for emissions reduction. MS have differentiated between the combustion (power generation) sector, which was more constrained during the allocation process with respect to its potential for CO_2 emissions reduction, and other covered sectors. The allocation to the power sector was based on historical emissions projections of electricity demand and the expected variation of electricity generation mix. The allocation to non-electricity sectors was based on emissions projections during 2001-2006 by extrapolating historical emissions per sector, *i.e.* the annual growth rate between 1990 and 2001.

iii) Allocation at the *installation* level: the approach adopted was free allocation. Allocation depends on average historical emissions of the installation during 2000-2002 and its share in sector emissions.

Allocation data at installation and sector levels collected on each national registry are transferred to the CITL.

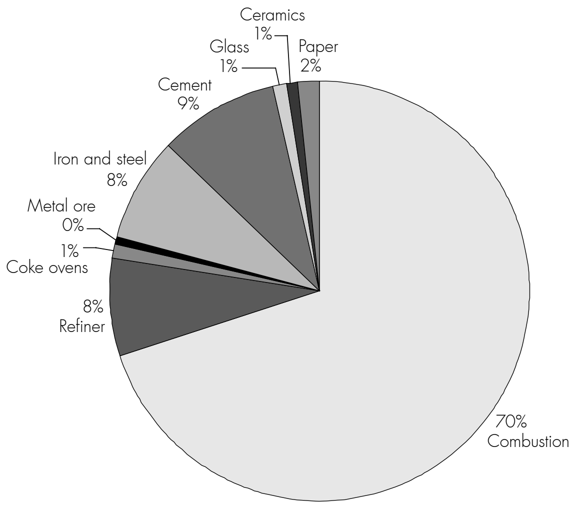
Figure 3 provides an overview of allowance allocation breakdown in 2006 by industries. The combustion sector represents the largest share of installations in the EU ETS with 70% of the EU allocation. The combustion sector was defined in a different way by each MS and contains too many sub-activities. Based on the CITL data and the Classification NACE Rev.1 C-F, Trotignon and McGuiness (2007), Trotignon *et al.* (2008) classify between large electricity production plants, district heating facilities (cogeneration when details were available) and other installations.

8. Note that Romania and Bulgaria have joined the EU ETS on January 1, 2007.

9. The Greek NAP was the last approved by the EC on June 2005.

10. On January 2004, the EC issued guidance on the implementation of the allocation process governed by articles 9 to 11 and Annex III of the Directive 2003/87/EC.

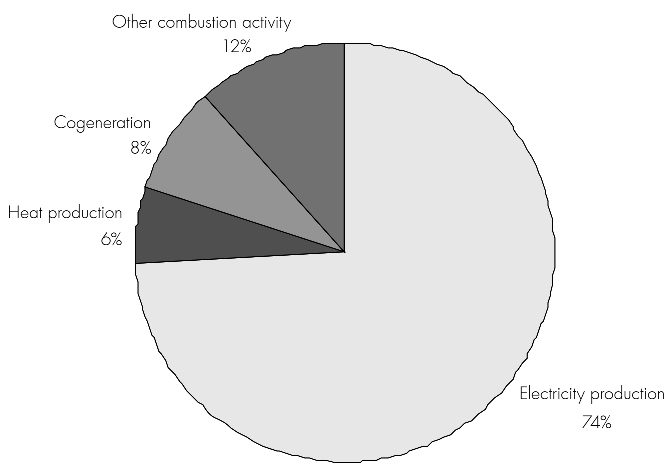
Figure 3 – Breakdown of allowance allocation by industry in 2006



Sources: CITL; Trotignon *et al.*, 2008.

Figure 4 exhibits the identification of combustion installations by activities in the EU ETS. At the EU level, electricity production represents approximately two thirds of the allocation to the combustion sector, and other sectors (including heat production and cogeneration) around one third. In each MS, the share of electricity production allocation in the combustion sector depends basically on their energy mix. The non-combustion sectors gather 30% of total allocation. Three sectors collected more than 7% of allowances: cement, iron and refineries. Other sectors represent only 1% of the EU allowance allocation.

Figure 4 – Characteristics of the combustion sector in the EU ETS



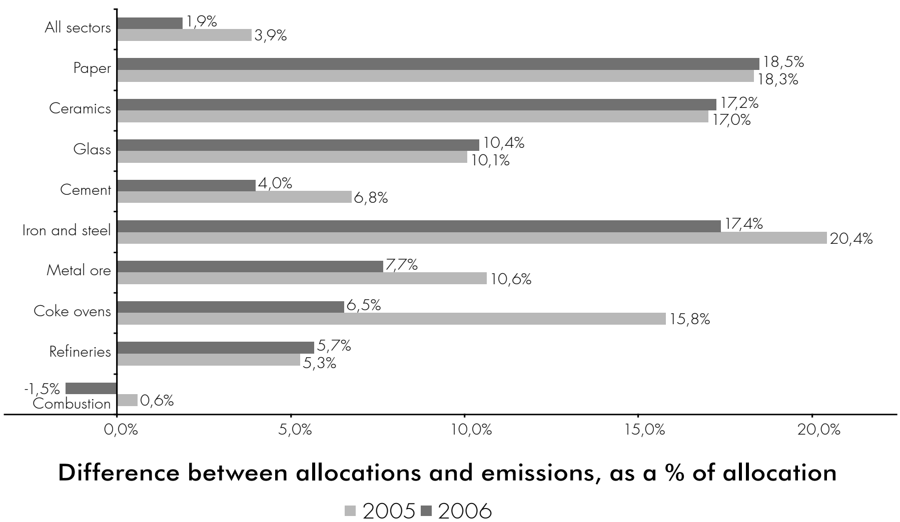
Sources: CITL; Trotignon *et al.*, 2008.

2.2.2. Verified emissions and yearly compliance results

Compliance with the emissions cap is measured at the installation level by the difference between the yearly amount of allowances allocated and actual emissions during the commitment year. This annual balance, termed as compliance, indicates the net short/long allowance position, be it at the installation, sector, country or EU 27 levels. An installation is defined as short (long) when it records a deficit (surplus) of allowances allocated with respect to actual emissions. Thus, a short (long) installation need (not) additional allowances to cover its emissions level and achieve its compliance.

Figure 5[11] provides an overview of the 2005 and 2006 compliance positions aggregated by sectors. These figures indicate the extent to which sectors are net short/long of allowances as a percentage of allocation.

Figure 5 – Emissions compliance positions by EU ETS sectors, 2005-2006



Source: Trotignon *et al.*, 2008.

