UNIVERSITY PARIS X – NANTERRE

DEPARTMENT OF ECONOMICS

Library N^{O}

Year 2008 |_|_|_|_|_|_|_|_|_|_|

PH.D. THESIS

For the award of the Degree of

DOCTOR OF PHILOSOPHY

Academic Discipline : Economics

Submitted by

Julien CHEVALLIER

Date of Defense: November 5, 2008

Titre : THE EUROPEAN CARBON MARKET (2005-2007):
BANKING, PRICING AND RISK HEDGING STRATEGIES

Thesis Supervisor :

Mr Gilles Rotillon, Professor at the University of Paris X - Nanterre

---

JURY

- Mr Olivier Beaumais, Professor at the University of Rouen
- Mr Thierry Bréchet, Professor at the Catholic University of Louvain
- Mr Derek Bunn, Professor at the London Business School
- Mr Christian De Perthuis, Professor at University of Paris-Dauphine, CDC
- Mr Denny Ellerman, Professor at the Massachusetts Institute of Technology
- Mr Pierre-André Jouvet, Professor at the University of Paris X - Nanterre

Abstract

The European carbon market (2005-2007): banking, pricing and risk hedging strategies

This thesis investigates the market rules of the European carbon market (EU ETS) during 2005-2007. We provide theoretical and empirical analyses of banking and borrowing provisions, price drivers and risk hedging strategies attached to tradable quotas, which were introduced to cover the CO_2 emissions of around 10,600 installations in Europe.

In Chapter 1, we outline the economic and environmental effects of banking and borrowing on tradable permits markets. More specifically, we examine the banking and borrowing provisions adopted in the EU ETS, and the effects of banning banking between Phases I and II on CO_2 price changes. We show statistically that the low levels of CO_2 prices recorded until the end of Phase I may be explained by the restriction on the inter-period tranfer of allowances, besides the main explanations that were identified by market observers.

In Chapter 2, we identify the carbon price drivers since the launch of the EU ETS on January 1, 2005. We emphasize the central role played by the 2005 yearly compliance event imposed by the European Commission in revealing the net short/long position at the installation level in terms of allowances allocated with respect to verified emissions. The main result of this study features that price drivers of CO_2 allowances linked to energy market prices and unanticipated weather events vary around institutional events. Moreover, we show the influence of the variation of industrial production in three sectors covered by the EU ETS on CO_2 price changes by applying a disentangling analysis, that has also been extended at the country-level.

In Chapter 3, we focus on the risk hedging strategies linked to holding CO_2 allowances. By using a methodology applied on stock markets, we recover the changes in investors' average risk aversion. This study shows that, during the time period considered, risk aversion has been higher on the carbon market than on the stock market, and that the risk is linked to an increasing price structure after the 2006 compliance event. With reference to Chapter 1, we finally evaluate how banking may be used as a risk management tool in order to cope with political uncertainty on a tradable permits market. We detail an optimal risk-sharing rule, and discuss the possibility of pooling the risk linked to allowance trading between agents.

Overall, this thesis highlights the inefficiencies following the creation of the European carbon market that prevented the emergence of a price signal leading to effective emissions reductions by industrials. However, in a changing institutional environment, these inefficiencies do not seem to have been transfered to the period 2008-2012.

Keywords: Tradable permits market, EU ETS, Banking and borrowing provisions, CO_2 Price fundamentals, Risk aversion, Optimal risk-sharing rule.

JEL Codes: C14, D21, D80, G14, Q28, Q52, Q58.

To my family

Contents

List of Figures

List of Tables

Acknowledgments

I wish to thank first Gilles Rotillon, who has accepted to supervise this thesis, and Pierre-André Jouvet, who has advised me also on many aspects of this work. By sharing their experience, both have taught me how fascinating the research activity may be when launched on original topics. On this matter, I wish to thank also Denny Ellerman, Olivier Godard and Katheline Schubert for organizing a research seminar on emissions trading in 2005, which has been very useful for this thesis.

The study on price fundamentals in Chapter 2 has been possible thanks to the fruitful collaboration with Emilie Alberola and Benoît Chèze. Our work has been facilitated by the use of the Tendances Carbone database by the Caisse des Dépôts. I wish to thank warmly Christian de Perthuis for allowing access to this data, as well as to all the members of the Mission Climat in Paris, which stands out as a centre of expertise on the European carbon market. Emmanuelle Taugourdeau and Gunther Capelle-Blancard have also made useful comments during the preparation of this work.

The research on risk aversion on the European carbon market provided a wealth of insights thanks to the collaboration with Florian Ielpo and Ludovic Mercier. We thank Dexia for the gracious use of the database on derivatives products. The work developed in the remaining of Chapter 3 stems from prior research of Johanna Etner and Pierre-André Jouvet on the topic of risk management and the use of banking on tradable permits markets. I am very grateful to both of them for allowing me to join this research project.

I thank Olivier Beaumais and Derek Bunn for having accepted to be external reviewers on this thesis, as well as to Thierry Bréchet and Denny Ellerman for accepting to be part of the jury. Last but not least, I wish to thank Valérie Mignon for her availability on econometric issues, her generosity and her precious proofreading on earlier versions of this work.

Finally, I wish to thank Slim, Pascal, Vincent, and other Phd students at the G-Building in Nanterre, and the administrative staff at EconomiX, for entertaining a convivial work atmosphere, as well as to Leslie for her unfailing support during these hard-working Phd years.

Introduction

The European Union Emissions Trading Scheme (EU ETS) has been created on January 1, 2005 to reduce by 8% CO_2 emissions in the European Union by 2012, relative to 1990 emissions levels. This aggregated emissions reduction target in the EU has been achieved following differentiated agreements, sharing efforts between Member States based on their potential of decarbonization of their economy (see Table 1). The introduction of a tradable permits market has been decided to help Member States in achieving their targets in the Kyoto Protocol, entered into force on February 2005 following the ratification of Iceland, and which aims at reducing the emissions of six greenhouse gases (GHG) considered as the main cause of climate change. Among the Members of Annex B, these agreements include CO_2 emissions reductions for 38 industrialized countries, with a global reduction of CO_2 emissions by 5,2% (see Table 2). These agreements have been fostered by the United Nations Framework Convention on Climate Change (UNFCCC) which recognizes three principles: the precautionary principle[1], the principle of common but differentiated responsibilities[2], and the principle of the right to development[3]. 174 countries, Australia being the latest on December 3, 2007, have ratified the Protocol, with the notorious exception of the United States. The first commitment period of the Kyoto Protocol goes from January 1, 2008 to December 31, 2012.

---

[1] Scientific uncertainty concerning the precise impacts of climate change does not justify to delay immediate action.

[2] Each signatory country recognizes the impact of its GHG emissions on climate change. The most industrialized countries carry an heavier historical responsibility, given their prior GHG-intensive development, which translates into tighter targets.

[3] Action will be taken in accordance with the economic development of each country.

Country	Part of EU emissions in 1990	Differentiated Agreements
Austria	1.7	-13.0
Belgium	3.2	-7.5
Denmark	1.7	-21.0
Finland	1.7	0.0
France	14.7	0.0
Germany	27.7	-21.0
Greece	2.4	25.0
Ireland	1.3	13.0
Italy	12.5	-6.5
Luxembourg	0.3	-28.0
Netherlands	4.8	-6.0
Portugal	1.6	27.0
Spain	7.0	15.0
Sweden	1.6	4.0
UK	17.9	-12.5
Total EU	100.0	8.0

Table 1: Differentiated Agreements of CO_2 Emissions Reduction in the EU from Marklunda et Samakovlis (2007)

This political will has been reaffirmed at the international level during the UN Conference that took place in Bali on December 2007, where a roadmap of negotiations that should lead to a post-Kyoto agreement has been adopted. The United States are expected to cooperate, given the initiatives of emissions reduction introduced at the regional level[4]. The next round of negotiations will take place in Copenhagen on December 2009. As the Clean Development Mechanism (CDM)[5] has revealed the strong potential of CO_2 emissions abatement in countries such as Brazil, China or India, the main issue of these negotiations is linked to achieving the largest possible level of cooperation, in order to avoid the well-known free riders

---

[4] We may cite the *Regional Greenhouse Gas Initiative* (RGGI), which contains several GHG reduction objectives in nine North-Eastern States, and the Assembly Bill 32 in California which aims at reducing CO_2 emissions by 25% by 2020 relative to 1990 emissions levels, and by 80% by 2050. At the federal level, the *Climate Stewardship Act* introduced by the Senator Lieberman-McCain did not find sufficient political support to become legally binding.

[5] According to the article 12 of the Kyoto Protocol, CDM projects consist in achieving GHG emissions reduction in non-Annex B countries. After validation, the UNFCCC delivers credits that may be used by Annex B countries for use towards their compliance position.

behaviours, and to preserve the global public good that constitutes the climate. On this matter, the European Union has clearly adopted a leadership position, which contrasts with its early reluctance during the first steps of the negotiation of the Kyoto Protocol.

On January 2008, the European Commission has extended the scope of its action against global warming by 2020 with the "energy and climate change" package. This package aims at reducing GHG emissions by 20%, at increasing the use of renewable energy in energy consumption to 20%, and at saving 20% of energy by increasing energy efficiency. The European carbon market, which has currently entered its Phase II (2008-2012), has been confirmed until 2020 also. Its scope has been extended to major sectors in terms of CO_2 emissions growth, such as aviation and petro-chemical industries during 2013-2020. These repeated public policies in favor of climate protection aim at correcting the negative externality attached to the release of uncontrolled GHG emissions in the atmosphere and thus, according to the well-known principle in economics, at internalizing the social cost of carbon. At the same time, these initiatives reveal the difficulty to create a scarcity condition regarding CO_2 emissions. These emissions indeed were not limited in the pre-existing institutional environment, and thus could not be considered as a scarce resource. A French report from the Centre of Strategic Analysis has been recently published on the temporal profile of the carbon price. It reveals a strictly increasing price path for carbon allowances, reaching a higher value than currently around 100 €/ton by 2050. These projections point out to industrials the necessity to take into account the costs attached to CO_2 emissions reductions in their investment plans on the mid-term.

Following this short review of current climate policies, and of the negotiations under way at the international level, we detail next the main advantages of introducing environmental regulation tools such as tradable permits markets.

How is a tradable permit different?

To answer this question, it appears useful to debate first about the notions of "right to pollute" and of "marketability of the environment". We may recall for

Members of Annex I	CO_2 Emissions in 1990 (gigagrams)	Part in % of emissions in 1990 among Annex I Members	Kyoto Target 2008-12 (% relative to 1990 emissions levels)
United States	4,957,022	36.00	93
European Union	3,288,667	24.05	92
Austria	59,200	0.43	92
Belgium	114,410	0.84	92
Denmark	52,025	0.38	92
Finland	53,900	0.39	92
France	366,536	2.68	92
Germany	1,014,155	7.42	92
Greece	82,100	0.60	92
Ireland	30,719	0.22	92
Italia	428,941	3.14	92
Luxembourg	11,343	0.08	92
the Netherlands	167,600	1.23	92
Portugal	42,148	0.31	92
Spain	227,322	1.66	92
Sweden	61,256	0.45	92
UK	577,012	4.22	92
Australia	288,965	2.11	108
Canada	462,643	3.38	94
Iceland	2,172	0.02	110
Japan	1,155,000	8.45	94
New Zealand	25,476	0.19	100
Norway	35,514	0.26	101
Switzerland	45,070	0.33	92
Liechtenstein	208	n.a.	92
Monaco	n.a.	n.a.	92
Transition Economies	3,364,259	24.60	103
Bulgaria	82,990	0.61	107
Czech Republic	165,792	1.21	92
Estonia	37,797	0.28	92
Hungary	71,673	0.52	110
Latvia	22,976	0.17	92
Lituania	n.a.	n.a.	92
Poland	414,930	3.03	108
Romania	171,103	1.25	107
Russian Federation	2,388,720	17.47	100
Ukraine	n.a.	n.a.	100
Slovakia	58,278	0.43	92
Croatia	n.a.	n.a.	95
Slovenia	n.a.	n.a.	92
Total 1990	13,675,067	100	95

Table 2: Status of the Kyoto Protocol from Barrett (1998)

instance the controversy initiated by the introduction of tradable permits markets in the United States, and summarized by Sandel (1997).

Since the aim of the Kyoto Protocol is to limit the global level of GHG, one might ask, what difference does it make which places on the planet send less carbon to the sky? It may make no difference from the standpoint of the heavens, but it does make a political difference. Turning pollution into a commodity to be bought and sold removes the moral stigma that is properly associated with it, if a company or a country is fined for spewing excessive pollutants into the air, the community conveys its judgment that the polluter has done something wrong. A fee, on the other hand, makes pollution just another cost of doing business, like wages, benefits and rents.

One may object to these remarks that it is not immoral to reduce acid rain by half through tradable permit system among electrical utilities in the United States, reducing sulfur dioxide faster than anyone had predicted, and saving up to $ 1 billion a year for electricity consumers. Besides, virtually any manufacturing activity entails the creation of some pollution. So the question is not will we pollute, but rather how much. Further, if there is to be pollution, the regulator shall try to provide economic incentives in order to fight against such negative consequences on the environment. Such a trade-off is facilitated by tradable rights.

Thus, maintaining a moral stigma on pollution makes sense for hazardous substances where polluters have choices, for reducing the pollution. But global warming is not such a situation. Indeed, do we need to feel ashamed when we cook dinner, switch on a light or turn on a computer to write an article? These daily habits may not be associated with immoral behaviours. However, the current level of consumption per capita, on several locations on the planet, does not seem compatible with the observed global warming. Thus, the debate on the introduction of tradable permits markets avoids to discuss the fact that the state of the planet can no longer afford consumption lifestyles with cheap energy prices.

Let us now discuss about the increasing influence of the market as a regulation tool of environmental externalities. With the extension of the scope of human activity, one can notice a trend of increasing demand for environmental goods.

High-income societies tend to value environmental goods more, according to the environmental Kuznets curve[6]. Therefore, how do we manage the scarcity of environmental goods? Simultaneously, a trend of increased reliance on markets may be underlined, as in Europe many fields have been deregulated (telecoms, electricity, etc.). Let us further distinguish between *organized* markets, where the government mainly enforces regulation[7], and *constructed* markets that appear in the environmental field where there is a need to set up an institution[8]. The latter case involves a redefinition of the government role which consists in creating the market for individual needs, and then not coming back to regulate.

The circumstances that are favorable to the adoption of tradable permits include a large number of agents to regulate, an asymmetrical and strategic access to information, a high level of heterogeneity of costs and opportunities across decentralised agents, and uncertainty about the shape of cost and damage curves[9]. In a cap and trade system, agents are allowed to exchange permits with a quantity limit, without regulator approval, where the regulator compliance requirement is to monitor emissions and surrender permits. The "rights to emit" are created as permits endow the installation. Firms need to meet the terms of that implicit contract: permits become an input to production, and are traded as such. The abatement decision is shifted to firms, since they have more information of what can be done than the regulator. Thus, the regulator only needs to enforce the emissions cap.

Does emissions trading have effects that would tamper enthusiasm for this instrument? The U.S. Acid Rain Program provided empirical support to the view that market-based instruments may be more environmentally efficient than command and control regulation. SO_2 emissions fell, and the program was characterized by a quick implementation, a positive role of banking (twice as much as required), a good compliance and no hot spots. These optimistic results may be

---

[6] Note that the empirical validation of this relationship is subject to numerous discussions, that we do not report here.

[7] antitrust activities for instance

[8] In order to provide clean air or water for instance.

[9] On this point, see the seminal article by Weitzman (1974).

limited to *flow* pollutants, since for *stock* pollutants like CO_2 the incentive to abate is less temporally and spatially constraining. Finally, Babiker et al. (2004) underline that all countries do not benefit equally from the introduction of an international system of exchangeable quotas, given the pre-existing institutional environment and the terms-of-trade effects.

Following the discussion of the main differences of tradable permits markets with regard to other environmental regulation tools, we detail next the choices that need to be made by the regulator during the creation of the tradable permits market, especially concerning the spatial and temporal limits, the initial allocation, as well as the introduction of a safety valve.

Market design: spatial and temporal limits

Spatial and temporal limits

Concerning spatial limits, it is worth emphasizing scaling issues. Increasing the scale of the cap and trade system increases economic efficiency, but also decreases trade security. The regulator also needs to take into account deposition constraints, by avoiding excedance of critical loads in specific geographical zones[10]. Another concern lies in the proper design of national emission ceilings.

Concerning temporal limits, banking and borrowing may be used to equalize marginal costs in present value. It forms another dimension of efficiency by adding the time dimension to cost savings. Banking incentives come from tightened regulation. The use of borrowing is often discarded as not optimal. But caps are not optimal to start with, since they are politically given. So, there is some room to open up the field of borrowing in order to correct design inefficiencies, as we shall see later.

Initial allocation

According to Raymond (1996), initial allocation reveals social norms, and what society considers as acceptable on how to distribute the newly created permits.

---

[10] This comment obviously depends on the nature of the pollutant.