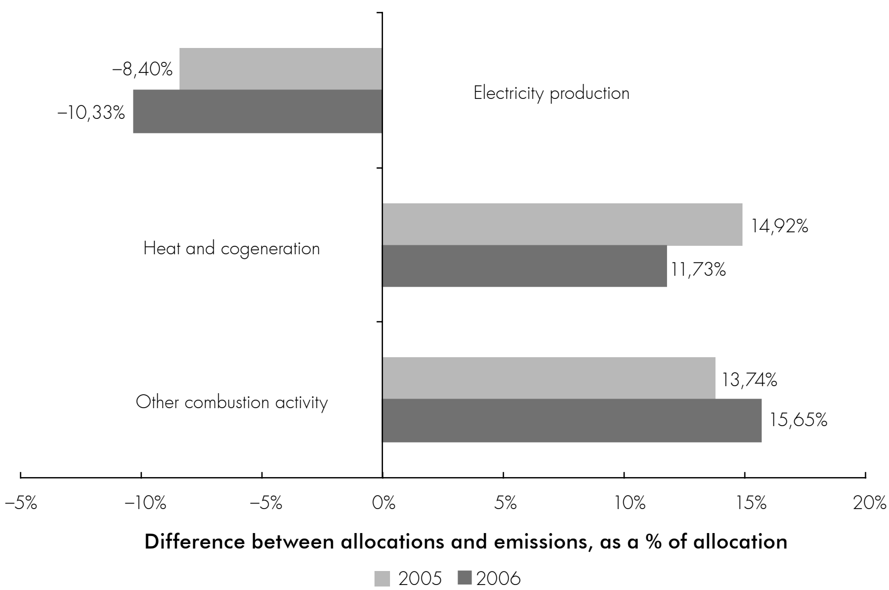
In 2005, no sector was in a short position, *i.e.* with higher verified emissions than allowances allocated. Conversely, four sectors recorded lower actual emissions than allowances allocated by 20%: iron, paper, ceramics and coke ovens. Other sectors exhibit net long positions by 5%. The combustion sector, which was more constrained, is net long by only 0.6%. The global result at the EU-level is a net long position by 4% (80 Mt CO_2) during the 2005 compliance year. In 2006, most sectors are also characterized by a net long position, but on a smaller scale than in 2005. The combustion sector is the only net short one with verified emissions being 1.5% higher than allowances allocated. Overall, the EU ETS is net long, but the allowance surplus was reduced from 4% to 2% between 2005 and 2006.

11. Sector compliance is computed as the difference between allocation and emissions as a percentage of allocation.

Figure 6 shows 2005 and 2006 compliance results for combustion sub activities aggregated from seven countries: Austria, France, Germany, Italy, Poland, Spain and the United Kingdom (Trotignon *et al.*, 2008). Installations from the combustion sector are grouped into electricity production, heat and cogeneration, and other combustion activity. In these MS, the electricity production sector exhibits a short position by −8.4% in 2005 and by −10.3% in 2006. Based on the disentanglement of the power sector from the combustion sector described earlier, Trotignon and McGuiness (2007) and Trotignon *et al.* (2008) confirm that allowance demand comes mainly from power generation installations, and allowance supply from other sectors. Electricity production plants are the biggest installations in the EU-ETS, whereas others are smaller installations and potential allowance sellers. Table 3 details allocation and emissions volumes expressed in Mt CO_2. The combustion sector and its power sector sub activity dominate EU ETS emissions, followed by the cement, refineries and iron sectors.

Note that compliance at the sector level does not necessarily reflect the situation at the installation level: a sector may be net long and the majority of its installations net short. However, we may draw the insight that, at the EU ETS level, the power sector is globally on the demand side while other sectors are on the offer side. Based on this detailed analysis of yearly compliance results, we attempt to link their expected impacts with industrial production on carbon price changes in the next section.

Figure 6 – Emissions compliance positions in the combustion sector, 2005 and 2006



Source: Trotignon *et al.*, 2008.

Table 3 - Total allowance allocations ($MtCO_2$), emissions level ($MtCO_2$) and compliance positions on the EU ETS, 2005-2006

CITL Activities	Allowances	Emissions	Compliance* (%)	Allowances	Emissions	Compliance* (%)	Number of installations
		2005			2006		
1. Combustion	1,465.6	1,456.9	0.6	1,438.3	1,459.8	1.5	7,230
Electricity production**	765.5	829.8	–8.4	747.5	824.6	–10.3	-
Heat and cogeneration**	144.8	123.3	14.9	143.2	131.9	11.7	-
Other combustion activity**	115.7	99.6	13.7	116.3	107.8	15.6	-
2. Oil refineries	158.1	149.8	5.3	157.5	148.5	5.7	154
3. Coke ovens	22.8	10.2	15.8	22.8	21.3	6.5	21
4. Metal ore	8.7	7.8	10.6	8.7	8.0	7.7	12
5. Iron or stell	168.5	134.1	20.4	168.0	138.8	17.4	237
6. Cement	189.6	176.8	6.8	188.7	181.2	4.0	543
7. Glass	22.1	19.9	10.1	22.1	19.8	10.4	418
8. Ceramic	17.7	14.7	17.0	17.9	14.8	17.2	1.134
9. Pulp and paper	36.7	30.0	18.3	36.9	30.1	18.5	818
All sectors	2,089.8	2,000.1	3.9	2,060.9	2,022.3	1.9	10,576

* The compliance ratio is computed as $\frac{Allowances_j - Emissions_j}{Allowances_j}$ where j = {2005,2006}.

** The figures are computed only for seven countries: Germany, Poland, Italy, Spain, France, Austria and the UK. Their installations account for 70% of the combustion sector emissions and 65% of the combustion installations (Trotignon *et al.*, 2008).

Sources: CITL, National Registries, NAPs, Trotignon *et al.* (2008).

2.3. Linking the potential impacts of industrial production and yearly compliance results on carbon price changes

The purpose of this section consists in detailing explicitly the channels through which EUA price changes may be affected by the evolution of industrial production in the various EU ETS sectors.

First, we discuss the relation between industrial production and CO_2 emissions. Changes in the level of industrial CO_2 emissions depend on numerous factors. Several studies based on the decomposition analysis have investigated those factors in the EU (Greening *et al.*, 1998; Liaskas *et al.*, 2000; Diakoulaki and Mandaraka, 2007). None of these studies have investigated changes in CO_2 emissions from the manufacturing sector in the context of a cap-and trade program. In the case of the EU ETS, sectors qualified for an emissions cap are motivated to reduce their emissions level either by switching their energy mix, by improving energy efficiency at the plant level or by investing in low carbon technologies. During 2005-2007, it was difficult for the EC and market participants to assess the gap between allowance allocation and industrials' emissions forecasts.[12] Thus, we attempt to capture the emissions-cap effects on EUA price changes *ex post* by introducing the emissions-cap effect which links industrial production, related CO_2 emissions levels and EUA price changes.

Second, the link between CO_2 emissions levels and EUA price changes is mainly based on yearly compliance results at the installation level. The EUA price is driven by the scarcity of allowances on the market at the installation level as experienced during the 2005 compliance event. Emissions net short/long positions need to be balanced against the variation of industrial production.

To this purpose, TABLE 3 presents the net compliance and the annual production growth rate recorded in each sector during 2005-2006.

From FIGURES 7 and 8, EU ETS sectors may be categorized in four groups:

- one with an *increasing* variation of industrial production and a net *long* compliance position;
- one with an *increasing* variation of industrial production and a net *short* compliance position;
- one with a *decreasing* variation of industrial production and a net *long* compliance position;
- one with a *decreasing* variation of industrial production and a net *short* compliance position.