Different allocation methodologies may be chosen, such as methodologies based on grandfathering (free distribution in proportion of recent emissions or a benchmark), auctioning, baseline emissions, or per capita allocation. It is not obvious to tell how tradable permits should be allocated. Even if theory suggests that auctioning is the best methodology (Ekins and Barker (2001), JMR (2005a, 2005b)), it rises equity-based objections. The definition of what is "fair" is problematic, and a "compromise"[11] must be found between local and global interests, which in return brings us to what appears "acceptable", for instance concerning climate policies at the international level.

Newell et al. (2005) emphasize that tradable permits create rents, and grandfathering distributes those rents to existing firms while also erecting barriers to entry. To counter-balance these negative effects, let us note that the direct allocation of grandfathered permits offers a degree of political control over the distributional effects of regulation, enabling the formation of majority coalitions. Once the permits market has been introduced, then the regulator may strenghten the environmental constraint.

Finally, let us note that the regulator may choose emission targets in absolute value (a fixed amount of permits known in advance), or in relative value (with respect to production or to a technological standard for instance) (Ellerman and SueWing (2003)).

It appears useful to distinguish between the *effectiveness* of a tradable permit market, *i.e.* how much emission reduction it will achieve, from its *economic performance*, *i.e.* what allocation effects are to be expected.

The main interest of auctioning permits consists in the *income transfer*, which may take the form of a lump-sum or a tax rebate, and reduces pre-existing distortions. This recycling revenue effect, also called *double dividend*, takes place when auctioning permits allows to decrease taxes and reduce distortions. This should have a positive effect on supply of capital and labor, but the net effect on high- or low-income quintiles depends on the tax structure. If the tax cut benefits more to richer people, then there is a clear trade-off between efficiency and equity (Dinan

---

[11] This notion is developed by Boltanski et Thevenot (1991).

and Rogers (2002)).

Safety valve

A safety valve is an hybrid instrument to limit the cost of capping emissions at some target level, whereby the regulator offers to sell permits in whatever quantity at a pre-determined price. If prices are greater than expected, the marginal cost of abatement would be limited to the safety valve price. The regulator tries to set the emissions cap at a level where the expected marginal cost of meeting the constraint will match the beliefs about marginal benefits. Another advantage consists in keeping the attractiveness of a quantity target, and the use of a price mechanism in order to regulate the emissions of pollutants. The main criticism of a safety valve consists in the determination of a "fair" price by the regulator: if the safety valve price is too high, it will have no effect. Conversely, if the safety valve is too low, the quantity constraint is not binding anymore and may be associated with a permanent tax. Moreover, there is a potential loss of "environmental integrity", *i.e.* a fear of relaxing towards target reduction instead of supporting economically efficient implementation. The regulator shall thus attempt to avoid excessive violations of the original target. Finally, it is worth asking whether it appears useful to dilute the quantity constraint.

The RECLAIM program in California regulating SO_2 and NO_X emissions constitutes a good example of a system that would have required a safety valve. With a limited temporal flexibility and geographic scope, unusual weather conditions and a lack of new capacity placed high demand on existing units, fostering a rise in the permit price from \$5,000 to \$90,000 per ton. The disconnection of electricity and environmental markets, associated with other program design failures[12], led the State to eventually took over, and to provide adequate electricity supply (Harrison (2003)).

Jacoby and Ellerman (2004) recall that the discussions on the adoption of a safety valve emerged in the United States around the costs related to the Kyoto

---

[12] Such as the lack of pre-specified civil and criminal penalty, the risk of facilities shutting down, and people buying small but highly polluting generators, etc.

Protocol as a way of raising the likelihood of the ratification of the Protocol, by blunting the criticism that the cost of meeting the Kyoto targets would be too high. However, it does not always appear profitable to limit price variations on markets. Quotas are distributed freely and form another asset compensating the cost of the constraint on CO_2 emissions, which tend to stabilize the net position of firms. Moreover, financial instruments are being developed in order to hedge against the risk of temporary price variations, for instance on the EU ETS. Thus, in order to obtain stable and predictable prices, Member States shall simply levy a tax, which does not appear politically feasible at the international level.

Given this wide array of choices that must be made by the regulator during the creation of the permits market, the EU ETS has been launched as a learning tool to emissions trading, which needs to be further explicited.

Organization and early development of the European carbon market

Scope

The Directive 2003/87/CE defines the scope of the EU ETS. This scheme concerns around 10,600 installations in Europe, mainly in the production sectors of combustion, iron and steel, pulp and paper, refineries, and cement. Installations in these sectors are eligible to emissions trading when their energy consumption is superior to the threshold of 20MWTh. This threshold has been decided by the European Commission so as to target the most energy-intensive industries during the first Phases of the program. This choice has been justified initially by the will of the European Commission to minimize political resistance, and to enforce a quick implementation of the scheme in 2005. To increase the environmental performance of the scheme, the debate is now centered on the progressive extension of its scope. The EU ETS Review has revealed that other sectors will soon be included, such as aviation as of 2013.

Allocation

The CO_2 emissions reduction target of each Member State has been converted into National Allocation Plans (NAPs). Each government is in charge of deciding the amount of quotas available for trading, after negotiating with industrials, and after the validation by the European Commission. The role of the Environment DG is central in this scheme in order to harmonize NAPs among Member States, and to recomment stricter NAPs validation criteria. The NAPs submissions may be rejected by the European Commission, and sent back to Member States for revision before the final decision. The sum of NAPs determines the number of quotas distributed to installations in the EU ETS.

2.2 billion of quotas per year have been distributed during 2005-2007. 2.08 billion of quotas per year will be distributed during 2008-2012, which corresponds to a more restrictive allocation, given some changes in the scope of the market with the inclusion of new Member States. Figures 1 and 2 represent, respectively, the repartition of quotas (in million tons of CO_2) between Member States during the commitment periods 2005-2007 and 2008-2012[13]. Germany, Poland, Italy, the UK and Spain total around two thirds of allowances distributed.

The allocation methodology consists in a free distribution of quotas in proportion of recent emissions, also known as grandfathering. With a value of around 20 € per quota, the launch of the EU ETS corresponds to a net creation of wealth of around 40 billion €. The environmental constraint during 2005-2007 has not been considered as sufficiently binding for most market observers, and the allocation methodology has been criticised for distributing rents to pre-existing market players, as some of them may make a net profit simply by selling their unused allowances.

During 2005-2007, allowances distributed have more than covered verified emissions, with a net cumulated surplus of 156 million tons. This surplus has however decreased, going from 83 million tons in 2005 to 37 million tons in 2006, and finally 36 million tons in 2007. Emissions have increased by 0.4% in 2007 compared

---

[13] The data comes from the Mission Climat - Caisse des Dépôts, available at: *http://www.caissedesdepots.fr*

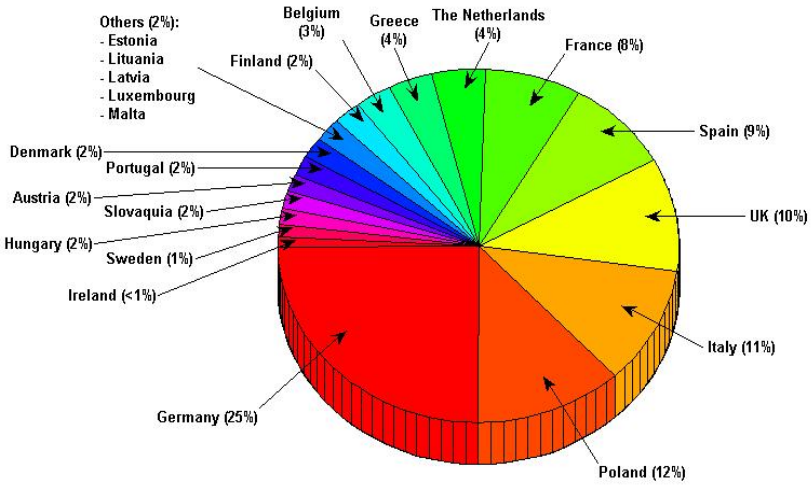

Figure 1: NAPs I in the EU ETS (2005-2007) from the CITL (2007) and the Caisse des Dépôts (2006)

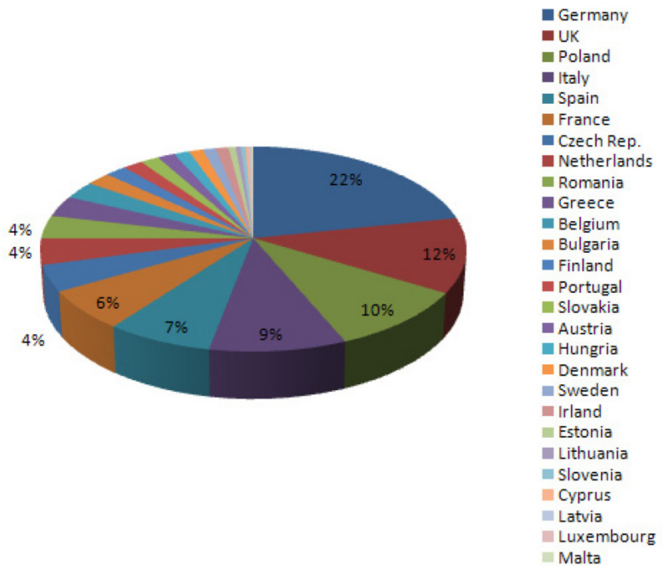

Figure 2: NAPs II in the EU ETS (2008-2012) from the CITL (2008) and the Caisse des Dépôts (2008)

to 2006, and reached 2043 million tons with respect to 2080 million allowances distributed.

Calendar

The EU ETS Phase I may be considered as a warm-up phase, during 2005-2007. Phase II corresponds to the commitment period of the Kyoto Protocol, *i.e.* 2008-2012. Phase III is supposed to correspond to a post-Kyoto agreement, *i.e.* 2013-2020. During each of these Phases, the delivery of allowances is made on a yearly basis, and follows a precise calendar:

- on February 28 of year N, European operators receive their allocation for the commitment year N;
- March 31 of year N is the deadline for the submission of the verified emissions report during year $N-1$, from each installation to the European Commission;
- April 30 of year N is the deadline for the restitution of quotas utilized by operators during year $N-1$;
- May 15 of year N corresponds to the deadline of the official publication by the the European Commission of verified emissions for all installations covered by the EU ETS during year $N-1$.

The annual frequency of verified emissions, imposed by the European Commission, corresponds thus to a central event, structuring the diffusion of reliable informations at the aggregated level on the European carbon market.

Allowance trading

One allowance exchanged on the EU ETS corresponds to one ton of CO_2 released in the atmosphere, and is called an *European Union Allowance* (EUA). Allowance trading is recorded electronically by the national registries, that the Caisse des

Dépôts manages in France for instance. The information contained in these national registries is centralized by the European Commission in the European registry, called the *Community Independent Transaction Log* (CITL)[14]. The CITL contains exhaustive information on CO_2 emissions for all installations covered by the EU ETS, and is used to account the compliance position of each firm. The information contained in the CITL is available at the installation level. As a first step, data compilation appears necessary to reconstruct the ownership structures between subsidiaries and parent companies, which yields to a more precise analysis for the evaluation of the scheme.

To comply with their emissions target, installations may exchange quotas either over-the-counter, or through brokers and market places. *Bluenext*, formerly Powernext Carbon, is the market place dedicated to CO_2 allowance trading based in Paris. The *European Climate Exchange* is the market place based in London, which is leader for derivatives products. *NordPool* represents the market place common to Denmark, Finland, Sweden, Norway, and is based in Oslo. The price of products exchanged on these market places are strongly correlated, which is conform with other market places like stock markets. Moreover, the European carbon market is characterised by an increasing sophistication of financial instruments using a quota of CO_2 as the underlying asset, and the development of option prices or swaps[15].

Figure 3 indicated the total volume of allowances exchanged in the EU ETS during Phase I. This graph reveals that the number of transactions has been multiplied by a factor four between 2005 and 2006, going from 262 to 809 million tons. This increasing liquidity of the market has been confirmed in 2007, where the volume of transactions recorded equals 1.5 billion tons. This peak of transactions may be explained by the growth of the number of contracts valid during Phase II, with delivery dates going from December 2008 to December 2012, which amount for 4% of total exchanges in 2005, and 85% in 2007. These transactions reached 5.97

---

[14] Available at: *http://ec.europa.eu/environment/ets*

[15] Note there exists also financial instrument with a CDM credit on the secondary market as the underlying asset, stemming from the Kyoto Protocol and fungible with quotas traded in the EU ETS with a maximum limit of around 13.4%.

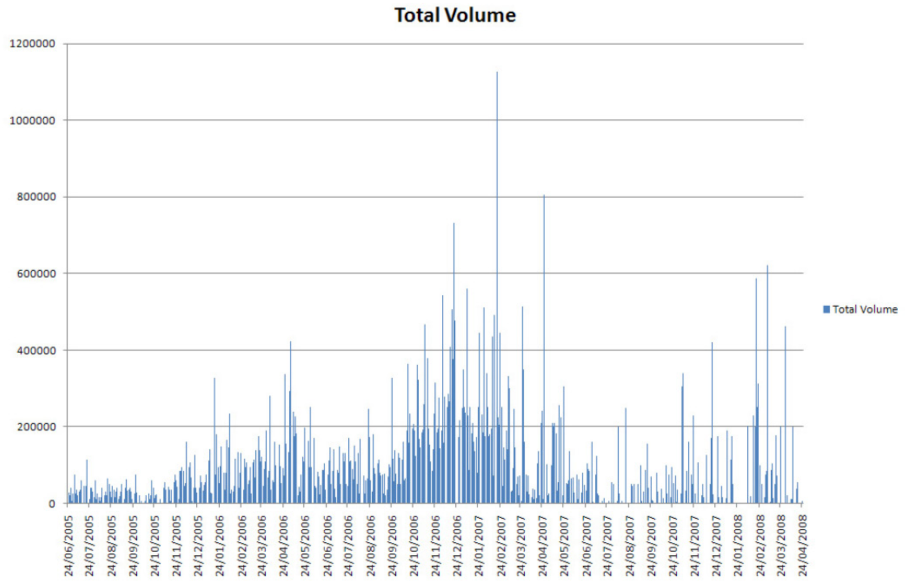

Figure 3: Volume exchanged for the spot price valid during 2005-2007 from June 24, 2005 to April 25, 2008 in tons of CO_2 from Bluenext

billion € in 2005, 15.2 billion € in 2006, and 24.1 billion € in 2007, thereby confirming the fact that the EU ETS represents the largest emissions trading scheme to date in terms of transactions.

Allowance transfer

Allowances are valid during a specific compliance year. However, an installation may have banked allowances during year N to cover its emissions during year $N+1$, if years N and $N+1$ correspond to the same Phase. The same mechanism applies for allowances borrowed from year $N+1$ in order to comply with the emissions target of the installation during year N. Thus, allowances banked or borrowed are fungible within the same Phase. However, allowances distributed during Phase I are not valid during Phase II. Allowances distributed during Phases II and III are fungible between the different Phases.

Penalties

During 2005-2007, if an installation does not meet its emissions target during the compliance year under consideration, the penalty is equal to 40 €/ton in excess, plus the restitution of one allowance during the next compliance period. During 2008-2012, this amount corresponds to 100 €/ton, following the same principle.

This broad description of the institutional context of European policies to fight climate change brings us to the definition of the central question of this thesis.

Central question

The European Union being at the forefront of environmental regulation dedicated to climate policies, this thesis evaluates the market rules of the European carbon market during Phase I. We investigate the role played by the regulator, among the various choices at stake when creating a tradable permits market, on the behaviour of firms. Thus, our work attempts to contribute to the literature on the "birth" of the European carbon market, by focusing our attention on the study of several key provisions in a moving institutional context, and by identifying learning effects.

First, we will examine the effects of banking and borrowing on tradable permits markets. We will use both a conceptual approach, in order to recall the main environmental and economic effects, and an empirical approach, in order to assess statistically the effects previously identified of the market rules adopted on the EU ETS.

Then, we will study the price fundamentals of CO_2 allowances, linked to the decisions of the regulator concerning initial allocation. The decision to create an allowance of CO_2 has fostered pricing strategies by firms, given the interactions with energy markets. We will also show evidence of the importance of weather events in the price determination of CO_2 allowances, as well as the role played by the evolution of industrial production in the sectors covered by the EU ETS.

Finally, we will use original methods in order to recover risk aversion on the European carbon market, and to identify how firms react in a context of uncertainty on the variation of political decisions. This latest study will also be linked to the role played by the banking provision, as well as to the risk management strategies previously identified.