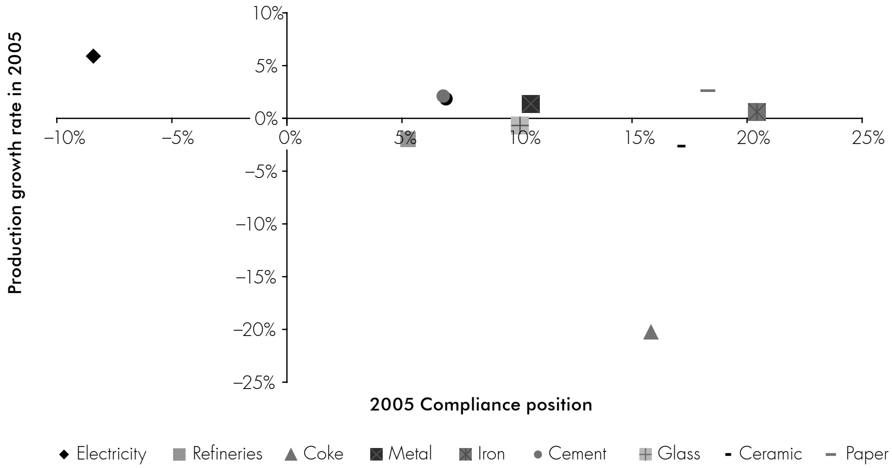
Therefore, the logic at stake to disentangle the potential impacts of industrial production and yearly compliance positions on EUA price changes is the following: *if a sector combines a net short (long) compliance position and/or an increasing (decreasing) variation of industrial production, then this sector is net buyer (seller) of allowances and the impact on the EUA price changes shall be positive (negative).*[13]

Based on this suggested causal relationship, two questions are further examined in the next section: which sectors have had a statistically significant influence on EUA price changes during 2005-2007? Among those sectors, is it possible to disentangle the effects of industrial production peaks, yearly compliance events and the interaction between them?

12. Similarly, the reverse causality argument that goes from the level of CO_2 prices to the level of CO_2 emissions and the corresponding level of industrial production is difficult to investigate due to very limited data availability concerning continuous CO_2 emissions at the installation level.

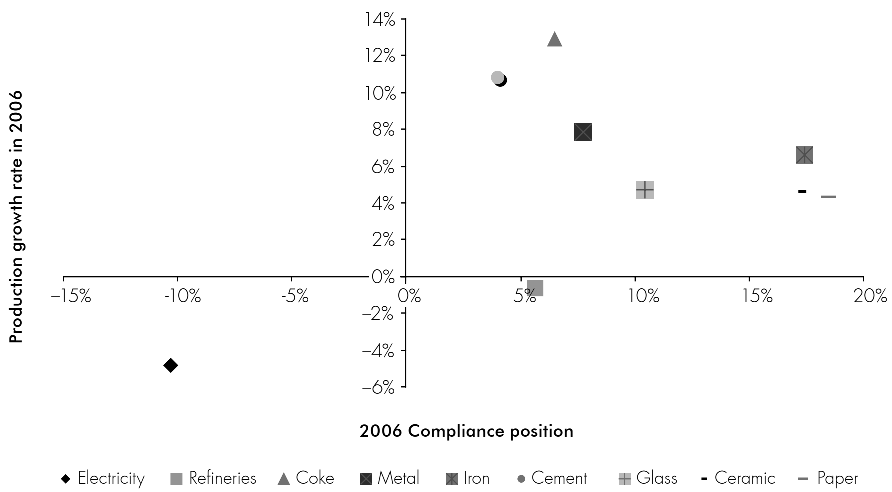
13. For instance, according to FIGURE 7, the power sector belongs to the category #2 which is expected to have a positive effect on EUA price changes. Conversely, the iron sector may be put with category #3 from which a negative effect on EUA price changes is expected. These expected effects on EUA price changes are however more ambiguous in categories #1 et #4, which underlines the limits of our disentangling analysis.

Figure 7 – Emissions compliance positions and production growth rates of EU ETS sectors in 2005



Sources: Eurostat, CITL and Trotignon *et al.*, 2008.

Figure 8 – Emissions compliance positions and production growth rates of EU ETS sectors in 2006



Sources: Eurostat, CITL and Trotignon *et al.*, 2008.

3. Data and econometric specification

We present first data for the carbon price, energy prices, temperature events and compliance breaks that have been previously identified as carbon price drivers in the literature. Second, three variables are introduced to disentangle the potential effects of industrial production on the carbon price: sector production indices and dummy variables representing production peaks, compliance results and squeeze probability around yearly compliance events. Third, econometric specifications are detailed.

3.1. Data

3.1.1. Carbon price, energy prices, temperatures events and compliance break variables

The database used in this article is provided by the Mission Climat (Caisse des Dépôts et Consignations, Paris) which publishes a monthly analysis on the EU ETS called *Tendances Carbone*. It contains extensive and up-to-date information on carbon and energy market prices, industrial production and temperatures indices, and CO_2 emissions compliance positions. It was first used for the determination of carbon price drivers and structural breaks during 2005-2007 in Alberola *et al.* (2008).

For the carbon price, we use the daily EUA spot price (Pt in €/tonne of CO_2) negotiated from July 1st, 2005 to April 30, 2007 on BlueNext13. The sample period starts at the launch of the BlueNext market place and ends at the disclosure of the 2006 compliance results when the EUA price path asymptotically tends towards zero until the end of Phase I.

For other energy prices, we use the daily futures Month Ahead natural gas price (*ngas* in €/Mwh) negotiated on Zeebrugge Hub, the daily coal futures Month Ahead price (*coal* in €/t) CIF ARA[14] and the electricity Powernext contract (*elec* in €/Mwh) of futures Month Ahead Base. We also use the Clean dark spread, *clean dark* expressed in €/MWh and the Clean Spark Spread, *clean spark* expressed in €/MWh both calculated by the *Mission Climat*.[15] Kanen (2006) identifies *brent* prices as the main driver of *natural gas* prices which, in turn, affect power prices and ultimately *carbon* prices. Yet, this variable has not been included in the data set because, as shown by Alberola *et al.* (2008), the *brent* price only affects CO_2 price changes through specific time period, but not during the full period considered in this article. Here, if the *brent* price has an influence on CO_2 price changes, it passes through the effect of the *ngas* variable. We introduce those spreads because power operators pay close attention to them as well as to 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. The equilibrium between these clean spreads represents the carbon price above

14. CIF ARA defines the price of coal inclusive of freight and insurance delivered to the large North West European ports, *e.g.* Amsterdam, Rotterdam or Antwerp.
15. The methodology is available at http://www.caissedesdepots.fr. Cited January 2008.

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. For more details on energy variables used in this econometric analysis, see Alberola *et al.* (2008).

Note that we are able to alleviate endogeneity concerns among energy prices variables with the following arguments. In Western Europe, the natural gas market is mainly characterized by long-term contracts that range in duration from twenty to twenty-five years.[16] Similarly, the coal is bought through long term contracts (Joskow, 1990). Since those contracts do not have the same determinants, they do not appear to be endogenous with the determination of other energy prices variables included in our model such as the electricity price.[17]

By influencing energy demand, temperatures conditions may have an impact on EUA price changes. Numerous studies, which highlighted the effect of temperatures on energy prices, indicate that only both temperatures increases and decreases beyond certain thresholds can lead to increases in power demand.[18] 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 levels increase (decrease) which should in return increase (decrease) the demand for allowances.

Extreme temperatures events are derived from the daily data of the Bluenext Weather index,[19] expressed in °C, for Spain, France, Germany and the United Kingdom. *Win07* is the cross product of the dummy variable characteristic of January and February, 2007 (winter hotter than seasonal averages) and the absolute value of the deviation from its seasonal average of the European temperature index.[20] This latter kind of interaction variable aims at testing the non-linearity of the relationship between temperatures and carbon price changes highlighted in previous literature, and may be interpreted as unanticipated temperatures changes.

The compliance break dummy variable is constructed by using the unit root tests with endogenous structural breaks developed by Lee and Strazicich (2003) and Lee and Strazicich (2001). This procedure statistically identifies the compliance break as going from April 25 to June 23, 2006. On late April 2006, first disclosures of the Netherlands, Czech Republic, France, and Spain revealing long positions caused this sharp price break of 54% within four

16. For instance, 86% of natural gas consumption in France is covered by long term contracts (MEDAD, 2007). See also Brown and Yucel (2008) for a detailed discussion on the drivers of natural gas prices.

17. See Chevalier and Percebois (2008) for a detailed study of those determinants.

18. For an extensive literature review on this topic, see Li and Sailor (1995).

19. Until January 2008, these indices were labelled as Powernext weather.

20. *Win07 = winter2007 * Temp_AbsDeviation.*

days. On May 15, 2006 the EC confirmed that verified emissions were about 80 Mt CO_2 or 4% lower than the 2005 yearly allocation. This break is included in our regressions using a dummy variable break.

To better take into account the impact of information revelation, we propose to use an additional cross-product variable, *psq*, that captures the allowance squeeze probability around yearly compliance announcements. This variable is constructed using the following two variables. *Difsq* computes at time t the number of days remaining before the yearly compliance event. This variable may be interpreted as a proxy of the allowance squeeze probability. *Sq* is a dummy variable which takes the value of one during the period going from March, 30 to April, 30 of each year[21], *i.e.* about fifteen days before the official EC announcement[22], and zero otherwise. The information embedded within the allowance squeeze probability appears especially relevant for industrials only around the yearly compliance announcement. Thus, the potential effect of the allowance squeeze probability, as proxied by *difsq*, should only be analyzed during the 30 days before the official EC announcement, as captured by *sq*. This is why, instead of using the variable *difsq*, we prefer to work with *psq*, which corresponds to the cross-product of the two previous variables: *psq = difsq *sq*.

3.1.2. Sector production indices

In order to measure how the variation of production in EU ETS sectors may affect EUA price changes through the need of allowances to cover their yearly emissions, we use industrial production indices. Since CO_2 emissions levels are not directly observable at the installation level[23], monthly industrial production indices are collected at the aggregated EU 27 level from Eurostat (2007) using the Classification NACE Rev.1 C-F as shown in TABLE 4.

According to the decomposition of sectors required by the CITL, the following industries indices are collected: paper and board, iron and steel, coke ovens, refineries, ceramics, glass, cement, metal, and combustion (electricity, gas, steam and hot water production). As explained above, the electricity sector represents 73% of allowances allocated in the combustion sector. Thus, the choice of the index of production and distribution of electricity, gas and heating in this article covers the main part of industrial production in the combustion sector. Each industrial production index has a base 100 in 2000 and is seasonally adjusted. These data are then re-sampled to convert monthly indices to daily frequency[24] (see IEEE, 1979, for reference).

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21. Note that for the 2005 compliance event, we rule out from the construction of the dummy variable the four days of strong EUA price adjustment that occurred starting on April 24, 2006.

22. Indeed, the EC is bound by law to disclose the results of verified emissions by May, 15 of each year at the latest (see Directive 2003/87/CE).

23. See Ellerman and Buchner (2008) for an extensive discussion.

24. The Matlab function by L. Shure performs linear interpolation so that the mean square error between the original data and their ideal values is minimized.

Table 4 - EU ETS sector decomposition and NACE classification system

EU ETS sector decomposition	NACE classification system
1. Combustion	E 40 Electricity, gas, steam and hot water supply
2. Coke ovens	DF 231 Manufacture of coke oven products
3. Refineries	DF 232 Manufacture of refined petroleum products
4. Metal ore	DJ 28 Manufacture of metal products, except machinery and equipment
5. Iron and steel	DJ 271 Manufacture of basic iron and steel and ferro alloys
6. Cement	DI 2651 Manufacture of cement
7. Glass	DI 261 Manufacture of glass products
8. Ceramics	DI 262 Manufacture of non refactory and refractory ceramics products
9. Paper and board	DE 232 Manufacture of pulp and paper products

Source: Eurostat.

Let us discuss two preliminary concerns with the use of sector production indices. First, the choice of production indices over product prices is motivated by the fact that we want to assess the impact of the level of industrial production on EUA prices changes through an estimate of sector emissions levels. Thus, we concentrate our analysis on production quantities.[25] Second, endogeneity between energy prices and production indices is not likely to be an issue since both kinds of variables do not overlay each other.[26] Besides, the matrix of partial cross-correlations between sector variables is reported in TABLE A1.1 (APPENDIX 1). If the explanatory variables in the model are highly correlated (multicollinearity), the reported regression coefficients may be severely distorted and thus the results are not reliable. Since it is possible to have low correlations together with colinearity, we have investigated the presence of multicolinearity by computing the inflation of variance between explanatory variables. As further explained in Section 4.1, these calculations did not reveal serious problematic multicolinearities.

As detailed in Section 2, two main reasons may explain the likely influence of sector production on carbon price changes: industrial production peaks and the emissions yearly compliance at the sector level. Hence, in order to disentangle these two effects, we compute three kinds of dummy variables for each of the nine EU ETS sectors. The first dummy variable concerns emissions compliance results. Recall that a given sector may be either net short or long in

25. Conversely, the price of goods traded in EU ETS sectors is used in analyses of the impact of the EU ETS on the competitiveness of sectors covered by the scheme (Reinaud, 2007; Demailly and Quirion, 2007).

26. For instance, the electricity price does not appear to be correlated with the combustion production index since it covers only two thirds of electricity production as explained in Section 2.

each yearly compliance. Thus, the dummy variable *sectcompl*[27] equals one if the sector is in an annual net short position and zero otherwise. The second dummy variable aims at capturing the effect of production peaks at the sector level: a production peak is defined by the variation of 1% in absolute value of the sector production index under consideration.[28] Thus, the dummy variable *sectpeak* equals one if the sector encounters a monthly positive production peak and zero otherwise.

Of course, there is no reason for the differential effect of the net short/long position dummy *sectcompl* to be constant across the two categories of production peaks variable *sectpeak* and conversely. Therefore, in order to capture the likely interaction effect between these two qualitative variables, we compute a third type of dummy variable which is the cross-product between the two latter dummies. For instance, *combcomplpeak = combcompl * combpeak* is the product of the dummy variables characteristic of the net short position and the production peaks in the combustion sector.