Overall, this research is composed of three chapters. These chapters follow the objectives described above, and are not independent, since our analysis on the evaluation of the scheme is building on the elements progressively identified. The outline is as follows:

Chapter 1 details the theoretical properties of banking and borrowing on tradable permits markets. We recall under which conditions the choice of the regulator should consist in allowing banking, and restricting borrowing by adopting a non-unitary intertemporal exchange ratio. The former decision is due to the fact that banking allows firms to smooth their emissions overtime, and offers a greater flexibility in order to meet the emissions target. The latter decision is linked to the fact that borrowing may lead to a concentration of emissions during early periods of the program, when firms have high abatement costs and have incentives to delay investments in depollution technologies. These first elements indicate that banking and borrowing have the potential to achieve their objectives in terms of efficiency, if these provisions are adequately configured by the regulators and their effects have been sufficiently discussed, evaluated and understood. This theoretical review of the properties of banking and borrowing yields to the investigation of the provisions adopted on the EU ETS. Phase I is characterized by a full intertemporal flexibility, like Phases II and III. Yet, given the simultaneity of the commitment periods between the Kyoto Protocol and Phase II, the intertemporal transfer of allowances has been strictly limited between Phases I and II. In this context, we investigate the effets of banning the inter-period transfer of allowances on the price development of CO_2 allowances during 2005-2007. Our results confirm statistically the hypothesis that the disconnection between Phase I prices, decreasing asymptotically towards zero, and Phase II prices, stabilized around 20 €/ton, may be explained by the restriction on the inter-period transfer of allowances enforced during Phase I. With reference to our central question, we are able to identify institutional learning effects between Phases I and II, as the early inefficiencies due to the youth of the European carbon market during 2005-2007 do not seem to have been transfered to the subsequent periods.

Chapter 2 focuses on the price fundamentals of CO_2 allowances. These fundamentals are mainly linked to energy prices and extreme weather events. We develop an original method in order to show structural breaks in the CO_2 price series during 2005-2007. These breaks are linked to yearly compliance events, and to official communications by the European Commission. We show that the influence of fundamentals linked to energy prices and temperatures variables vary before and after the periods of structural breaks previously identified. Thus, our study confirms that CO_2 price drivers are mainly linked to interactions with energy prices and temperatures, but that their influence vary through time, and may sometimes be undermined by major changes in the anticipations of market operators due to institutional events. These first conclusions lead us to the identification of other CO_2 price fundamentals that have been only suggested so far by the professional litterature. We show statistically the role played by the variation of industrial production in the sectors covered by the EU ETS on CO_2 price changes. Industrial production is used here as a measure of the evolution of economic activity, which therefore constitutes another CO_2 price driver in three among nine sectors covered by the EU ETS. These sectors are the following: the production of electricity, the production of iron and steel, and the production of pulp and paper. We apply a disentangling analysis in order to derive those results. Our understanding of the functioning of the European carbon market indeed stems from the central role played by the compliance position. Depending whether an installation is net short or long of quotas, it will adopt a net buyer or seller position on the market. In conjunction with these effects due to allocation, we introduce production peaks specific to the evolution of industrial production in the sectors under consideration, and which may also impact CO_2 price changes. This disentangling analysis shows that the effects of allocation and production peaks are statistically significant in explaining CO_2 price changes. This study also allows us to emphasize the predominant role played by the allocation effect on the production peak effect as a CO_2 price driver. Finally, we extend this analysis at the country-level, and underline the central role played by German power producers on the EU ETS.

Chapter 3 deals with the risk-hedging strategies used by firms. This Chapter builds on the preceding ones by estimating changes in investors' risk aversion on the European carbon market around the 2006 compliance event. This study is based on methods used on stock markets, which proved to be robust in quantifying changes in investors' anticipations. Given the central role played by the 2005 compliance event that we have highlighted in Chapter 2, we focus on the 2006 compliance event, which is the only event empirically observable. We show that the risk on the EU ETS is linked to an increase in the allowance price after the 2006 compliance event. This result differs widely from what is usually observed on stock markets, and reveals that investors anticipate an increasing scarcity of allowances on the medium term, which is conform to the restriction of NAPs II validation criteria enforced by the European Commission. Our results also show that risk aversion is higher on the emerging European carbon market than on stock markets under the period under consideration, which confirms the view that anticipations are not yet homogeneous on this market. With the start of Phase II on a sound institutional framework, risk aversion on the European carbon market is likely to tend progressively towards the values found on stock markets. Besides, we use our development on banking provisions in Chapter 1, to study their impact as a potential risk management tool. More precisely, we assume that allowance trading between firms has already occurred, and that they use their remaining bank of permits to hedge against the variation of political decisions by the regulator, concerning allocation rules for instance. We show that banking may be used by firms in presence of a mean preserving increase in the level of risk concerning the quantity of quotas distributed. Moreover, we identify an optimal risk sharing rule by an agency, which is valid when the distribution of quotas over all periods is known in advance. With uncertainty on the amount of quotas distributed during the next compliance period, we show that the agency may pool the risks between firms and smooth their emissions, by taking into account the sensitivity of the marginal productivity with respect to the environmental variable. Finally, these results are discussed in the context of the EU ETS to detail the banking behavior at the installation level, and the pooling of risks attached to allowance trading between the parent company and its subsidiaries. This approach is simply descriptive, and opens the field for further research.

Presentation of the database for Chapters 1 and 2

The database used in Chapters 1 and 2 comes from the Mission Climat - Caisse des Dépôts. The energy prices and temperatures variables detailed below are published in the monthly Bulletin *Tendances Carbone*[16].

The carbon price

Since we are mostly interested in the institutional features of the EU ETS pilot phase[17], we conduct an analysis of the EUA spot price which is related to daily needs. 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 with 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[18].

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

---

[16] Available at the following address: *http://www.caissedesdepots.fr/spip.php?article659*

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

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

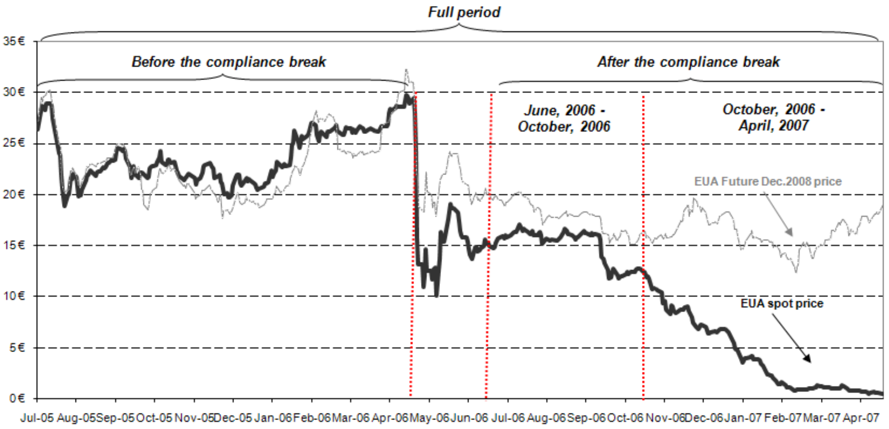

Figure 4: EUA Price Development from July 1, 2005 to April 30, 2007 from Bluenext

spot price (p_t in €/ton of CO_2) negotiated from July 1, 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 pattern tends towards zero (see Figure 4).

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 €/ton) is the daily coal futures Month

Ahead price CIF ARA[19].

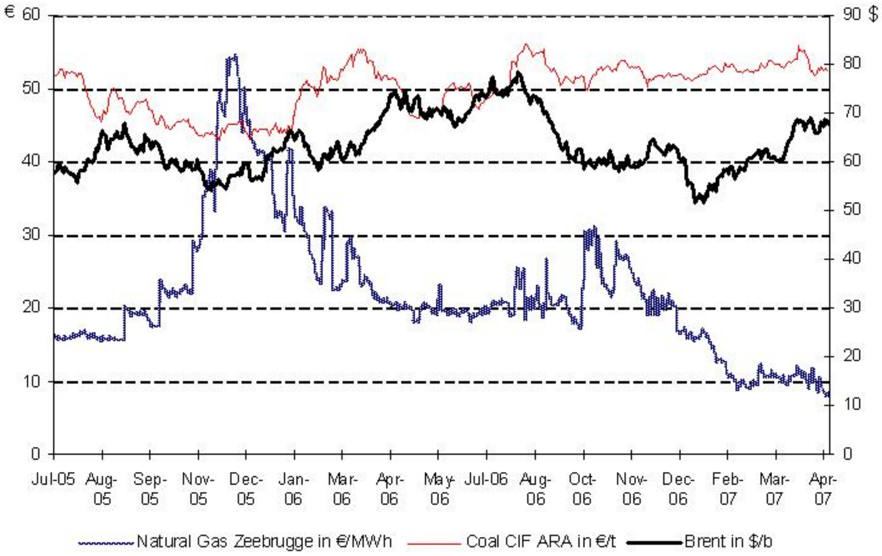

Figure 5: ICE Brent Month Ahead prices, Zeebrugge Natural gas Month Ahead, CIF ARA coal Month Ahead prices from July 1, 2005 to April 30, 2007 from Reuters

As shown in Figure 5, during 2005-07, natural gas prices exhibit strong volatility compared to coal prices. During the months of November-December 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 end of 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[20]. First, the Clean Dark

---

[19] 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.

[20] As calculated by the Caisse des Dépôts–Climate Task Force for Tendances Carbone. The methodology is available on the website: *http://www.caissedesdepots.fr/IMG/pdf_Document_Methodologie_Tendances_Carbone_EN_V4-*

Spread (*clean dark spread* expressed in €/MWh) represents the difference 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 and the costs of CO_2:

$$clean\ dark\ spread = elec - (coal * \frac{1}{\rho_{coal}} + p_t * EF_{coal}) \qquad (1)$$

with ρ_{coal} the net thermal efficiency of a conventional coal-fired plant[21], and EF_{coal} the CO_2 emissions factor of a conventional coal-fired power plant[22].

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 and the costs of CO_2:

$$clean\ spark\ spread = elec - (ngas * \frac{1}{\rho_{ngas}} + p_t * EF_{ngas}) \qquad (2)$$

with ρ_{ngas} the net thermal efficiency of a conventional gas-fired plant[23], and EF_{ngas} the CO_2 emissions factor of a conventional gas-fired power plant[24].

As shown in Figure 6, 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.

Third, the *switch* price of CO_2, expressed in €/MWh, is used as a proxy of the abatement cost:

$$switch = \frac{cost_{ngas}/MWh - cost_{coal}/MWh}{tCO2_{coal}/MWh - tCO2_{ngas}/MWh} \qquad (3)$$

with $cost_{ngas}$ the production cost of one MWh of electricity on base of net CO_2 emissions of gas in €/MWh, $cost_{coal}$ the production cost of one MWh of electricity

---

2.pdf, accessed on August, 2007.

[21] *i.e.* 40% according to the 2005 NEA/IEA report, *The Projected Costs of Generating Electricity.*

[22] *i.e.* 0.86 tCO_2/MWh according to the same source as above.

[23] *i.e.* 55% according to the same source as above.

[24] *i.e.* 0.36 tCO_2/MWh according to the same source as above.

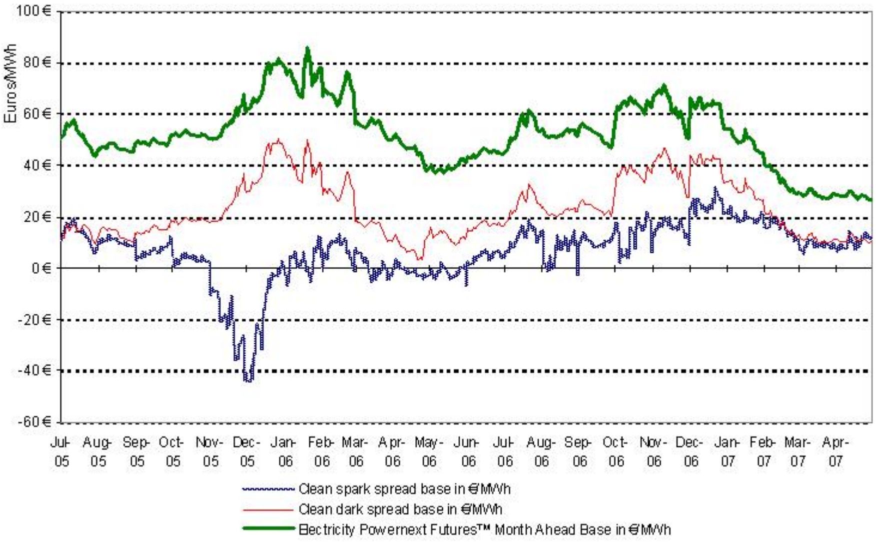

Figure 6: Powernext Futures Month Ahead Base prices, Clean spark spread and Clean dark spread from July 1, 2005 to April 30, 2007 from Bluenext and Tendances Carbone from the Caisse des Dépôts

on base of net CO_2 emissions of coal in €/MWh, $tCO2_{coal}$ the emissions factor in CO_2/MWh of a conventional coal-fired plant, and $tCO2_{ngas}$ the emissions factor in CO_2/MWh of a conventional gas-fired plant as detailed above.

Figure 7 shows on July 2005 and since February 2007, CO_2 spot prices and the *switch* price of CO_2 were very close suggesting at this carbon price level Emissions abatements may have occurred.

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 20 to 25 years[25]. Similarly, the coal is bought through long-term contracts (Joskow(1990)). Since those contracts do not have the same determinants, they does not appear to be endogenous with the determination of other energy prices variables included in

---

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

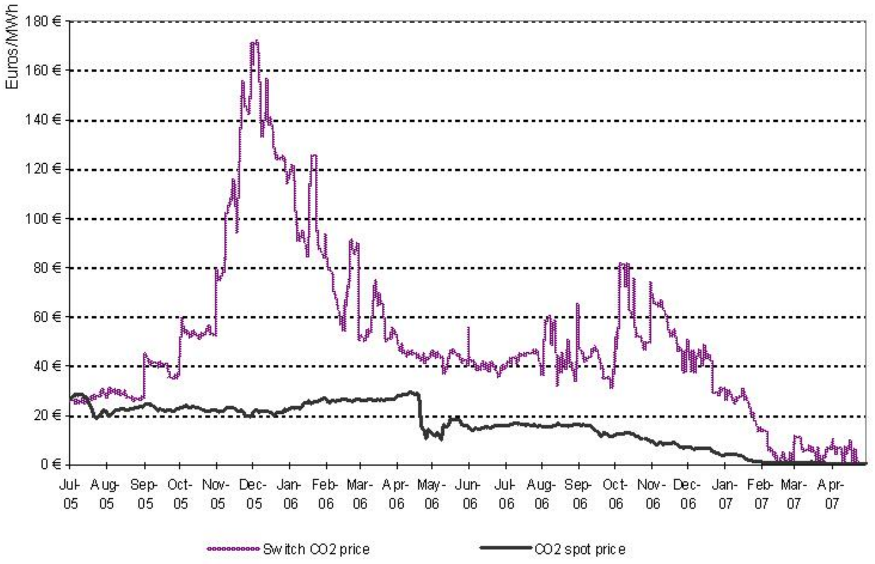

Figure 7: CO_2 spot prices and *switch* CO_2 prices from July 1, 2005 to April 30, 2007 from Bluenext and Tendances Carbone from the Caisse des Dépôts

our model such as the electricity price[26].

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)).

Following Helfand et al. (2006), energy variables are constructed by computing "one-step ahead" forecast errors for all price series. In 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 CO_2 prices.

Temperatures variables

According to previous literature, our investigation focuses on the most impor-

---

[26] See Chevalier and Percebois (2008) for a detailed study of those determinants.

tant 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 the United Kingdom. These indices are computed as the temperature average at the representative regional weather station weighted by regional population:

$$\Theta = \frac{\sum_{i=1}^{N} pop_i * \Theta_i}{\sum_{i=1}^{N} pop_i} \tag{4}$$

with N the number of regions in the country under consideration, pop_i the population of region i, and Θ_i the average temperature of region i during the month under consideration in $^{\circ}C$.

The European temperature index published by Tendances Carbone[27] is also used. It is equal to the average of national temperatures indices provided by Powernext weighted by the share of each NAP in the previous four countries:

$$T = \frac{\sum_{j=1}^{4} Q_j * \Theta_j}{\sum_{j=1}^{4} Q_j} \tag{5}$$

with Q_j the number of allowances allocated by the NAP in country j, and Θ_j the national temperature index of country j. The national share of allocation during Phase I in total allocation of EUAs are equal to 14.55% for France, 46.40% for Germany, 22.82% for the UK, and 16.23% for Spain, according to the European Commission.

For each of these five temperature series, the deviation from their seasonal average[28] is computed. Two quantitative weather variables are then obtained: the temperatures value and the deviation from their seasonal average expressed in absolute value.

---

[27] As calculated by the Caisse des Dépôts–Climate Task Force for Tendances carbone. The methodology is available on the website *http://www.caissedesdepots.fr/IMG/pdf_Document_Methodologie_Tendances_Carbone_EN_V4-2.pdf*, accessed on August, 2007.