Energy prices variables and sector indices have been transformed to "one step ahead" forecast errors to take into account unexpected changes in market conditions (Helfand *et al.*, 2006). Usual unit root tests were conducted and reveal that all energy price series are stationary when taken in first difference. Thus, all price series are integrated of order 1 (I(1)).[29] TABLE 5 presents descriptive statistics for energy and sector variables.

3.2. Econometric specification

The role played by industrial production and compliance positions on EUA price changes is now estimated. Following the discussion presented in Section 2, two distinct specifications are introduced. The first specification aims at identifying which production indices in EU ETS sectors have a potential impact on carbon price changes. The second specification attempts to disentangle, among those statistically significant sectors, the potential impact of production peaks and compliance net short/long positions.

3.2.1. The variation of industrial production in EU ETS sectors and its impact on EUA price changes

On top of energy variables, temperatures events and compliance breaks that were previously identified as carbon price drivers in the literature, we include all sector production indices that may also have an effect on EUA price changes. This first step consists in identifying the reduced form model with only sector production indices that significantly impact EUA price changes.

27. Sect refers to the sector under consideration. *Sect = comb, iron, paper, coke, refin, ceram, glass, cement, metal.*

28. This threshold has been fixed considering the average level of monthly variation of production over the two years. We experimented with a wide range of other proxies of industrial production, such as variations with higher thresholds over several months. We only found measures of production peaks to be statistically significant as such.

29. A journal of unit root tests may be accessed upon request to the authors.

Table 5 - Descriptive statistics*

	p_t	Natural gas	Coal	Electricity	Clean dark	Clean spark
Mean	–0.0085	0.0027	–0.0002	–0.0161	–0.0036	–0.0125
Median	0.0000	–0.1391	–0.0026	–0.2421	–0.0747	0.1524
Max	0.2973	11.5427	0.5480	24.9946	16.0509	13.5620
Min	–0.4368	–10.5700	–0.2370	–19.395	–11.6950	–19.3414
Std. Dev.	0.0562	1.6748	0.0662	3.7817	2.0967	3.1848
Skew.	–1.3409	0.9916	1.2958	0.9112	1.0980	–0.9863
Kurt.	14.7843	14.7610	13.6089	15.5969	19.8393	10.8975
N	481	481	481	481	481	481

	Elecsect	Ceram	Cement	Coke	Glass	Iron	Metal	Paper	Refin
Mean	0.0023	–0.0001	–0.0281	0.0305	–0.0189	–0.0066	–0.0104	–0.0031	0.0136
Median	0.0143	0.0014	–0.0043	0.0127	–0.0128	–0.0046	–0.0077	–0.0033	0.0222
Max	0.1833	0.1348	0.2203	0.5190	0.1237	0.1693	0.1066	0.1305	0.2344
Min	–0.2196	–0.1569	–0.4194	–0.2440	–0.3146	–0.2827	–0.1486	–0.1307	–0.2206
Std. Dev.	0.0845	0.0575	0.1441	0.1812	0.0822	0.0876	0.0538	0.0560	0.0963
Skew.	–0.3795	–0.1066	–0.6713	0.5496	–1.5348	–0.4112	–0.4218	–0.0963	–0.0889
Kurt.	2.5970	3.2708	3.0847	2.5930	6.4709	3.8076	3.0601	2.6643	3.4918
N	481	481	481	481	481	481	481	481	481

* With p_t the first log-differenced EUA price series, all energy variables and sector production indices transformed to forecasts errors, *StdDev.*, the standard deviation, *Skew.*, the skewness, *Kurt.*, the kurtosis and *N*, the number of observations.

The estimated model is:

$$p_t = \alpha + \beta_i(L)p_t + \delta break_1 + \nu psq_{i,t} + \varphi(L)ngas_t + \gamma(L)coal_t \quad (1)$$
$$+ \iota(L)elec_t + \kappa(L)dark_t + \lambda(L)spark_t + \sigma Win07$$
$$+ \varsigma(L)cement_t + \tau(L)refin_t + \upsilon(L)coke_t + \omega(L)comb_t + \xi(L)glass_t$$
$$+ \psi(L)metal_t + \varsigma(L)paper_t + \rho(L)ceram_t + \chi(L)iron_t + \varepsilon_t$$

For energy variables and compliance breaks, t is the time period under consideration, p_t is the first log-differenced EUA price series, *break* is a dummy characteristic of the period after the structural break on April, 2006, $psq_{i,t}$ is the allowance squeeze probability for $i = \{1, 2\}$ referring to the 2005 and 2006 compliance results, $ngas_t$ is the Natural gas price series, $coal_t$ is the Coal price series, $elec_t$ is the Electricity price series, $dark_t$ is the Clean Dark price series, $spark_t$ is the Clean Spark price series, *Win07* is the extreme temperatures event for January and February 2007 and ε_t is the error term.

For sector variables, $cement_t$ is the cement production index in the EU 27 which applies for all sectors; $refin_t$ is the production index in the refineries sector; $coke_t$ is the production index in the coke ovens sector; $comb_t$ is the production index in the combustion sector (*i.e.* heating from electricity and gas); $glass_t$ is the glass production index; $iron_t$ is the production index in the iron and steel sector; $metal_t$ is the production index in the metallurgy sector; $ceram_t$ is the production index in the ceramics sector; and $paper_t$ is the production index in the paper and pulp sector. All energy price series and sector indices have been transformed to "one-step ahead" forecast errors as explained above. *L* is the lag operator such that $L\,Xt = Xt - n$ where *n* is an integer and polynomes such as $(X)L$ are lag polynomials.

As explained in Section 4, this first specification allows us to identify three sector activities among the industries in the EU ETS that significantly affect EUA price changes: combustion, iron and paper.

Thus, we take our analysis one step further by investigating in the next section why those sectors impact EUA price changes. Two main reasons were highlighted above, *i.e.* the influence of compliance positions and production peaks.

3.2.2. Do sector production peaks and compliance positions impact EUA price changes? A disentangling analysis

To disentangle the potential impacts of industrial production peaks and compliance positions on EUA price changes, we add to the significant sector production indices the following three dummy variables: $sectpeak_{i,t}$, $sectcompl_{i,t}$, and $sectcomplpeak_{i,t}$. $sect_i$ is the industrial sector under consideration and i = {comb, iron, paper} corresponds either to the combustion, iron and paper sectors that were significant after estimating the reduced model with all sectors in eq.(1). We then estimate three equations which may be summarized as:

$$p_t = \alpha + \beta_i(L)p_t + \delta break_1 + \nu psq_{i,t} + \varphi(L)ngas_t + \gamma(L)coal_t + \iota(L)elec_t + \kappa(L)dark_t + \lambda(L)spark_t + \sigma Win07 + \omega sect_{i,t} + \xi sectpeak_{i,t} + \vartheta sectcompl_{i,t} + \eta sectcomplpeak_{i,t} + \varepsilon_t \quad (2)$$

where $sectpeak_{i,t}$ is a dummy variable capturing monthly positive production peaks, $sectcompl_{i,t}$ is a dummy variable for the net short annual compliance position in the sector under consideration and $sectcomplpeak_{i,t}$ is an interaction variable capturing the impact of positive monthly production peaks and a net short compliance position in the sector under consideration. Other variables are explained in eq.(1). Estimation results of eq.(1) and eq.(2) are provided in the next section.

4. Results and discussion

As highlighted by Seifert *et al.* (2007), the EUA spot price series exhibit jumps during 2005-2007. This very steep volatility may be explained by the immature state of EU allowance market where investors lack of experience to build their expectations during the Pilot Phase. Therefore, official communications by the EC are essential to reach a better information flow on installations' net short/long positions. Such announcements have had a structuring effect on EUA price changes during both 2005 and 2006 compliance periods.

Taking into account this quite dynamic behavior for EU allowance prices and volatilities, and the dependence of the variability of the time series on its own past, Borak *et al.* (2006) and Benz and Truck (2008) recommend to address the problem of heteroskedasticity with GARCH models. Indeed, GARCH(p,q) models put forward by Bollerslev (1986) capture the conditional variance based not only on the past values of the time series $(pt)_{t>0}$, but also on a moving average of past conditional variances which better fits the data. Paolella and Taschini (2008) conclude that the GARCH specification that provides the best likelihood-based goodness-of-fit for the EUA return series is a GARCH(1,1) model with generalized asymmetric t innovation distribution. Thus, they justify to work at least with an asymmetric GARCH to characterize EUA price series returns, even if it does not provide fully satisfactory results for VAR forecasts.

We depart from Paolella and Taschini (2008) by choosing an asymmetric TGARCH(p,q) model (Zakoian, 1994)[30] with a Gaussian innovation distribution.[31] As demonstrated by Gourieroux *et al.* (1984), even in the presence of non-Gaussian residuals which is standard for financial time series, the choice of the probability distribution will not yield to biased estimates when estimating by Pseudo Maximum Likelihood (PML). Thus, our estimates will not be affected by any ill-chosen distribution assumption. The estimates covariance matrix is estimated with the BHHH algorithm (Berndt *et al.*, 1974).

30. TGARCH stands for Threshold GARCH.

31. See Alberola *et al.* (2008) for the calibration of the autoregressive order and the moving average of the EUA price series.

This specification fits well with descriptive statistics of EUA price changes displayed in TABLE 5. First, the kurtosis coefficient is by far higher than 3 which is the value of the kurtosis coefficient for the normal distribution. This excess kurtosis denotes a high likelihood of outliers. Second, the skewness coefficient is different from zero and negative which highlights the presence of asymmetry. This asymmetry characterizes a lower level of volatility after price increases than after price decreases.

Estimation results are presented in TABLE A1.2. 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 Ljung-Box *Q*-test statistic, the ARCH Lagrange Multiplier (LM) test, the Akaike Information Criterion (AIC) and the Schwarz Criterion (SC).

4.1. The effects of sector production indices

First, we estimate eq.(1) with only energy variables, temperatures events and compliance breaks. In TABLE A1.2, regression (1a) shows the results for eq.(1). Based on the autocorrelation function of the dependent variable, we have introduced lag operators of order 2. Both the adjusted *R*-squared and the *R*-squared are included between 14.9% and 17.5%, and, as judged by the *F*-test *P*-value, the joint significance of results is accepted at the 1% significance level. The Ljung-Box *Q*-test statistic is equal to 5.1886 for a maximum number of lags *K* equal to 20. This statistic follows a Chi-Square distribution with ($K - p - q$) degrees of freedom, *i.e.* 18 here. The theoretical value of the Chi-Square distribution with 18 degrees of freedom is 28.87 at a 5% significance level. As a consequence, we accept the null hypothesis of no autocorrelation of the residuals. The ARCH LM test does not reject at the 5% significance level the null hypothesis of no autoregressive conditional heteroskedasticity in the residuals for this model.

For energy variables, *natural gas* and *clean spark* impact positively EUA price changes, whereas *coal* and *clean dark* have negative coefficients. 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. *Clean spark* affects EUA price changes with a positive coefficient significant at 1%. During the two years, *clean dark* stays above *clean 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 1%. 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 at 5% significance level.

For the compliance break, the 2006 structural change dummy break is statistically significant at 1%. This dummy variable refers to the sudden price collapse that occurred following the first report of 2005 verified emissions with most of the adjustment being made in four days on April 25-29, 2006. It tends to prove there is a structural change caused by the disclosure of new information by the EC concerning installations' net long positions. It also highlights the importance of institutional information during 2005-2007 on this new commodity market. This analysis is confirmed by a Chow's test of structural change.[32]

For temperatures events, *win07* is significant at 1% level.[33] Its negative coefficient could be explained by the fact that on January-February, 2007 temperatures were hotter than the decennial seasonal average. Actually, this result leads to two main conclusions. First, extreme cooling days do have an impact on EUA price changes. Second, it is not temperatures themselves but deviations from seasonal average which have an impact on EUA price changes during extreme temperatures events.[34] When extremely cold events are colder (hotter) than expected, power generators have to produce more (less) than they forecasted which may conduct to an increase (decrease) of allowances demand to cover their CO_2 emissions beyond their emissions cap and finally to an increase (decrease) of EUA price changes. Thus, unanticipated temperatures changes seem to matter more than temperatures themselves when one tests for the influence of climatic events on EUA price changes. For more details on the results comments, see Alberola *et al*. (2008).

Second, we turn to the inclusion of sector variables. Compared to previous literature, the point here is to test whether industrial production indices significantly impact EUA price changes besides other drivers highlighted in regression (1a), TABLE A1.2; Results of eq.(1) are presented in TABLE A1.2, regression (1b). We only present the reduced form estimate of eq.(1).[35] Both the adjusted *R*-squared and the *R*-squared are, respectively, equal to 14.9% and 18%. The AIC and the SC both decrease. Therefore, the inclusion of sector variables appears more relevant in explaining EUA price changes. All diagnostic tests are validated for these estimates. First, the structural change dummy variable, break, now becomes not significant. As the main comment, losing significance on break suggests that the inclusion of sector production indices in our model contributes to a sharper explanation of carbon price changes. Note that the second indicator of the role of information revelation on this new market, the squeeze probability dummy psq_1, is significant at 1% level. Its positive sign reflects a strong allowance demand from installation operators before 2005 compliance results, which contributes to increasing EUA price changes. The non significance of psq_2 may be interpreted as an indication that before 2006 compliance results market participants had anticipated a lower level of CO_2 emissions compared to allowances allocated and more accurately hedged their allowances during that year. Thus, the allowance squeeze probability did not appear relevant. Those comments apply to the remainder of the paper.

32. Chow's test results may be obtained upon request to the authors.

33. Other temperatures events were also tested such as 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). None of them turned out to be statistically significant on the whole period.

34. Note this remark applies only for extremely cold days.

35. That is to say, we only keep the significant sector variables, and to do so, we withdraw one-by-one the non significant variables from eq.(1).