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

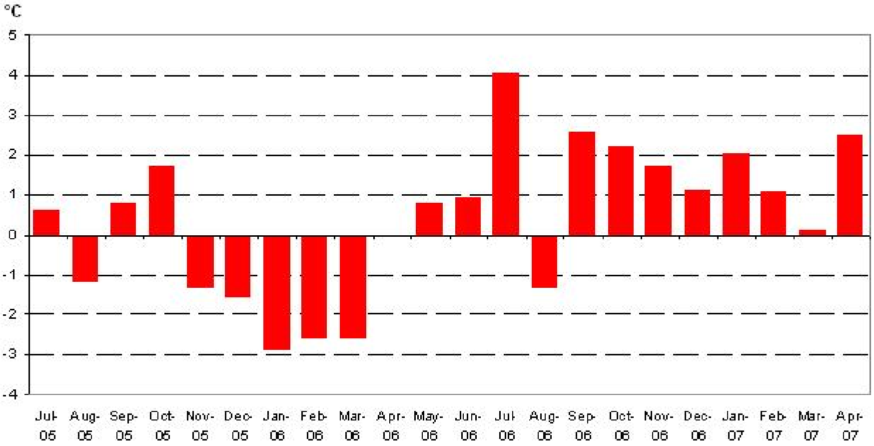

Figure 8: European Temperatures Index from July 2005 to April 2007 from Bluenext and Tendances Carbone from the Caisse des Dépôts

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 specific monthly extreme weather events which may have an impact on CO_2 price changes. As shown in Figure 8, after computing and comparing for each country the monthly temperatures average during 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[29]. Thus, these latter extreme events dummies, the temperature series and the abso-

---

[29] Note some modelling techniques exist in order to capture these linearities, such as threshold models which appear useful for that kind of study, but that we do not develop here.

lute 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 value of the deviation from its mean value of the European temperature index ($Temp\_AbsDeviation$). Note that this latter kind of interaction variable may be interpreted as unanticipated temperatures changes.

Chapter 1

The role of banking and borrowing provisions

Introduction

In emissions trading schemes, the introduction of banking and borrowing mechanisms reduces overall compliance costs by allowing for intertemporal flexibility. Chapter 1 focuses on the economic rationale behind the decision to allow banking and borrowing, a decision which is typically overlooked by the debate to introduce the permits market itself among other environmental regulation tools.

First, we review the theoretical pros and cons of banking and borrowing. The theoretical studies agreed on the fact that when it is effective, banking and borrowing allows a reduction of climate policies costs.

Second, we provide an in-depth assessment of banking and borrowing provisions in the EU ETS. In this setting, we test the empirical relationship between EUA spot price changes during 2005-2007, and the inter-period banking restrictions enforced at the end of Phase I, *i.e.* between December 31, 2007 and January 1, 2008. The price of European Union Allowances (EUAs) has indeed been declining at far lower levels than expected during Phase I (2005-2007). Previous literature identifies among its main explanations over-allocation concerns, early abatement efforts in 2005 and possibly decreasing abatement costs in 2006. We advocate low allowance prices may also be explained by banking restrictions between 2007 and 2008, which undermine the ability of the EU ETS to provide an efficient price signal. Based on a Hotelling-type analysis, our results suggest EUA spot prices do not meet equilibrium conditions in the intertemporal permits market due to a sub-optimal allocation during Phase I. We also provide statistical evidence that, during the negotiation of National Allocation Plans for Phase II, the French and Polish decisions to ban inter-period banking contribute to the explanation of low EUA Phase I prices. Finally, we show that the cost-of-carry relationship between EUA spot and futures prices for delivery during Phase II does not hold after the enforcement of the inter-period banking restrictions. This situation may be interpreted as a sacrifice of the temporal flexibility offered to industrials in Phase I, to give a chance to correct design inefficiencies and achieve an efficient price pattern leading to effective abatement efforts in Phase II.

1.1 Banking and Borrowing: A Review of Economic Modelling, Current Provisions and Prospects for Future Design

On tradable permits markets, *banking* refers to the possibility for agents to save unused permits for future use, while *borrowing* represents the possibility to borrow permits from future allcations for use in current period. By allowing agents to arbitrate between actual and expected abatement costs over specific periods, banking and borrowing permits form another dimension of flexibility where agents can trade permits not only spatially but also through time. Such provisions enabled agents to smooth their emissions stream through time and played a key role in the success[1] of the US SO_2 or Acid Rain Program (Ellerman et al. (2000)). Surprisingly, the inclusion of banking and borrowing does not appear as a corner-

---

[1] The notion of success may be approximated by various effects (pre-existing regulatory environment, technology innovation and diffusion, reduction of regulatory uncertainty, aggregate cost savings, etc.) but we will focus on the efficiency of the permits price, *i.e.* its ability to reflect current information on spot and future prices.

stone of new "grand policy experiments"[2] dealing with climate change. At the negotiation stage of the Kyoto Protocol, banking provisions were clearly defined depending on the allowance type (see Table 1.1). But only implicit provisions on borrowing may be found in the paragraph II.XV of the UNFCCC (2000) report. As explained by Newell et al. (2005)[3]: "*International climate policy discussions have implicitly included borrowing within possible consequences for noncompliance under the Kyoto Protocol, through the payback of excess tons with a penalty (*i.e., *interest)*". The banking and borrowing provisions of some permits schemes are summarized in Table 1.2. The provisions regarding the EU ETS are detailed in Section 1.2.1.

We aim at bridging this gap by providing a detailed theoretical and empirical analysis of the various effects of banking and borrowing that need to be accounted for when designing tradable permits markets. This instrument is described indeed as a double-edged sword in the literature. On the one hand, banking provides incentives to over-comply and leads to an intertemporal reallocation of emissions so as to reach lower social damages. On the other hand, borrowing may give agents with high abatement costs an incentive to delay costly investments in clean technologies by borrowing allowances from future periods, and to concentrate emissions in early periods. While the total allocation of permits sets the present value of discounted permits prices, we will see that other effects on the permits price may arise when introducing an intertemporal trading ratio for banked and borrowed allowances. We therefore address the following key question: what insights can we draw from the existing literature concerning the use of banking and borrowing in tradable permits markets? To detail the impacts of banking and borrowing on the potential increase / decrease of environmental damages will also be a priority throughout our analysis.

First, we detail the economic and environmental effects of banking and borrowing. Then, we provide a litterature review of their theoretical properties.

---

[2] This expression was coined by Stavins (1998).

[3] p.149

1.1.1 Environmental and economic effects of banking

A fully intertemporally flexible emissions trading scheme is said to be superior, in terms of efficiency, to a scheme where the transfer of allowances is restricted, from both environmental and economic viewpoints. As Haites (2006) noted[4], "*allowance banking provisions affect basically environmental performance, economic efficiency and market participants' behaviour*". Hence, the regulator's decision of allowing banking creates the significant effects listed below.

In terms of environmental effects, allowance banking and borrowing may change the temporal path of emissions and aggregate emissions, including public health effects. While *banking reduces* social damages in presence of a convex damage function coming from emissions and stricter future standards (Kling and Rubin (1997)), unrestricted borrowing may have *negative* consequences with a concentration of emissions on early periods by delaying abatement decisions. To correct these unwanted allowance paths, the regulator may introduce a non unitary Intertemporal Trading Ratio (ITR) including interests on banking and discouraging borrowing : if firms borrow a lot of allowances in early periods, they will reimburse more allowances than actually used in the next period (Kling and Rubin (1997), Leiby and Rubin (2001)). Furthermore, banking provisions could affect the rate of non-compliance and the resulting excess emissions[5].

In terms of economic effects, the theoretical literature suggests allowance banking and borrowing may improve economic efficiency under specific assumptions[6]. First, banking links future allowance prices to the spot price as stated by Maeda (2004). Second, banking and borrowing improve price stability (Ellerman and Montero (2007)). If inter-period banking is not allowed, allowance prices are likely to be more volatile at the end of each compliance period. In case of surplus, allowances are worthless and their price should fall to zero. In case of excess

---

[4] p.7

[5] Cason and Gangadharan (2006) find that banking increases non-compliance and total emissions in experiments with weak enforcement. Borrowing provisions could increase the rate of compliance in current period, but that would only shift excess emissions to the next period.

[6] *i.e.* the abatement cost function does not change over time and there is complete information on the marginal damage function and emissions of sources (Rubin (1996), Schennach (2000)).

emissions, the allowance price should rise sharply at the end of the period. The authorization of inter-period banking should dampen such end-of-period price fluctuations[7]. Third, banking and borrowing improve liquidity in the allowance market by increasing the quantity of allowances available to the market[8] and the volume of allowances traded (Godby et al. (2000)). Fourth, allowance banking and borrowing should facilitate adjustment to changes in the emissions cap, especially if the regulator enforces stricter targets, as for Phases II and III of the EU ETS.

By using a regional model of the world economy[9] with endogenous technical change[10], Bosetti et al. (2008) validate empirically some insights on the implications of banking. Banking not only increases economic efficiency, but also the environmental effectiveness of climate policy particularly in the short term. Indeed, banking increases the amount of emissions abated in the first decades, thus reducing the risk of irreversible environmental impacts on climate. Besides, banking plays an important role in accelerating the adoption and diffusion of energy efficient and carbon free technologies. Overall, Bosetti et al. (2008) find that significant cost savings in terms of avoided GWP losses are indeed possible by allowing a greater intertemporal flexibility than on existing ETS at the international scale.

These theoretical considerations on the banking provisions are also supported by Ellerman et al. (2000) in the context of the US Acid Rain Program: during the first five years of the program constituting Phase I (1995-99), only 26.4 million of the 38.1 million permits distributed were used to cover emissions, while the remaining 11.65 million allowances (30% of all the distributed allowances) were banked and have been gradually consumed during Phase II (2000 and beyond). As a result, the Phase II cap is expected to be reached sometime between 2008

---

[7] We discuss in details the consequences of such restrictions on the EU ETS in Section 1.2.

[8] Note that this positive effect of banking may be distorted by initial allocation, thus leading to the possibility of strategic manipulation as in the *Hot Air* situation of the Kyoto Protocol.

[9] World Induced Technical Change Hybrid Model (WITCH), see Bosetti et al. (2006) for more details.

[10] Another interesting result is that banking provides relevant incentives to the early adoption of cleaner technologies, thus inducing a positive intertemporal spill over effect.

and 2010[11].

Ellerman and Montero (2007) analyze in depth the efficiency of this banking behavior. The economically optimal level of banking depends *i)* on the SO_2 emissions in the absence of the trading scheme, *ii)* on the SO_2 emissions reduction cost function, and *iii)* on the discount rate. Using ranges of reasonable values for the discount rate, and for the rate of growth of SO_2 emissions in the absence of the trading scheme, the authors find that banking behavior has been reasonably efficient during Phase I and the first few years of Phase II.

Following this review of the various effects of banking and borrowing that need to be accounted for when tailoring environmental regulation, we expose in the next section the theoretical properties of banking and borrowing.

1.1.2 A literature review of emissions trading with banking and borrowing under certainty

This second section presents the main theoretical results on the use of banking and borrowing. To isolate the specific effects of banking and borrowing on cost efficiency and environmental damage, the literature has followed a partial equilibrium modelling of the permits market, and tends to neglect the interaction with the output market. Our review stems from the original contribution by Rubin (1996), who defined the efficiency properties of intertemporal emissions trading, but where there lacks a necessary restriction to the use of borrowing. That is why we also refer to the article by Kling and Rubin (1997). We first explain the assumptions of these models, and then distinguish between several configurations of banking and borrowing provisions to evaluate the pros and the cons of the authorization of intertemporal flexibility mechanisms.

The model by Rubin (1996) features cost minimizing agents who include the environmental constraint in their decision parameters. As detailed by Cronshaw and Kruse (1996) and summarized by Bosetti et al. (2008), the modeling of banking and borrowing developed in this strand of literature also hinges on the following

---

[11] See p.161.

assumptions: there is a constant number of profit-maximising firms acting with perfect foresight in a competitive market for permits, each firm receives an equal endowment of permits for each period, and marginal abatement costs are constant over time.

When creating the tradable permits market, the task of the regulator consists, among other tasks, in setting a cap on emissions for a set of heterogenous polluting firms. The cap fixed by the regulator may be further decomposed into individual permits allocation to firms. It is further assumed that firms will comply with the environmental constraint, either by spatial or intertemporal emissions trading.

The permits bank is strictly positive in case of banking, and strictly negative in case of borrowing. Any change in the permits bank is equal to the difference between firm's permits allocation and its emission level at time t.

Notwithstanding differences between a permit and an exhaustible resource[12], it is assumed in the literature that the Hotelling conditions for exhaustible resources must apply on a permits market. Consequently, the terminal and exhaustion conditions are detailed.

At the end of the planning period, the terminal condition implies that cumulated emissions must be equal to the sum of each agent's depollution objective, and therefore to the global cap set by the regulator[13]. Besides, the exhaustion condition implies that there is no more permit in the bank, either stocked or borrowed, at the end of the planning period. Those conditions ensure that agents gradually meet their depollution objective so that the marginal cost of depollution is equalized in present value over the time period, and the permits bank clears in the end. If the permits bank at the end of the period is strictly positive, surplus allowances

---

[12] According to Liski and Montero (2005), the following differences may be highlighted between a tradable permits and a non-renewable resource. First, on a permits market with banking, the market may remain after the exhaustion of the bank; while the market of a non-renewable resource vanishes after the last unit extraction. Second, permits extraction and storage costs are equal to zero; while those costs are generally positive for a non-renewable resource. Third, the demand for an extra permit usually comes from a derived demand of other firms that also hold permits; while the demand for an extra unit of a non-renewable resource comes more often from a derived demand of another actor (e.g., a consumer).

[13] See also Leiby and Rubin (2001).

are worthless and agents are wasting permits. Conversely, ff the permits bank at the end of the period is strictly negative, agents need to pay a penalty.

To comply with the emissions reduction objective fixed by the regulator, firms are confronted with investment choices in cleaner technologies. The cost associated with these investments is called abatement cost, and may be represented by a function decreasing and convex in the emissions level[14].

Firms' marginal abatement costs (MAC) are associated with a one-unit reduction from their emissions level at time t. At the equilibrium of a permits market in a static framework[15], price-taking agents adjust emissions until the MAC is equal to the price at time t.

Next, let us study three different configurations of intertemporal flexibility mechanisms: "banking only", "banking and borrowing", "banking and restricted borrowing".

"Banking only" case

In this scenario, agents may reduce their emissions directly, trade and bank permits so as to comply with the environmental constraint. If, for instance, a firm decides to pollute less than the cap, it can sell its permits surpluses to other firms, bank it for future use or sell them later.

Each firm adjusts its emissions level as a function of production, and manages its permits bank. The firm minimizes its discounted abatement costs by choosing the optimal level of emissions and the volume of permits traded[16].

We may comment the results for the "banking only" case as follows: if there is a net banking position at the end of the period, then surplus allowances are worthless. The firm equalizes its present-discounted MAC with the permits price at the equilibrium. This first assessment leads us to authorize the use of banking

---

[14] This fonction has been stated first by Montgomery (1972). Leiby and Rubin (2001) include conditions on the output, where the abatement cost function is strongly convex. Properties of non-convex abatement cost functions may be found in Godby (2000).

[15] See Hahn (1980).

[16] See Rubin (1996) for the formal resolution of the optimization program, as well as for the detail of the program of the regulator, along with the conditions of existence of an equilibrium and the social optimum.

to add the intertemporal flexibility mechanism to cost savings induced by spatial trading. But there lacks the borrowing mechanism to allow full temporal flexibility, which we study in the next section.

"Banking and borrowing" case

In this scenario, firms may trade, bank and borrow permits without restrictions. Borrowing consists for a firm in polluting more than it is allowed to in present period, but the cumulative deficit must be reduced by the end of the period. The authorization of borrowing consists in removing the non-negativity contraint on the permits bank.

In the "banking and borrowing" case, we may complement our previous analysis: if the firm has a net borrowing position at the end of the compliance period, then it needs to pay a penalty. The firms equalizes its MAC with the permits price. Thus, the authorization of borrowing allows firms to adjust the emissions stream through time and cut compliance costs in a more flexible way. Next, we discuss the case with restrictions on the use of borrowing.

"Banking and restricted borrowing" case

Due to the effect of discounting future abatement costs, we need to penalize borrowing by an ITR exogenously chosen by the regulator so that if firms borrow a lot of allowances in early periods, they will reimburse more allowances than actually used in the next period. Using the interest rate on allowance balances, the regulator may change the time profile and cumulative quantity of allowances to approximate more nearly the social optimum.

Let us introduce the following notation for the discount rate: $\delta^t = e^{-\rho t}$. Therefore, firms have an incentive to trade permits according to the discount rate δ^t. This "banking and restricted borrowing" case yields the following comments (Kling and Rubin (1997)):

- setting $\delta^t < 1$ provides an efficient incentive to banking, while firms need to reimburse **more** allowances in second period than were borrowed in first period;

- the weight of debt is greater under a modified banking system than under the original system;
- such a modified banking and borrowing system allows the private and social solutions to converge, assuming constant and linear social damages.

Assuming both banking and borrowing are allowed and a *positive* private discount rate, the introduction of an ITR yields:

- concerning borrowing, for each ton of CO_2 non abated the gain from firms' private interest rate is reduced by the ITR;
- the primary effect of a non zero ITR is on the time profile of emissions, not on quantities emitted. There is a change in marginal stock damages over time (more banking and less borrowing relative to a permit system without ITR) and a small effect on quantities intertemporally exchanged.