Third, among the nine sectors included in the EU ETS, three sectors are statistically significant at 1% level: combustion, iron and paper.[36] As shown in FIGURE 3, combustion and iron gather around 78% of allowances allocated, with respectively 70% and 8%. Neither refineries nor cement were identified as having any impact on EUA price changes. Both sectors, with respectively 7.6% and 9.1% of allowances allocated, are characterized by a compliance breakdown among installations that equally splits between net long and net short installations (Trotignon and McGuiness, 2007). Therefore, a potential justification for these non-significant results may come from a pool management of allowances between firms within sectors, so that the considered sectors are globally in compliance.[37]

In FIGURE 2, we observe a decreasing variation of industrial production in the combustion sector during 2006, which may explain why we observe a negative sign for comb in regression (1b). By contrast, in FIGURES 1 and 2, the iron and paper sectors record positive industrial production growth rates. At this stage, we cannot further explain the reason behind the negative coefficients of paper and iron.

As already mentioned in Section 2.2.2, other effects such as the net short/long compliance position may explain the impact of industrial production in EU ETS sectors on EUA price changes. Therefore, we take the analysis one step further in the next section by disentangling the effect of production peaks and compliance positions on EUA price changes.

4.2. The effects of production peaks and compliance positions

As explained in Section 3.2.2, we now estimate eq.(2) for each of the three sectors which were significant in eq.(1) (regression (1b), TABLE 7): combustion, iron and paper sectors.

4.2.1. Analysis of the combustion sector

The combustion sector stands out as the most important sector for this study since it represents a mere 70.13% and 69.85% of total emissions at the EU level in 2005 and 2006 respectively (Trotignon and McGuiness, 2007; Trotignon *et al.*, 2008). The combustion sector is also of particular interest since it is the only sector characterized by the alternation of a net long position (+0.6% in 2005) and a net short position (–1.5% in 2006).

In TABLE A1.2, regressions (2a) and (2b) show the results of eq.(2) for the combustion sector. The regression (2a) contains *combcompl* and *combpeak* whereas regression (2b) contains these latter dummy variables as well as the interaction variable, *combcomplpeak*. Given the fact that coefficient estimates are stable for energy prices and extreme temperatures events variables, we do not comment them further. Note the stability of results for these latter variables coefficients between eq. (1) and (2) estimates proves the robustness of our results (regressions (1a) and (1b), TABLE A1.2). This comment applies in the remainder of the paper.

36. According to the Klein test, the comparison of the squared correlation between each of these exogenous variables (TABLE A1.1) and the *R*-squared of regression (1b) (TABLE A1.2), does not reveal any problematic colinearity.

37. The economic logic behind this presumed pooling behavior is left for further research.

The *comb* coefficient remains negative in both estimates (regressions (2a) and (2b), TABLE A1.2). Besides, *combcompl* and *combpeak* coefficients are both positive and significant at 1% level. The sign of these two dummy variables is conform to arguments presented in Section 2. First, as presented in regression (2a) (TABLE A1.2), with no interaction effects, *ceteris paribus*, the growth rate of EUA prices is higher (by about 0.5%) when the combustion sector record a short allowance position. As explained above, emissions net short/long position needs to be balanced with production peaks.

Comparing the positive coefficient of *combpeak* (about 0.02) to the negative one of *comb* (about –0.07) allows us to improve our analysis on the impact of industrial production on EUA price changes. Recall that Section 2 details the expected effects of the variation of production: industrial sectors which record a higher (lower) production growth than their baseline projections over 2005-2007 are expected, due to their deficit (surplus) of allowances, to be net buyers (sellers) of allowances and should have a positive (negative) impact on EUA price changes. This economic logic explains the positive coefficient of *combpeak*: we observe in regression (2a) (TABLE A1.2) that the growth rate of EUA prices is higher (by about 2%) when the combustion sector encounters a positive production peak *ceteris paribus*. Moreover, the negative coefficient of comb is explained by its declining variation of production during the whole period. This effect remains even after taking into account the positive effect of production peaks.

Note however that the coefficient estimates of the two latter dummy variables may be biased because we do not take into account their likely interaction effects. In other words, the effect of *combcompl* and *combpeak* on mean p_t may not be simply additive as in regression (2a) but multiplicative as well as specified in regression (2b). That is why we now compare the results of eq.(2) estimates (regression (2a), TABLE A1.2) with those of the same equation (regression (2b), TABLE A1.2) which includes the interaction effects between the two dummies, *combcomplpeak*. Values of adjusted *R*-squared, AIC and SC indicate that the inclusion of the interaction variable therefore allows us to gain a better insight into the effects of industrial production and compliance position on EUA price changes. Concerning the dummy variables, the two additive dummies *combcompl* and *combpeak* and the interaction variable *combcomplpeak* are still statistically significant at 1% significance level. Holding other variables constant, when the combustion sector exhibits a net short allowance position and encounters a positive production peak, the growth rate of EUA prices is higher by about 2.3% (0.0231 = 0.0513 + 0.0063 – 0.0345), which is between the value of 0.6% (the effect of *combcompl* alone) and 5% (the effect of *combpeak* alone). The next section presents estimation results for the iron and paper sectors.

4.2.2. Analysis of the iron and paper sectors

In this section, we detail the results for both *iron* (regression (3), TABLE A1.2) and *paper* (regression (4), TABLE A1.2) sectors. As these sectors were net long during both 2005 and 2006 compliance periods, we cannot carry on the analysis with both the compliance and interaction dummies. The iron and steel sector totals only 8% of EU allowance allocation in

2005-2006. The paper sector represents a minor sector for the purpose of this study, with only 1.80% of EU allowance allocation in 2005-2006.

Although the adjusted *R*-squared statistic is known as being controversial, it is worth underlining the lowest value is achieved for the paper sector which totals the lowest level of allocation. The two sector variables for each estimate (*iron*, *ironpeak*, *paper*, *paperpeak*) are significant at 1% level. *Iron* (regression (3)) and *paper* (regression (4)) have both a negative coefficient estimate, whereas *ironpeak* (regression (3)) and *paperpeak* (regression (4)) have a positive sign.

As explained in Section 4.1, the negative sign of *iron* (regression (3)) and *paper* (regression (4)) variables is not explained by their increasing variation of production, (respectively 2.61% in 2005 and 4.31% in 2006, and 0.62% in 2005 and 4.31% in 2006) but ultimately by their net long position on the whole period. Thus, we are able to identify the predominant impact of the net long position over the increasing production trend effect as drivers of EU carbon prices as a potential justification of the negative coefficients of *iron* (regression (3)) and *paper* (regression (4)). The reason behind the positive sign of *paperpeak* and *ironpeak* (regression (4)) is similar to what has been explained in Section 4.2.1 for *combpeak* (regression (2a)). When a sector has an increasing activity peak, then it becomes a potential net buyer which yields to a positive impact on the allowance price.

5. Summary and concluding remarks

Previous literature has identified energy prices, temperatures events and institutional information variables as EUA carbon price drivers during 2005-2007 (Mansanet Bataller *et al.*, 2007; Rickels *et al.*, 2007; Alberola *et al.*, 2008). The analysis of EU ETS price drivers is taken one step further in this article by investigating *i)* whether variations of industrial production from sectors covered by the EU ETS also have an impact on CO_2 price changes and *ii)* through which channels these effects may operate.

As both the European Commission and market participants experienced difficulties in assessing the gap between allowance allocation and industrial emissions forecasts, such analysis may only be conducted around compliance events. The European Commission disclosed on April 2, 2008 the data on 2007 verified emissions from 94% of installations, revealing that the EU ETS records a surplus by 8% (162.5 Mt CO_2). With the diffusion of 2007 compliance data, a complete *ex-post* analysis of the relationship between sectors economic activity and EUA price changes may be further detailed in terms of actual CO_2 emissions abatement for the whole period of the EU ETS Pilot Phase (2005-2007).

To our best knowledge, this article constitutes the first attempt to test the empirical relationship between industrial production and EUA price changes. After having detailed both the expected effect of EU ETS sectors industrial production and emissions compliance on EUA price changes, we present an econometric analysis of EUA price drivers including energy prices, extreme temperatures events, institutional events and industrial production indices of each sector at the EU 27 Member States level. The two most important results may be summarized as follows.

First, we show evidence that only three among nine sectors have a significant effect on EUA price changes from July 1, 2005 to April 30, 2007. These sectors are combustion, paper and iron and total 78% of allowances allocated. This result is especially interesting since the combustion sector is the largest sector of interest in the EU ETS with 70% of allowances allocated. Second, the analysis attempts to better understand why these three sectors stand out as being significant by identifying through which channels variations of industrial production from EU ETS sectors may operate on EUA price changes. The role played by yearly compliance positions and production peaks on this new market is demonstrated. For each of the three sectors previously identified, the analysis confirms our intuitions: both the variation of production and the net short/long position are significant and have the expected effects on CO_2 price changes.

E. A., J. C. & B. C.[38]

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APPENDIX 1

Table A1.1 - Matrix of partial cross-correlations between sector production variables

	Elecset	Iron	Paper	Ceramics	Refineries	Cement	Glass	Metal	Coke
Elecset	1								
Iron	0.0747	1							
Paper	0.2250	0.4628	1						
Ceramics	0.2307	0.0148	0.4056	1					
Refineries	0.3183	0.2472	0.0532	0.2613	1				
Cement	–0.1268	0.1543	0.3132	0.2004	–0.5393	1			
Glass	0.0244	0.1210	0.1998	–0.0458	–0.5409	0.5968	1		
Metal	0.1654	0.4773	0.3225	–0.1060	–0.2306	0.4816	0.6396	1	
Coke	–0.1953	–0.0284	–0.3483	–0.0376	0.1602	–0.6293	–0.3762	–0.2178	1

Table A1.2[1] - Results of equations (1) (2), estimates for the TGARCH(1,1) model

	(1a)[2]	(1b)	(2a)	(2b)	(3)	(4)
Mean equation						
Constant	–0.0104***	–0.0104***	–0.0131***	–0.0132***	–0.0108***	–0.0083***
	(0.006)	(0.0007)	(0.0006)	(0.0006)	(0.0008)	(0.0005)
Break	0.0075***	–	–	–	–	–
	(0.0013)					
Psq_1		0.0002***	0.0004***	0.0004***	0.0005***	0.0008***
		(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Psq_2		–	–	–	–	–
Natural gas	0.1378***	0.1305***	0.1343***	0.1344***	0.1371***	0.1353***
	(0.0033)	(0.0029)	(0.0029)	(0.0030)	(0.0026)	(0.0018)
Coal	–0.1971***	–0.1775***	–0.1840***	–0.1842***	–0.1872***	–0.1841***
	(0.0103)	(0.0101)	(0.0076)	(0.0077)	(0.0062)	(0.0054)
Electricity	0.0009**	0.0013***	0.0008***	0.0010***	0.0010***	0.0005**
	(0.0004)	(0.0004)	(0.0003)	(0.0003)	(0.0003)	(0.0002)
Clean dark	–0.0777***	0.0742***	–0.0756***	–0.0758***	–0.0776***	–0.0750***
	(0.0014)	(0.0013)	(0.0014)	(0.0015)	(0.0013)	(0.0008)
Clean spark	0.0767***	0.0727***	0.0749***	0.0749***	0.0765***	0.0756***
	(0.0018)	(0.0016)	(0.0016)	(0.0017)	(0.0014)	(0.0010)
Win07	–0.0080***	–0.0191***	–0.0263***	–0.0259***	–0.0266*	–0.0309***
	(0.0029)	(0.0019)	(0.0018)	(0.0017)	(0.0018)	(0.0017)
Combustion		–0.0524***	–0.0671***	–0.0678***		
		(0.0068)	(0.0057)	(0.0060)		

	(1a)[2]	(1b)	(2a)	(2b)	(3)	(4)
Mean equation						
Iron		–0.0262***			–0.0226***	
		(0.0059)			(0.0062)	
Paper		–0.0548***				–0.0447***
		(0.0121)				(0.0083)
Combpeak			0.0195***	0.0513***		
			(0.0019)	(0.0021)		
Combcompl			0.0051***	0.0063***		
			(0.0012)	(0.0012)		
Combpeakcompl				–0.0345***		
				(0.0029)		
Ironpeak					0.0085***	
					(0.0008)	
Paperpeak						0.0117***
						(0.0)
Variance equation[3]						
Constant	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
α_1^+	0.3182***	0.3170***	0.5000***	0.5179***	0.5467***	1.0746***
	(0.0569)	(0.0686)	(0.0575)	(0.0593)	(0.0569)	(0.1181)
α_1^-	0.2236***	0.2608***	0.5094***	0.4096***	0.4900***	0.3374***
	(0.0736)	(0.0689)	(0.1701)	(0.1527)	(0.1373)	(0.2058)
β	0.7331***	0.7254***	0.5736***	0.5800***	0.5707***	0.3690***
	(0.0171)	(0.0262)	(0.0339)	(0.0320)	(0.0329)	(0.0270)
R-squared	0.1746	0.1796	0.1394	0.1851	0.1143	0.0625
Adj. *R*-squared	0.1495	0.1491	0.1073	0.1529	0.0832	0.0297
F-Stat.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Log-Likelihood	1033.271	1059.103	1091.737	1104.632	1069.825	1060.271
Q-Stat.	5.1886	5.7559	6.7367	6.5985	4.7321	7.9070
ARCH LM Test	0.1826	0.2234	0.3812	0.4285	0.5576	0.9903
AIC	–4.2965	–4.3928	–4.5305	–4.5807	–4.4423	–4.4020
SC	–4.1648	–4.2348	–4.3725	–4.4139	–4.2931	–4.2527

Notes:

1: See Alberola *et al.*, 2008.

2: The estimated model is $\sigma_t = \alpha_0 + \alpha^+(L)\varepsilon_t^+ - \alpha^-(L)\varepsilon_t^- + \beta(L)\sigma_t$ where $\left\{ \begin{array}{l} \varepsilon_t^+ = \max(\varepsilon_t, 0) \\ \varepsilon_t^- = \min(\varepsilon_t, 0) \end{array} \right\}$

3: In TABLE A1.2, the dependent variable is the first log-differenced EUA price series. Other variables are explained in Section 3.

*** significance at 1%, ** at 5% and * at 10%.

Standard errors in parenthesis. *P*-values are reported for *F*-stat and ARCH LM tests.

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