Kling and Rubin (1997) suggest the implementation of a discount rate equal to the industry average rate of interest used to finance medium term capital expenditures. For greenhouse gases, the optimal rate of intertemporal substitution has been suggested by Leiby and Rubin (2001) as being the ratio of current marginal stock damages to the discounted future value of marginal stock damages, less the decay rate of emissions in the atmosphere, increased by the difference between firm's discount rate and the social planner's discount rate[17]. Besides, we may cite several time devices used in tradable permits programs such as the Progressive Flow Control in the US Northeastern NO_X Budget Program, and the changed redemption ratios in the US Clean Air Interstate Rule (2:1 from 2010; 3:1 from 2015).

We have detailed in this section that the correct determination of the intertemporal discount rate may yield greater efficiency gains. In what follows, we discuss several issues that arise from the use of banking and borrowing without restrictions.

---

[17] This result is obtained in a different setting since they distinguish between *flow* (emissions flow) and *stock* (accumulated) pollutants. Typically, CO_2 emissions are characterized by stock damages that do not stop at the end of the program.

Link with the Hotelling rule

A number of researchers have studied the effects of banking on the temporal path of allowance prices, including in particular Rubin (1996) under certainty, and Schennach (2000) under uncertainty. The analysis typically produces a price path for allowances that follows the so-called Hotelling (1931) rule that the (real) price of an exhaustible resource over time rises at a percentage equal to the discount rate. Hotelling's result shows that in an efficient exploitation of an exhaustible resource, the percentage change in net-price per unit of time should equal the discount rate, in order to maximize the present value of the resource capital over the extraction period.

Taking into account the effects of banking and borrowing on the temporal profile of permits prices, Kling and Rubin (1997) show that:

- if borrowing is allowed, the permits price follows the Hotelling rule for exhaustible resources;
- if borrowing is forbidden, then the permits price rises at a rate *inferior* to the interest rate.

The Hotelling rule serves as an indicator of scarcity for exhaustible resources under perfect competition, but it usually lacks empirical grounding as we develop in the secpnd part of this Chapter. Let us examine finally the role of banking and borrowing provisions with regard to the distribution of the emissions stream through time.

Distribution of the emissions stream through time

We are interested in how firms adjust their emissions stream when they benefit from the possibility to freely bank and borrow permits. These developments are common to the models of Rubin (1996) and Kling and Rubin (1997), and yield the following comments:

- when firms would like to borrow emissions and are allowed to, the emissions stream *declines* over time;

- when firms would like to borrow emissions and are not allowed to, the emissions stream *might increase* if future emissions caps are less constraining. It is constant otherwise, and the multiplier associated with the non-negativity constraint may be interpreted as a periodic payment that the firm consents to pay for a perpetual rent whose price is equal to the discounted permits price.

A key issue lies in the discount rate picked by firms: higher or lower values imply, respectively, more or less borrowing, while a zero discount rate leads to the same level of pollution at each period. In the specific case where permits prices are decreasing overtime, firms have an incentive to delay investments in abatement technologies by borrowing permits in early periods, and reimburse them later with cheaper permits *ceteris paribus*. Our analysis therefore highlights potential *negative* consequences of the use of unrestricted borrowing: the concentration of emissions on early periods by delaying abatement decisions and borrowing may aggravate environmental harm. Consequently, the level of global pollution is higher than in a situation without borrowing. Concerning banking, firms invest in abatement technologies and bank allowances when they anticipate an increase in abatement costs superior to the discount rate, otherwise they would not bear additional abatement costs in current period. In presence of a convex damage function coming from emissions and stricter future targets[18], the decision to allow banking *reduces* social damages[19]. We have highlighted a *positive* effect of banking: by giving incentives to firms to go beyond their emissions target, firms re-allocate emissions intertemporally and reach lower social damages[20]. Thus, we have identified an important property of banking, *i.e.* it allows firms to smooth their emissions stream through time. When social damages are an increasing function of the pollution level at time t, our policy recommendation therefore consists

---

[18] Indeed, when the cap is constant or becomes less constraining, the decision to allow borrowing leads to either increasing social damages and decreasing costs for firms.

[19] This result obviously depends on the discount rate picked by firms. If it is zero, firms are eager to bank allowances in initial periods for future use. If it is high, firms do not have incentive to bank permits.

[20] Note that total damages are reduced if the emissions stream is more constant through time.

in authorizing banking and enforce stricter pollution targets through time.

We have seen in this litterature review[21] how intertemporal permits trading alter the *timing* and the *magnitude* of damages. The decision to allow or not borrowing depends on the arbitrage between firm's cost efficiency and a higher pressure on the environment. Firms tend to use borrowing if the environmental contraint is constant or does not become a lot stricter overtime. That is why we have recommended earlier to introduce a discount rate specific to borrowed allowances, so that the distribution of emissions through time need not yield to a concentration in early periods[22].

Note that some other potential effects of banking and borrowing may exist, such as the possibility of strategic manipulation of the emissions permits market, as it has already been documented in the literature concerning the Russian *Hot Air* in the context of the Kyoto Protocol[23], and that we do not develop here.

In this first section, banking has been introduced as an intertemporally flexible environmental regulation tool to minimize total cost for pollution abatement. Thus, these results shall not be misinterpreted as suggesting that allowing banking and borrowing decrease the efficiency of the permits market, but rather as a tool that helps agents to smooth their emissions. In the second section of Chapter 1, we examine more specifically the consequences of the banking and borrowing provisions adopted on the EU ETS.

---

[21] For a more exhaustive discussion of existing banking and borrowing models, see Newell et al. (2005).

[22] Note that among the two sources of inefficiencies that might affect the social optimum, *i.e.* the discount rate used by firms and the fact that total damages depend on the distribution of the emissions stream through time, a modified banking system may correct the first type of inefficiency highlighted above, but not necessarily the second type.

[23] The distribution of a large number of permits to Former Soviet Union and Eastern Europe countries (Russia, the Ukraine forming two thirds) may be seen indeed as an imperfection of the KP, as those countries were given generous allocations. Market power concerns arise as industrial firms may benefit from the gap between their initial permits allocation based on 1990 production levels and their real emission needs in 2008-2012, after a period of recession (Baron (1999), Burniaux (1999), Bernard et al. (2003), Bohringer and Loshel (2003), Holtsmark (2003), Korppoo et al. (2006)).

1.2 European Carbon Prices and Banking Restrictions: Evidence from Phase I (2005-2007)

On the EU ETS launched in 2005 to help Member States (MS) achieve their Kyoto target to reduce 1990 emissions by 8% during 2008-2012, covered installations are only allowed for banking and borrowing allowances within 2005-2007 and within 2008-2012. We have detailed in Section 1.1 that, when banking and borrowing are allowed without restrictions, the scheme is characterised by full intertemporal flexibility (Rubin (1996), Schennach (2000)). With such provisions, market prices reflect opportunity costs leading to an efficient choice of abatement measures (Schleich (2006)). To our best knowledge, no empirical analysis on the impact of intra-period banking coupled with a ban on inter-period banking on European Union Allowances price changes has yet been realised. In a game simulation, Ehrhart et al. (2005) found that a ban on banking leads to an inefficient adjustment with first an under-investment in abatement technologies and a low allowance price during 2005-2007, and second a more stringent cap with a price peak and over investment in emission reduction during 2008-2009.

Among the main explanations of low allowance prices towards the end of Phase I, previous literature identifies over-allocation concerns, early abatement efforts in 2005 due to high allowance prices, and possibly decreasing abatement costs in 2006 due to abnormal temperatures and switching from coal- to gas-fired electricity in a context of falling natural gas prices compared to coal (Ellerman and Buchner (2008), Mansanet-Bataller et al. (2007), Alberola et al. (2008)). Therefore, a thorough analysis of banking and borrowing provisions is missing. It appears necessary to disentangle those effects on allowance prices which develop differently in the following two cases. If inter-period banking is allowed, it is reasonable to expect that allowance price changes do not exceed Hotelling's rule, rising at the market rate of interest. If inter-period banking is restricted, lower Phase I prices and higher Phase II prices are expected. The former result is due to the validity of allowances which is shorter than the time horizon required by market firms. The latter is due to increased allowance scarcity compared to full inter-period banking.

Within 2005-2007, EU ETS participants are allowed to use unrestricted banking and borrowing. EU allowances are issued annually on industrial accounts and are valid to cover emissions within the commitment period. This annual issuance of allowances occurs at the end of February, two months before allowances must be surrendered for the preceding year in April. Based on this intra-period banking provision, we test whether the allowance price pattern is consistent with a competitive equilibrium in the intertemporal market. The theoretical model of Schennach (2000) applied by Helfand et al. (2006) to the US SO_2 market guides our Hotelling-type analysis.

Between 2007 and 2008, participants are not allowed to use banking and borrowing mechanisms. To identify the impact of the inter-period ban on banking on daily price variations, we study the relationships between the EUA spot price and futures contracts of maturities December 2006, 2007 and 2008. Thus, we aim at evaluating whether the EUA futures price has the power to forecast consistently the future EUA spot price, according to the futures term structure highlighted by Fama and French (1987). Besides, the impact of the late restriction on inter-period banking is evaluated through dummy variables representing official communications between France, Poland and the European Commission (EC).

Compared to the literature on efficient banking in the US SO_2 Program (Helfand et al. (2006)), our results are twofold. Concerning *intra*-period banking provisions, we show the Hotelling rule does not hold during 2005-2007 which confirms the Phase I allocation was not sucessful in creating a perception of allowance scarcity among market firms. Concerning *inter*-period banking provisions, we observe a divorce between the EUA spot price, which is steadily decreasing towards zero, and the EUA price of the December 2008 futures contract, which is stabilizing around 20€. Our statistical analysis reveals the cost-of-carry relationship between spot and futures prices for delivery in Phase II does not hold from October 2006 until the end of Phase I. This result suggests that the restriction to transfer allowances between Phases I and II undermines the ability of the EU ETS to provide an efficient price signal. Besides, the French and Polish NAPs II submissions and final decisions confirm this statistically significant effect of banning banking in explaining low allowance prices until the end of Phase I. These results are robust to the introduction of energy market shocks and extreme temperatures events previously identified as being the main determinants of EUA prices in the literature, and that we detail in Chapter 2.

The remainder of the second Section of Chapter 1 is organized as follows. Section 1.2.1. details the reasons to ban banking between 2007 and 2008 in the EU ETS, and the EUA price development during 2005-2007. Section 1.2.2 introduces our Hotelling-type approach. Section 1.2.3 presents the data. Section 1.2.4 contains estimation results, and a discussion.

1.2.1 Banking and borrowing provisions in the EU ETS

In this section, we explain first the motives that led Member States to ban inter-period banking between 2007 and 2008. Second, we examine the allowance price development along with its charateristic structural break on April 2006.

Reasons to ban banking between 2007 and 2008

In the Directive 2003/87/EC[24], the EC left to Member States (MS) the decision to allow or not the transfer of banked allowances from Phase I to Phase II. Nevertheless, the Commission's statement of its assessment methodology for the review of the National Allocation Plans (NAPs) effectively negated these provisions by requiring that any banked EUAs be deducted from the cap for Phase II[25].

Hence, discussions on the banking feature were characterized by abrupt decision changes. At the beginning of the EU ETS in 2005, all MS decided, with the exception of Poland and France, against the inter-period transfer of allowances. All allowances not surrendered by the end of 2007 will be cancelled and not transfered

---

[24] The Directive 2003/87/EC may be downloaded on the EC website *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32003L0087:EN:NOT*

[25] *"For each allowance allowed to be banked, an allowance must be deducted from the total quantity issued for the second trading period. In addition, banking has to be examined under EU state aid rules. Where banking is not a result of real emission reductions having been made, it is likely to be found incompatible with state aid rules."* IP/06/1650, Brussels, November 29, 2006

to the subsequent five-years implementation period. Since then, at the date of the elaboration of NAP II, France and Poland decided to ban the transfer of allowances to Phase II.

Two main reasons may explain this inter-period ban on banking by MS *vis-à-vis* their Kyoto commitment (Ehrhart et al. (2005), Schleich (2006)). First, the transfer of banked allowances from 2007 to 2008 may weaken the ability of a MS to meet its Burden-Sharing Agreement target starting in 2008. Besides, large quantities of banked allowances may trigger the Commitment Period Reserve (CPR) rule which postulates to keep a reserve of Assigned Amount Units (AAUs)[26] above 90%. Second, the inter-period ban on banking avoids negative side effects at the EU ETS level. It might have been problematic for MS to forecast in 2006 the amount of banked allowances when drawing up their National Allocation Plans (NAPs) for 2008-2012. In presence of unexpected large amounts of banked allowances, sectors non-covered by the EU ETS need to make additional abatement efforts [27].

Therefore, MS decided to prohibit the transfer of unused allowances from the EU ETS Phase I (2005-2007) into the Kyoto Protocol (KP) first commitment period (2008-2012). Therefore, installations covered by the EU ETS may not use banked allowances during Phase I to meet their obligations during Phase II (2008-2012). Prior to 2008, only Certified Emissions Reductions[28] would have acted as a limited form of interperiod banking whether the connection has been effective as expected before the end of Phase I. (CERs)[29]. Neither may installations use

---

[26] *i.e.* allowances from the KP.

[27] The relationship between sectors covered / not covered by the EU ETS adds another layer of complexity to the scheme, given that mandatory national abatement targets were signed at the national level under the Kyoto Protocol.

[28] *i.e.* allowances from Clean Development Mechanism (CDM) projects.

[29] During the EU ETS Phase II (2008-2012), European installations could use to achieve their emissions compliance credits from CDM (*Clean Development Mechanism*) and JI (*Joint Implementation*) projects, but in a limited proportion defined by each NAP. Thus, installations operators could use credits to meet up to 13.4% of their emissions commitments in average during 2008-2012. The delivery of credits on EU industrials accounts will be possible as the connection between the European and International transactions registries. In practice, the link between the European and international transactions registries, respectively the Community Transaction Log and the International Transaction Log was expected before the end of 2007. This connec-

borrowed allowances between the two periods.

On January 2008, the review of the EU ETS Directive stated very clearly that there will be no change concerning the current banking provisions: *"The Directive foresees unlimited banking of Phase II allowances into Phase III. This means that every allowance not surrendered or retired in the second trading period can be used at face value in Phase III"*[30].

Let us examine in the next section the EUA price development corresponding to this specific restriction on banking provisions during Phase I.

EUA Price development during 2005-2007

Figure 1.1 exhibits the evolution of the EUA spot price and futures contracts prices of delivery horizons December 2007 and December 2008 from July 1, 2005 to December 17, 2007[31]. Beginning at 8€ on January 1, 2005 EUA prices rose to 25-30€ until the release of 2005 verified emissions. On April 24, 2006 EUA prices experienced a sharp break due to the first compliance disclosures by MS. Verified emissions were about 80 million tons or 4% *lower* than the amount of allowances distributed to installations during the 2005 compliance period (Ellerman and Buchner (2008)). Since the official EC report[32], the EUA market is sending two price signals responding to different dynamics. As the 2005 compliance confirmed the allowance market is over-supplied and the EC reaffirmed on October 2006 its will to enforce tighter targets during Phase II, the EUA spot price and December 2007 futures price have been declining towards zero, whereas the December 2008 futures price exhibits an *increasing* price pattern of 25€ at the end of 2007. The divorce between the EUA spot price, the futures price of delivery December 2007 on the one hand, and the futures price of delivery December 2008

---

tion will allow deliveries of credits from CDM projects on European registries. However, due to institutional and technical delays the EC has established April 2009 as the deadline for the European registries to be linked to the ITL.

[30] MEMO/08/35 Brussels, January 23, 2008.

[31] *i.e.* on the closing date of the futures contract of maturity December 2007

[32] See the EU Press Release IP/06/612 on May 15, 2006. Available at *http://www.europa.eu.* Cited October 2007.

on the other hand, in other words the disconnection between EUA prices of Phase I (2005-2007) and prices of Phase (2008-2012), is largely explained by the end of the allowances validity after the 2007 compliance that occurred on April 2008 due to the impossibility to transfer unused allowances to the next commitment period.

As displayed in Figure 1.1, the dataset is divided into two sub-periods due to the presence of a structural break following the simultaneous releases of 2005 verified emissions by the Walloon Region of Belgium, France and Spain, which serve as a proxy for the adjustment of firms' expectations. Using the method developed by Lee and Strazicich (2001, 2003)[33] that endogenously looks for structural breaks while testing for the existence of a unit root, we identify April 20, 2006 as a breakpoint in our dataset and exclude extreme price changes from our regressions, except for the full period[34]. Two sub-periods need to be considered : the "Before the compliance break" period from July 1, 2005 to April 20, 2006 and the "After the compliance break" period from June 22, 2006 to December 17, 2007. This endogenous structural break may be associated to institutional features of the EU ETS during Phase I. As 54% of the EUA spot price adjustment was made within four days[35] starting on April 24, 2006 this break eliminates prior uncertain information and reveals firms' net short/long positions[36].

As expressed before, the main explanations of low EUA prices toward zero the end of Phase I include over-allocation concerns, the possibility early abatement and the influence of climatic and energy variables (Ellerman and Buchner (2008), Mansanet-Bataller et al. (2007), Alberola et al. (2008)). The model estimated in the next section evaluates the specific role played by the restriction of banking and borrowing provisions that may contribute to a sharper explanation of low allowance price levels until the end of Phase I.

---

[33] In this method, data themselves suggest the possible timing of structural breaks. Their GAUSS code may be found at *http://www.cba.ua.edu/ jlee/gauss/*. Cited October 2007.

[34] Since the time series has a unit root when taken in log first-difference, even in presence of a structural break.

[35] See Ellerman and Buchner (2008).

[36] An installation is defined as net 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.

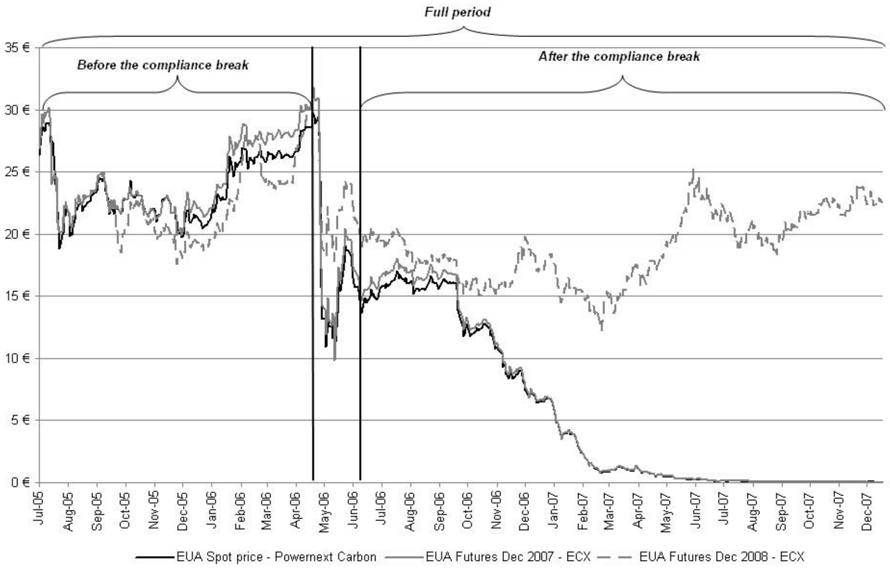

Figure 1.1: EUA Spot and Futures Prices from July 1, 2005 to December 17, 2007 from BlueNext and ECX

1.2.2 Analysis

In this section, we describe first the theoretical framework from which we derive our estimation methodology. Second, we explain our econometric specification.

Economic Modelling

To characterize the equilibrium of the intertemporal allowances market during 2005-2007, the model we estimate is based on two strands of literature developped by Schennach (2000) and Slade and Thille (1997), which were first applied to the US SO_2 market by Helfand et al. (2006).

First, Schennach (2000) studies the banking behavior of regulated industrials in the Acid Rain Program, and implicitly the behavior of spot prices in a stochastic, continous-time, infinite horizon model for allowance allocation, use and storage. Under certainty, the model predicts that the CO_2 price path would increase smoothly at the rate of interest according to the Hotelling rule. Under uncertainty, the optimization program of risk-neutral agents is modelled as follows:

$$\begin{cases} \min_{e_t} \left\{ E_0 \left[\int_0^\infty e^{-\mu t} c_t(\epsilon_t - e_t) dt \right] \right\} \\ \dot{S}_t = Y_t - e_t \\ S_t \geq 0 \end{cases}$$

with $E(t)$ a Von Neumann-Morgenstern expected utility function, e_t the emissions level after abatement, ϵ_t the counterfactual emissions level, $a_t = \epsilon_t - e_t$ the total amount of abatement by all firms at time t, $c_t(a_t)$ the minimum total cost incurred by all firms to abate a_t, Y_t the total amount of allowances distributed to agents, S_t the number of allowances in the bank at time t, r the risk free interest rate, ρ the risk premium specific to holding allowances as an asset in a diversified portfolio of investments, and $\mu = r + \rho$ the rate specific to risky assets in the spirit of the capital asset pricing model (CAPM).

The solution to this problem is a continuous time version of the model by Pindyck (1993) of rational commodity pricing:

$$E_t[p_{t+1}] = (1 + \mu)p_t - \psi_t \tag{1.1}$$

with ψ_t a convenience yield[37]. Eq. (1.1) therefore represents the basic relationship we want to test.

Second, assuming an allowance may be considered as an exhaustible resource[38], the model of Slade and Thille (1997) provides an analogous theoretical framework by maximizing the function $V(R, p, \phi)$:

---

[37] According to Ellerman et al. (2000), an agent may benefit from holding a stock of allowances on hand to buffer itself against unexpected changes in emissions, which is called a convenience yield.

[38] See the discussion developed in Section 1.1.

$$\begin{cases} \max_{q\tau} E_t \left\{ \int_t^{\infty} e^{-\rho(\tau-t)} \pi_\tau d\tau \right\} \\ \dot{R}_\tau = -q\tau \\ R_\tau \geq 0, q\tau \geq 0 \\ \frac{\partial \phi}{\phi} = \mu_\phi dt + \sigma_\phi dz_\phi \\ \\ \frac{\partial p}{p} = \mu_{pt} dt + \rho_p dz_p \end{cases}$$

with $\pi_\tau = [p_\tau q_\tau - C(q_\tau, R_\tau, \phi_\tau)]$ the risk-adjusted profit at the discount rate ρ, ϕ a random productivity shock, $\dot{R}$ the state of the bank R as a function of the extraction rate q. The last two constraints represent a set of Ito processes with drift to model uncertainty.

At the equilibrium, the evolution of the allowance price P_t is:

$$\frac{\frac{1}{\partial t} E_t \partial P_t}{P_t} = r + \beta(r^m - r) \equiv \rho \tag{1.2}$$

with E_t expected utility, r the risk-free interest rate, r^m the investment rate of return in a diversified portfolio, and β the risk premium specific to the asset. ρ represents to risk-adjusted discount rate used by firms to choose the emissions path that minimizes abatement costs. Therefore, we notice that at the equilibrium, the evolution of the allowance price p_t follows a Hotelling-CAPM relationship between the risk-free interest rate, the investment rate of return in a diversified portfolio, and the risk premium specific to the asset similar to eq.(1.1). Next, we detail how we use this theoretical framework in our estimation strategy.

Econometric Specification

As developed in Helfand et al. (2006), we rearrange eq.(1.1) to isolate first-difference prices on the left-hand side:

$$E_t \; p_{t+1} - p_t = r_t^f p_t + \rho_t p_t - \psi_t \tag{1.3}$$

Rewriting $\rho_t = \frac{\sigma_{am}}{\sigma_{mm}}(r_t^m - r_t^f)$, which is standard practice for CAPM, yields:

$$E_t\ p_{t+1} - p_t = r_t^f p_t + \frac{\sigma_{am}}{\sigma_{mm}}(r_t^m - r_t^f)\ p_t - \psi_t \tag{1.4}$$

where r_t^f is the risk-free rate, r_t^m is the rate of return on the market portfolio, σ_{am} is the covariance between the rate of return of EUA prices and r_t^m, and σ_{mm} is the variance of r_t^m. The first term $r_t^f p_t$ represents the Hotelling rule for cost-minimizing intertemporal arbitrage in the EU ETS. The second term $\frac{\sigma_{am}}{\sigma_{mm}}$ is the risk premium for holding allowances as part of a diversified portfolio. The expression $(r_t^m - r_t^f)$ is the excess return on the market portfolio at time t.

Since the expected value of p_{t+1} is known only with errors at time t, we substitute $E_t\ p_{t+1}$ by $p_{t+1} + \epsilon_{t+1}$:

$$p_{t+1} - p_t = r_t^f p_t + \frac{\sigma_{am}}{\sigma_{mm}}(r_t^m - r_t^f)\ p_t - \psi_t + \epsilon_{t+1} \tag{1.5}$$

where the dependent variable is the first log-differenced EUA price series and ϵ the error term.

Next, assuming the convenience yield is constant ($\psi_t = \psi$) and adding dummy variables to capture the structural break and get rid of extreme price changes, we get:

$$\begin{aligned} p_{t+1} - p_t =& \alpha + \beta_1(L)p_t + \beta_2 r_t^f p_t + \beta_3(r_t^m - r_t^f)\ p_t \\ &+ \beta 4 break + \beta_5 p_t min + \beta_6 p_t max + \epsilon_{t+1} \end{aligned} \tag{1.6}$$

with $\alpha = -\psi$, $\beta_2 = \frac{\sigma_{am}}{\sigma_{mm}}$, *break* the dummy characteristic of the period *after* the structural break on April 2006, $p_t min$ and $p_t max$ the dummy variables for minimum and maximum price changes. 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. In eq.(1.6), the null hypothesis $\beta_1 = 1$ tests the Hotelling rule, and β_2 provides information on the CAPM risk premium for CO_2 allowances which is the difference between the expected return on allowances and the return of the risk-free asset.

We detail next the environmental policy variables used in our estimations.

Environmental policy constraint

Phase I and Phase II allowance prices reflect different environmental policy constraints as defined by NAPs I and II. In presence of the inter-period ban on banking, we aim at capturing the disconnection between EUA Phase I and II price changes by analysing the relationship between spot and futures prices, as well as the impact of announcements concerning the banking restriction within NAPs II.

By the cost-of-carry relationship, and without storage costs for EUA allowances, the futures and spot prices are linked through $S_t = F_T e^{-r(T-t)}$ with S_t the spot price at time t, F_T the futures prices of a contract with delivery in T and r the interest rate (Working (1949), Brennan (1958)). This no-arbitrage condition states that the only cost of buying a commodity at time t and delivering it at maturity T is the foregone interest. Agents incur the opportunity cost of purchasing the asset, but in return they benefit from possessing the commodity and being able to trade it until maturity. Equivalently, futures prices are linked through $F_{T1}e^{-r(T1-t)} = F_{T2}e^{-r(T2-t)}$ with $T = \{1, 2\}$ contracts of different delivery dates. We compute the premium between the EUA spot price and each futures contract of maturity $i = \{$December 2006, December 2007, December 2008$\}$, as well as the premium between futures of different maturities by discounting the futures prices by the interest rate and the remaining time to maturity for each contract, according to the cost-of-carry formula. Thus, we obtain five variables which may be used either during the full period or during one of the sub-sample depending on their delivery horizon: one the one hand, the premium between the spot price and the futures contract of maturity December 2006, December 2007 and December 2008; on the other hand the premium between the futures contracts of maturity December 2006-December 2007 and between December 2007-December 2008.

The main interest of introducing futures prices of varying delivery horizons consist in being able to capture the effects of the inter-period banking restriction on the futures term structure, which may be defined as the change across delivery dates in the futures prices observed on a given trading date (Bessembinder et al. (1995)). Thus, the term structure of futures prices describes several points on the asset path that market firms expect the spot price will take. Recall that in absence of inventory costs for EUA allowances, the cost-of-carry condition describes the futures term structure based on a no-arbitrage condition: the slope of the futures term structure equals the net cost of holding the asset between delivery dates, and thus should only be discounted at the risk-free interest rate.

Besides, to better take into account the effects of banning banking in France and Poland, we compute two sets of regressions depending on the country under consideration:

$$\begin{aligned} p_{t+1} - p_t =& \alpha + \beta_1(L)p_t + \beta_2 r_t^f p_t + \beta_3(r_t^m - r_t^f)\ p_t \\ & + \beta 4 break + \beta_5 p_t min + \beta_6 p_t max \\ & + \beta_7 spot/futurespr_{i,t} + \beta_8 futurespr_{i,t} \\ & + \beta_9 bansub_{j,t} + \beta_{10} banadd_{j,t} + \beta_{11} bandec_{j,t} + \epsilon_{t+1} \end{aligned} \tag{1.7}$$

with $spot/futurespr_{i,t}$ and $futurespr_{i,t}$ the spot/futures and futures premia computed as the difference respectively between the spot price and the futures prices and between two futures contracts of maturity $i = \{$December 2006, December 2007, December 2008$\}$ depending on the time period, $bansub_{j,t}$ the NAP II official submission, $banadd_{j,t}$ any NAP II additional information, and $bandec_{j,t}$ the NAP II final decision by country $j = \{$France, Poland$\}$. For each country, the dummy variable takes the value of 1 when there is a relevant information regarding either the official submission, any additional information or the final decision concerning NAPs II, and 0 otherwise as detailed in Table 1.1 (see the Appendix A).

Finally, we explain how we include the effets of possible external shocks on EUA price changes linked to energy and climatic variables.

Energy markets shocks and unanticipated temperatures events

To avoid model misspecification, we introduce brent prices, natural gas prices and extreme temperatures events that were identified as being the main determinants of EUA prices and that we study in details in Chapter 2 (Mansanet-Bataller et al. (2007), Alberola et al. (2008)).

This final step also serves as robustness check of the results obtained in eq.(1.7) which becomes:

$$\begin{aligned} p_{t+1} - p_t = & \alpha + \beta_1(L)p_t + \beta_2 r_t^f p_t + \beta_3(r_t^m - r_t^f)\ p_t \\ & + \beta 4 break + \beta_5 p_t min + \beta_6 p_t max \\ & + \beta_7 spot/futurespr_{i,t} + \beta_8 futurespr_{i,t} \\ & + \beta_9 bansub_{j,t} + \beta_{10} banadd_{j,t} + \beta_{11} bandec_{j,t} \\ & + \beta_{12} brent + \beta_{13} ngas + \beta_{14} Win07 + \epsilon_{t+1} \end{aligned} \tag{1.8}$$

with $brent$ the Brent price series, $ngas$ the Natural gas price series[39] and $Win07$ the extreme temperatures event for January-February 2007[40].

In the next section, we present the data used in our study.

1.2.3 Data

The former Chapter details energy prices and temperatures variables used in Chapters 1 and 2.

Note that, in the second section of Chapter 1, the introduction of the brent and natural gas prices in eq.(1.8) is only used as a robustness check of the results concerning inter-period banking obtained from eq.(1.7). Similarly, the introduction of climatic variables only serves as a robustness checks of the results derived for the inter-period banking restrictions on EUA price changes.

Besides, we detail below the data used specifically in Chapter 1. Descriptive statistics are presented in Table 1.6 (see the Appendix A).

Spot and futures carbon prices

We use the daily EUA spot price (p_t in € per ton of CO_2) negotiated on BlueNext[41] and daily EUA futures prices of contracts with varying delivery horizons (December

---

[39] Following Helfand et al. (2006), we compute forecast errors using the "one-step ahead" forecast method for energy variables.

[40] The methodology to compute various kinds of temperatures variables is detailed in Chapter 2.

[41] See the preceding Chapter for more details on the CO_2 spot price series used.

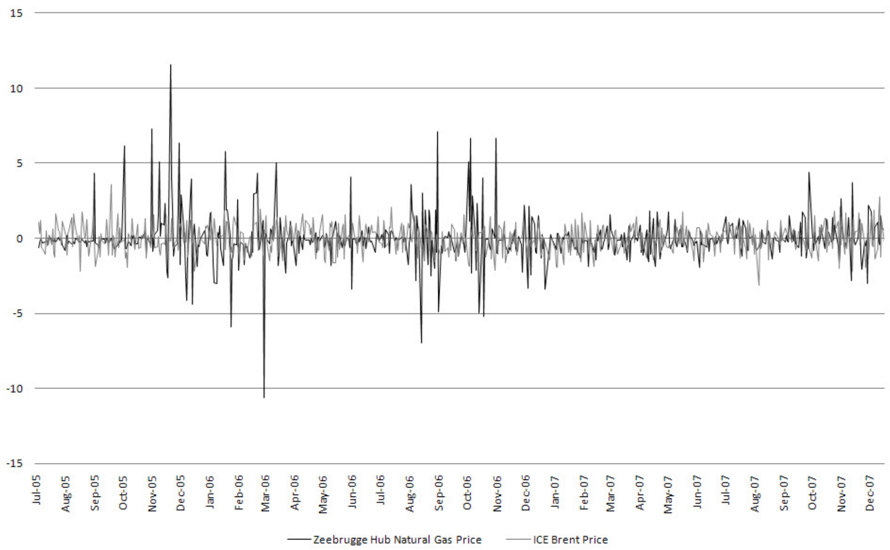

Figure 1.2: Natural Gas and Brent prices transformed to forecast errors from July 1, 2005 to December 17, 2007 from Zeebrugge Hub and ICE

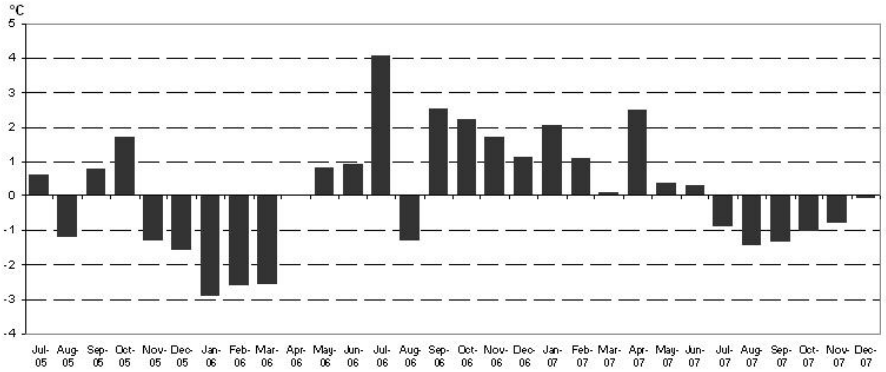

Figure 1.3: European Temperatures Index from July 2005 to December 2007 from Bluenext Weather Indices, Tendances Carbone from the Caisse des Depots

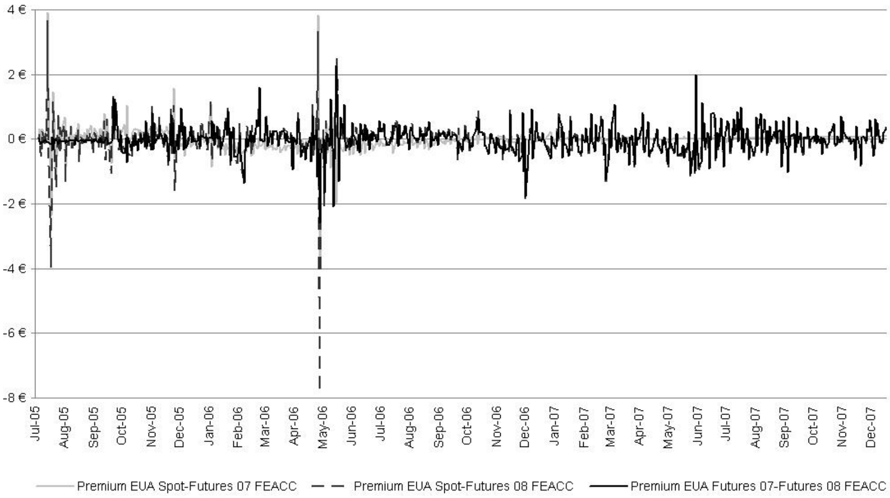

Figure 1.4: Premium between EUA spot and futures with maturities 2007-2008 prices transformed to forecast errors from July 1, 2005 to December 17, 2007 from BlueNext and ECX

2005 to 2008). The data range goes from July 1, 2005 to December 17, 2007, *i.e.* from the start of the BlueNext carbon trading platform until the delivery of futures EUA with the December 2007 maturity. Futures prices have been transformed to "one-step ahead" forecast errors (Helfand et al. (2006)) to capture the role of market uncertainty and model new information from unexpected changes in markets and conditions that might affect EUA prices (see Figure 1.2).

CAPM rates of return

The risk-free rate of return (r_t^f) is the 3-months Euribor presented as annual percentages with daily data frequency. The rate of return on the market portfolio of risky assets (r_t^m) is the Dow Jones EURO STOXX 50 Index annual return with a daily data frequency. We convert each daily observation to a daily interest rate[42].

---

[42] For r_t^f, we used the following formula: $r = (1 + \frac{i}{4})^4 - 1$ with r the annual interest rate with a daily data frequency and i the quarterly interest rate with a daily data frequency. For r_t^m, we used the following formula: $r = (1 + \frac{i}{250})^{250} - 1$ with r the annual interest rate with a daily data frequency and i the daily interest rate.

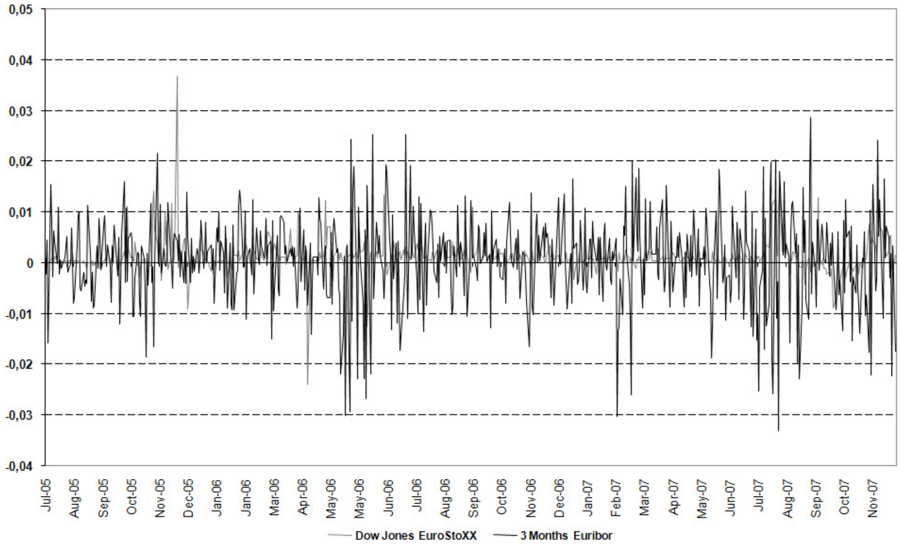

Figure 1.5: Rates of return for 3 Months-Euribor and Dow Jones EURO STOXX 50 in percentage points at daily rates from July 1, 2005 to December 17, 2007 from Banque de France and Euronext

Thus, r_t^f and r_t^m are expressed in percentage points at daily rates (see Figure 1.3).

Stationarity tests

Because econometric results may be unreliable if the dependent variable is non-stationary, we first need to test the stationarity of all price series and their first-difference. One possible complication of unit root tests for stationarity is that the presence of structural changes during the time series may make rejection of a unit root more difficult (Perron (1989)). We performed usual unit root tests (ADF, PP, KPSS) and found that all price series are characterized by a unit root. 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)).

1.2.4 Estimation results and discussion

Results of eq.(1.7) and eq.(1.8) for the full period and the two sub-periods are presented in Tables 1.2 to 1.4 (see the Appendix A). Estimations are computed using OLS and the Newey-West procedure to correct for serial correlation and generate robust standard errors (NW-OLS). The dependent variable in this analysis is the first log-differenced EUA price series[43]. Based on its correlogram, the true data generating process is characterized as an ARMA(p,q) of order 1. This is confirmed by autoregressive and moving average coefficients being statistically different from 0. The quality of the 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 the Breusch-Godfrey Serial Correlation Lagrange Multiplier test (LM), the p-value of the White heteroskedasticity test ($White\ test$), the Akaike Information Criterion (AIC) and the Schwartz Criterion (SC). For each regression, the Lagrange-Multiplier test indicates residuals are not autocorrelated. Robustness checks concerning the choice of the rate of return on the market portfolio of risky assets, the determination of the structural break and the presence of heteroskedasticity in coefficient estimates are detailed at the end of this Section. Let us discuss first the results obtained for the full sample.

Full sample

Table 1.2 (see the Appendix A) presents the results for the full period. Columns (1) and (3) show estimations results of eq.(1.7) respectively for France and Poland. Both the adjusted R-squared and the R-squared are included between 7.5% and 12.1%. For the validation of the Hotelling rule, the significance of $r_t^f p_t$ in columns (1) and (3) is not a primary concern, since it tests the restriction $\beta_1 = 0$. We are rather interested in the null hypothesis $\beta_1 = 1$. Thus, we calculate the confidence interval (CI) where the true value of the β parameter has a 95% probability to be according to the formula: $CI = [\hat{\beta} \pm 2.11 * Std.error]$. These calculations, presented in Table 1.5, lead us to reject the Hotelling rule in full period. The rejection of this rule suggests that, due to the banking restrictions, the EU ETS during Phase I did not meet the necessary conditions for an efficient intertemporal price development. Several other inferences may be made from the Hotelling-CAPM model. The lack

---

[43] Thus, we are interested in the growth rate of the dependent variable.

of significancy of the β_2 coefficient suggests CO_2 allowances do not bear a risk-premium as part of a diversified commodities portfolio. The *ptmin* dummy variable is significant at 5% level in columns (1) and (3) which improves the quality of this regression. Similarly, the structural change dummy variable *break* is significant at 1% level and negative, which is conform to the expected sign after the sudden price collapse on April 2006.

The relationship between the EUA spot price and the futures price of maturity December 2008, $spot/dec08pr$, contains statistically significant information about changes in the EUA spot price at 1% level during the full period (Table 1.2, columns (1) and (3)). Its positive sign suggests that from July 2005 to December 2007, the December 2008 futures contract has the power to forecast changes in future spot prices[44]. This result seems *a priori* counter-intuitive given the *decreasing* EUA price pattern during Phase I. It may be explained by the fact that the EC announced stricter NAPs for Phase II, and thus market firms expect a higher scarcity of allowances on the EU ETS. This allowance scarcity expected by market participants on the medium term is thus reflected in the positive sign of the coefficient for the EUA Futures contract of maturity December 2008. Yet the statistical significance of $spot/dec08pr$ over the full period uncovers the normative situation expected on the EU ETS: in absence of inter-period banking restrictions, the EUA price development should have been consistent with the evolution of the price of the futures contract of maturity December 2008. That this relationship holds on the full period and then breaks during the sub-period analysis indeed constitutes one of the major findings of our study: the futures term structure reflects the changes in market participants' expectations at different points in time of the EUA spot price, and thus allows us to capture the effets of the inter-period ban on banking[45]. The non-significance of $spot/dec07pr$ and $dec07/dec08pr$ variables suggests that the inclusion of $spot/dec08pr$ in our model contributes to a sharper explanation of EUA spot price changes. This comment for the non-significance

---

[44] See the seminal paper by Fama and French (1987) concerning the interpretation of regression results with spot/futures and futures premia.

[45] Recall that at the beginning of the period, the transfer of allowances from Phase I to Phase II was allowed in France and Poland, and has been restricted lately during Phase I.

of other potential explanatory variables as detailed in Table 1.6 applies in the remainder of the paper.

Institutional variables *bansub* concerning the NAPs II submission to the EC by France (September 2006) and Poland (June 2006) are both significant at 1% (Table 1.2, columns (1) and (3)). Their positive sign suggests the possible restrictions on banking as included in these NAPs II contributes to the explanation of low allowance price levels until the end of Phase I. Similarly, the positive and significant coefficients at 1% levels of the $banfrdec$ and *banpldec* dummies variables (Table 1.2, columns (1) and (3)) confirm that the final NAPs II decision by the EC announcing the inter-period restriction also contribute to the explanation of EUA price changes asymptotically decreasing towards zero. The non-significance of the *banadd* dummy variable may be explained by the fact that the information embedded within these communications between MS and the EC was not used by market participants to confirm the likelihood of the inter-period ban on banking. This comment applies in the remainder of this Section.

In Table 1.2, column (2) and (4) show the estimation results of eq.(1.8). The stability of coefficient estimates proves the robustness of our results with the introduction of other energy markets shocks and temperatures events. This comment applies in the remainder of the paper. For energy variables, *ngas* and *brent* affect positively EUA price changes at 5% and 10%, which is in line with previous literature on EUA price determinants (Mansanet-Bataller et al. (2007)). Unanticipated temperatures changes during January-February 2007, as captured by $Win07$, are statistically significant at 5% level and negative, which is conform to the fact that this extreme temperatures event was hotter than the decenial everage seasonal, thus leading to less needs in heating and CO_2 allowances to cover emissions[46]. In the next section, we detail the results for the first sub-period.

”Before the compliance break”

Table 1.3 presents results for the sub-period ”before the compliance break” of eq.(1.7) and (1.8) in columns (5) and (6) respectively. Both the adjusted R-

---

[46] See (**?**) for a more exhaustive discussion on this topic.

squared and the R-squared are included between 42% and 48.4%. Institutional dummy variables related to the banking restriction decisions from France and Poland are not included from July 2005 to April 2006 since they took place *after* the compliance break. Similarly to the full period, calculations of the confidence intervals lead to the rejection of the Hotelling rule (see Table 1.5). The *ptmin* dummy variable is significant at 1% level.

For the variables establishing the relationships between spot and futures prices, regression results in column (5) exhibit that both $Spot/Dec07pr$ and $Spot/Dec08pr$ are significant at 1% and 5% levels respectively. As explained above, the fact that the cost-of-carry relationship holds between the EUA spot price and December 2007 and December 2008 futures prices correspond to the medium-term price signal embedded in the futures term stucture, whereby market firms' expectations are coherent over time. Their positive sign explains the *increasing* price pattern of the spot price during this first sub-period.

The inclusion of energy prices in column (6) does not change qualitatively the results. *Brent* and *brent* lagged one are significant and positive at 1% level in explaining EUA price changes, which is in line with the previous literature (Alberola et al. (2008)). We cannot detect the influence of unanticipated temperatures events during this first sub-period. We extend our analysis to the second sub-period in the next section.

"After the compliance break"

Table 1.4 presents regression results of eq.(1.7) and (1.8) for the sub-period "after the compliance break" in columns (7) to (10). Both the adjusted R-squared and the R-squared fall at a range between 4.8% and 9%. Calculations of the confidence intervals also yield to the rejection of the Hotelling rule (see Table 1.5). The dummy variable *ptmax* is significant and positive, which improves the quality of this regression. Contrary to the "before the compliance break" period, only the $spot/dec07pr$ variable between the EUA spot price and the December 2007 futures price remains significant at 5% level (columns (7) to (10), Table 1.4). We may compare the results obtained here with the two preceding sections. Compared to the "before the compliance break" period, only the December 2007 futures price has the power to forecast the futures spot price. Compared to the full period, the relationship between the EUA spot price and the futures price for delivery in December 2008 was broken. This result proves statistically the visual inspection of the data from Figure 1.1: "after the compliance break", only the cost-of-carry relationship holds between the EUA spot price and the futures contract of delivery date at the end of the first trading period. Due to inter-period banking restrictions, the EUA spot price during Phase I was disconnected from the futures contracts valid during the second trading period. Hence, our analysis has shown that this disconnection is due to the non-validity of banked allowances after the 2007 compliance during Phase II. Contrary to the normative situation described for the full sample, the ban on banking prevents the emergence of a price signal consistent with firms' expectations for Phase II embeded within the December 2008 futures contract. The dummies variables *bandec* for France and Poland statistically confirm the final decision of the EC to ban inter-period banking on the low EUA price pattern until the end of Phase I at 1% significance level (columns (7) to (10)). Finally, these results are robust to the introduction of the unanticipated temperatures changes variable $Win07$. In what follows, we briefly discuss the gist of the results obtained in our different samples.

Discussion

In what follows, we discuss first the failure of the Hotelling rule, second the effects of institutional learning, and third the influence of energy market shocks and unanticipated temperatures events. Fourth, we detail our robustness checks.

On the failure of the Hotelling rule

As shown in Table 1.5, the failure of the Hotelling rule is not worrying in itself. Recent empirical applications state that, even if it fails, such analysis still brings a better understanding of the intertemporal scheduling of the resource use overtime (Heal (2007)). In the context of the EU ETS, the rejection of the Hotelling rule implies that the institutional setting during Phase I did not meet the necessary conditions for an efficient intertemporal price signal to emerge. Arguably, the inter-period ban on banking overwhelmed any within period smoothing of abatement efforts. If full information existed initially and throughout Phase I, and if there were no impediment to temporal trading between periods, then it would have been reasonable to expect an allowance price that would rise steadily, despite fluctuations, during the period observed. In the absence of full information, our analysis shows that the introduction of other factors affecting agents' expectations, such as compliance break events, the study of price relationships between Phases I and II, the influence of energy market prices and weather events, is not sufficient for the price signal to be strong enough to emerge from the data. The failure of this test during the full and corresponding sub-periods therefore indicates that the ban on inter-period banking and borrowing has a sharp explanatory power in explaining the low level of EUA spot prices until the end of Phase I[47].

On institutional learning

Following the release of 2005 verified emissions, much of the attention was focused on the sudden EUA price break, but little was said on the relationship between EUA prices of Phases I and II. "Before the compliance break" on April 2006, the EUA spot price was connected to the futures contracts of delivery in December 2007 and December 2008. Thus, the cost-of-carry relationship was holding between the spot and futures prices of varying delivery dates, which is conform the futures term structure highlighted in the previous Section. "After the compliance break", market participants form their anticipations more accurately in a context of a low environmental policy constraint coupled to a ban on inter-period banking, which explains the divorce of the relationship between EUA spot prices and the futures contract of maturity December 2008. Besides, the submission of NAPs II, in which both MS indicated their progressive will to ban banking, and the EC validation significantly affected allowance price changes. These official communi-

---

[47] See also Helfand et al. (2006) and Kronenberg (2006) for a more extensive discussion on other criteria that may contribute to the explanation of the failure of the Hotelling rule, for instance by paying attention to the fact that allowances are characterized by a costless extraction, or by focusing on strategic interactions between firms.

cations between France, Poland and the EC contribute to a sharper explanation of low allowance prices until the end of Phase I. As EUA price changes are statistically affected by compliance events such as on April, 2006, by the French and Polish ban on banking and by the disconnection in the futures term structures between contracts with different delivery dates, a main finding of our tests lies in the evidence of institutional learning within Phase I. The medium-term price signal is provided by the EUA futures contract of maturity December 2008, which is linked to Phase II EUA prices. The EUA Phase I spot price has only been able to give an efficient on the short-term, until the ban on interperiod banking.

On the influence of energy markets shocks and unanticipated temperatures events

As stated by Mansanet-Bataller et al. (2007), EUA price changes are affected by brent and natural gas markets shocks, and by climatic events. Our point here is simply to show that the effects of the inter-period banking restrictions are robust to the introduction of these shocks, knowing that we detail the carbon price drivers in Chapter 2.

Robustness checks

Adding energy variables to the model serves as a first robustness check for coefficient estimates. Concerning the choice of the rate of return of a diversified portfolio, the inclusion of the Euronext 100 Index instead of the Dow Jones EURO STOXX 50 does not change the results, since financial market places are strongly correlated. The Hotelling rule is still rejected in all models. When the White test shows evidence of heteroskedasticity, a GARCH(p,q) model of order 1 has been implemented using Bollerslev Wooldrige robust standard errors and covariance for each period. GARCH coefficients are stable with significant estimates in the mean and variance equations. Since both estimation techniques yield similar results, we present only NW-OLS coefficients to simplify the exposition.

Let us summarize the results obtained in our empirical analysis.

Concerning unrestricted intra-period banking within Phase I, we show statistical evidence that the NAPs I allocation process was not successful in creating the allowance scarcity needed for the Hotelling rule to emerge (Slade and Thille (1997), Schennach (2000), Helfand et al. (2006)). With regard to high allowance prices until the compliance break, early abatement occurred in the EU ETS to meet the cap requirements. After the 2005 compliance event and the correction of the expectation error concerning the amount of abatement required to comply with the cap, the restriction on inter-period banking limited additional abatement. As stated by Ellerman and Montero (2007) concerning the US SO_2 program, "*when allowed in phased-in cap-and-trade programs, banking can be expected to produce more abatement and higher allowance prices in the early phases of the program*".

Concerning restricted inter-period banking between Phases I and II, the cost-of-carry relationship does not hold between EUA spot prices and the December 2008 futures contract "after the compliance break", as the EC announced its final decision to ban this provision within NAPs II. Thus, only the futures contract of maturity December 2007 is found to be statistically significant in explaining EUA spot price changes during this second sub-period. This disconnection between Phase I and II prices sharply departs from the results during the full period which indicate a predominance of the December 2008 futures contract to explain EUA spot price changes, *i.e.* in the normative situation where allowances should have been transferable between Phases I and II. "Before the compliance break" period, both futures contracts of maturity December 2007 and December 2008 are found to be statistically significant in explaining the price variations of the EUA spot price, which is consistent with the futures term structure analysis developed in the previous literature (Bessembinder et al. (2005)). This strong effect of inter-period banking restrictions is confirmed by our analysis with dummies variables concerning official communications between France, Poland and the EC where the decisions to ban banking were embeded within NAPs II submissions and final decisions. These results are robust to the introduction of energy market shocks.

Conclusion

In Chapter 1, we attempt to ascertain the effect of banking and borrowing provisions for the successful implementation of a permits trading program such as the EU ETS.

The first section of Chapter 1 aims at gathering the main theoretical results as well as empirical evidence concerning the intertemporal flexibility of tradable permits markets for use in environmental regulation. We have highlighted the pros and cons of this instrument: while banking provides incentives for early compliance, unrestricted borrowing may aggravate the environmental harm by a concentration of the emissions stream over specific periods. These potential negative side-effects could be compensated by implementing a specific discount rate for borrowing. A ban on banking leads to an inefficient situation with respect to cost minimization because cost savings cannot be traded overtime. Combined with generous and free permits endowments, this situation confirms the view the EU ETS is only "warming-up" during Phase I, at the expense of suboptimal abatement choices. With two different price signals for the current and subsequent periods of the EU ETS, we may conclude that without banking the scheme cannot achieve its expected efficiency gains.

The second section of Chapter 1 estimates the impact on EUA price changes during Phase I of intra-period banking during Phase I following by inter-period banking restrictions between Phase I and II of the EU ETS. Beginning at 8 € on January 1, 2005 allowance prices initially rose to 20-30 €, declined suddenly after the disclosure of 2005 verified emissions on April, 2006 and steadily tended towards zero after October 2006 with the EC annoncement of its will to enforce tighter targets during Phase II. Previous literature identified among the main explanations of this price pattern over-allocation concerns, early abatement efforts in 2005 and possibly decreasing abatement costs in 2006 due to the interaction with other energy markets and temperatures events (Mansanet-Bataller et al. (2007), Ellerman and Buchner (2008)). Our analysis demonstrates the specific banking and borrowing provisions adopted between Phases I and II may also contribute to the explanation of low EUA prices.

Considering Phase I as a learning period, these results give insight into the possible sacrifice of the banking instrument to limit the transfer of design inefficiencies in Phase II. Finally, for Member States to take advantage of the banking provision in longer-term mitigation plans, the publication of the net amount of allowances either banked or borrowed at the end of each compliance period by the European Commission may be of precious use.

To further develop our analysis of price development signal in the EU ETS, we conduct in Chapter 2 a thorough analysis of the main price fundamentals of EUAs during 2005-2007.

Appendix to Chapter 1

Appendix A

1.1 Banking Borrowing in the EU ETS: A Review of Economic Modelling, Current Provisions and Prospects for Future Design

Assigned Amount Unit	AAU means a unit derived from an Annex B Party's Assigned Amount. They are tradable units that Annex B Parties may count towards compliance with their emissions target. Each AAU is equal to one tonne of carbon dioxide equivalent gases.
Certified Emission Reduction	CER means a unit issued pursuant to Article 12 of the Kyoto Protocol. These are tradable units generated by projects in non-Annex B Parties under the Clean Development Mechanism. They may be counted by Annex B Parties towards compliance with their UN and EU emissions target and are equal to one tonne of carbon dioxide equivalent gases.
Emission Reduction Unit	ERU is a unit issued pursuant to Article 6 of the Kyoto Protocol. These are tradable units generated by projects in Annex B Parties under Joint Implementation. Annex B Parties may count them towards compliance with their emissions target. Each ERU is equal to one tonne of carbon dioxide equivalent gases.
Removal Unit	RMU is a tradable unit issued on the basis of removals of greenhouse gases from the atmosphere through LULUCF activities under Articles 3.3 and 3.4 of the Kyoto Protocol. Annex B Parties may count them toward compliance with their emissions target. Each RMU is equal to one tonne of carbon dioxide equivalent gases.

Table 1.1: Glossary of Kyoto Units

These are units derived from Annex B Party's emissions target under the Kyoto Protocol. They may be counted by Annex B Parties towards compliance with their emissions target and are equal to one tonne of carbon dioxide equivalent gases.

Scheme	**Gas**	**Banking and related provisions**	**Bank amount**	**Allowances traded as % of Annual emissions**
Current emissions trading schemes				
Acid Rain program for electric utilities	SO_2	No limit on allowance banking	11.62 million	75% to 180%
RECLAIM (Greater Los Angeles area)	NOx	No allowance banking. Can sell surplus allowances to a buyer with a later compliance deadline and buy allowances with a later vintage.	0	20 % to 125%
	SOx	idem	0	10% to 105%
Future emissions trading scheme				
Kyoto mechanisms	GHGs	Banking of different units from 2008-2012 period to the subsequent commitment period is restricted as follows: - RMUs may not be carried over - ERUs, which have not been converted from RMUs, may be carried over up to a maximum of 2.5% of the party's assigned amount - CERs may be carried over up to a maximum of 2.5% of the party's assigned amount - AAUs may be carried over without restriction.		

Table 1.2: Summary of banking provisions and liquidity data for different emissions trading schemes from Haites (2006)

1.3 European Carbon Prices and Banking Restrictions: Evidence from Phase I (2005-2007)

		France				Poland			
		NAP II submission	Additional information	EC Decision	NAP II	NAP II submission	Additional information	EC Decision	NAP II
30/06/2006	Letter from MS to EC					1			1
06/07/2006	EC registration					1			1
28/09/2006	Letter from MS to EC	1			1				
28/09/2006	EC registration	1			1				
27/10/2006	Letter from MS to EC		1		1				
08/11/2006	EC registration		1		1				
28/11/2006	Withdrawing from MS		1		1				
29/12/2006	Letter from MS to EC		1		1		1		1
05/01/2007	EC registration		1		1				
08/01/2007	EC registration						1		1
09/01/2007	Letter from MS to EC						1		1
17/01/2007	Letter from MS to EC		1		1				
23/01/2007	EC registration		1		1		1		1
14/03/2007	Letter from MS to EC		1		1				
15/03/2007	Letter from MS to EC		1		1				
26/03/2007	EC NAP Approval			1	1			1	1

Table 1.3: Dates of official communications between France, Poland and the EC regarding NAPs II from the EC Environment DG

	Full period			
	France		Poland	
	(1)	(2)	(3)	(4)
$Constant$	0.0002	0.0001	0.0001	-0.0001
	(0.0014)	(0.0015)	(0.0014)	(0.0014)
$Break$	-0.0115***	-0.0094***	-0.0114***	-0.0094***
	(0.0040)	(0.0036)	(0.0040)	(0.0036)
$r_t^f\ p_t$	-0.0506	-0.0667	-0.0490	-0.0654
	(0.0483)	(0.0504)	(0.0478)	(0.0499)
$(r_t^m - r_t^f)\ p_t$	-0.0081	-0.0117	-0.0098	-0.0132
	(0.0105)	(0.0107)	(0.0105)	(0.0108)
$P_t min$	-0.0464**	-0.0577***	-0.0458**	-0.0571***
	(0.0227)	(0.0215)	(0.0226)	(0.0214)
$P_t max$	-	-	-	-
$Spot/dec07pr$	-	-	-	-
$Spot/dec08pr$	0.0257***	0.0258***	0.0255***	0.0256***
	(0.0103)	(0.0104)	(0.0104)	(0.0104)
$Banfrsub$	0.0529***	0.0437***		
	(0.0111)	(0.0114)		
$Banfradd$	-	-		
$Banfrdec$	0.1014***	0.0871***		
	(0.0339)	(0.0323)		
$Banplsub$			0.0377***	0.0329**
			(0.0143)	(0.0141)
$Banpladd$			-	-
$Banpldec$			0.1027***	0.0884***
			(0.0346)	(0.0328)
$Ngas$		0.0037**		0.0036**
		(0.0016)		(0.0016)
$Brent$		0.0053*		0.0053*
		(0.0028)		(0.0028)
$Win07$		-0.0071**		-0.0070**
		(0.0034)		(0.0034)
$R - squ.$	0.0929	0.1209	0.0929	0.1210
$Adj.R - squ.$	0.0750	0.0992	0.0751	0.0993
$F - Stat$	0.0000	0.0000	0.0000	0.0000
$D.W.$	2.0372	2.0323	2.0364	2.0315
$LM\ test$	0.2823	0.3569	0.3057	0.3814
$White\ test$	0.0000	0.0000	0.0000	0.0000
AIC	-2.3141	-2.3358	-2.3141	-2.3359
SC	-2.2216	-2.2219	-2.2216	-2.2221

Table 1.4: Full Sample Results

*** indicates 1% significance, ** 5% significance and * 10% significance. Standard errors in parentheses. The values reported for F-stat are the p-values.

	"Before the compliance break" period	
	(5)	(6)
$Constant$	0.0033	0.0025
	(0.0022)	(0.0021)
$r_t^f\ p_t$	-0.0142	-0.0158
	(0.0099)	(0.0113)
$(r_t^m - r_t^f)\ p_t$	-0.0079*	-0.0088*
	(0.0047)	(0.0051)
$P_t min$	-0.0375***	-0.0352***
	(0.0106)	(0.0107)
$P_t max$	-	-
$Spot/dec07pr$	0.0217***	0.0227***
	(0.0036)	(0.0038)
$Spot/dec08pr$	0.0054**	0.0068***
	(0.0023)	(0.0026)
$Ngas$		-
$Brent$		0.0042***
		(0.0014)
$Brent(-1)$		0.0042***
		(0.0014)
$Jul05$		-
$Win06$		-
$R-squ.$	0.4530	0.4846
$Adj.R-squ.$	0.4201	0.4476
$F-Stat$	0.0000	0.0000
$D.W.$	1.8523	1.8556
$LM\ test$	0.3767	0.3479
$White\ test$	0.0707	0.4551
AIC	-5.2729	-5.3119
SC	-5.0715	-5.0769

Table 1.5: "Before the Compliance Break" Results

*** indicates 1% significance, ** 5% significance and * 10% significance. Standard errors in parentheses. The values reported for F-stat are the p-values.

	"After the compliance break" period			
	France		Poland	
	(7)	(8)	(9)	(10)
$Constant$	-0.0165***	-0.0179***	-0.0165***	-0.0179***
	(0.0058)	(0.0052)	(0.0058)	(0.0052)
$r_t^f\ p_t$	0.5270***	0.5166***	0.5271***	0.5166***
	(0.1605)	(0.1509)	(0.1605)	(0.1509)
$(r_t^m - r_t^f)\ p_t$	-0.0382	-0.0517*	-0.0382	-0.0517*
	(0.0317)	(0.0303)	(0.0317)	(0.0303)
$P_t min$	-	-	-	-
$P_t max$	0.0196**	0.0205***	0.0196**	0.0205***
	(0.0092)	(0.0078)	(0.0092)	(0.0078)
$Spot/dec07pr$	0.0759**	0.0733**	0.0759**	0.0733**
	(0.0399)	(0.0383)	(0.0399)	(0.0383)
$Spot/dec08pr$	-	-	-	-
$Banfrsub$	-	-		
$Banfradd$	-	-		
$Banfrdec$	0.1276***	0.0946***		
	(0.0486)	(0.0360)		
$Banplsub$			-	-
$Banpladd$			-	-
$Banpldec$			0.1276***	0.0946***
			(0.0486)	(0.0360)
$Ngas$		-		-
$Brent$		-		-
$Win07$		-0.0069*		-0.0070*
		(0.0040)		(0.0040)
$R-squ.$	0.0764	0.0901	0.0764	0.0901
$Adj.R-squ.$	0.0481	0.0596	0.0481	0.0596
$F-Stat$	0.0024	0.0000	0.0000	0.0000
$D.W.$	1.9824	1.9850	1.9825	1.9850
$LM\ test$	0.9832	0.8836	0.9832	0.8836
$White\ test$	0.0000	0.0000	0.0000	0.0000
AIC	-1.9636	-1.9731	-1.9636	-1.9731
SC	-1.8370	-1.8359	-1.8370	-1.8359

Table 1.6: "After the Compliance Break" Results

*** indicates 1% significance, ** 5% significance and * 10% significance. Standard errors in parentheses. The values reported for F-stat are the p-values.

Regression	Confidence Interval
Full period	
Regression (1)	[-0.153;0.051]
Regression (2)	[-0.113;0.099]
Regression (3)	[-0.149;0.051]
Regression (4)	[-0.170;0.039]
"Before the compliance break" period	
Regression (5)	[-0.035;0.006]
Regression (6)	[-0.039;0.008]
"After the compliance break" period	
Regression (7)	[0.188;0.865]
Regression (8)	[0.198;0.835]
Regression (9)	[0.188;0.865]
Regression (10)	[0.198;0.835]

Table 1.7: Confidence Intervals for the Test of the Hotelling Rule*

*The null hypothesis of the test of the Hotelling rule is $\beta_1 = 1$. From coefficient estimates in Tables 1.1 to 1.3, confidence intervals are computed according to the formula $CI = [\hat{\beta} \pm 2.11 * Std.error]$.

	Mean	Median	Max.	Min.	SE	Skew.	Kurt.	N
Full period								
p_t	-0.010	0.000	0.511	-0.511	0.078	-0.302	12.231	635
spot/dec07 pr	¡-0.001	0.017	3.916	-3.693	0.373	1.672	57.814	635
spot/dec08 pr	-0.009	0.008	3.627	-7.813	0.595	-3.345	55.391	635
dec07/dec08 pr	¡0.001	-0.005	2.271	-2.599	0.427	-0.200	8.883	635
brent	-0.008	0.007	3.585	-3.135	0.887	0.025	3.095	635
ngas	-0.007	-0.103	11.589	-10.592	1.536	0.987	16.265	635
”Before the compliance break”								
p_t	¡0.001	0.001	0.085	-0.134	0.025	-1.022	8.652	208
spot/dec06 pr	-0.032	-0.081	3.901	-1.534	0.447	3.970	34.214	208
spot/dec07 pr	0.015	-0.033	3.916	-2.349	0.483	2.365	25.544	208
spot/dec08 pr	0.013	0.041	3.627	-3.941	0.597	-0.331	17.619	208
dec06/dec07 pr	-0.001	-0.003	0.317	-0.346	0.077	-0.074	7.904	208
dec07/dec08 pr	0.009	-0.021	1.613	-1.351	0.351	0.660	6.807	208
brent	0.077	0.049	3.585	-2.212	0.906	0.215	3.292	208
ngas	0.056	-0.153	11.589	-10.592	1.953	0.993	14.231	208
”After the compliance break”								
p_t	-0.015	0.000	0.511	-0.511	0.090	0.045	9.277	384
spot/dec07 pr	0.005	0.026	0.332	-0.451	0.085	-1.305	6.962	384
spot/dec08 pr	-0.013	-0.010	1.900	-1.833	0.400	-0.097	5.308	384
dec07/dec08 pr	0.003	¡-0.001	2.004	-1.784	0.395	0.029	5.635	384
brent	-0.047	-0.025	2.772	-3.135	0.869	-0.086	3.042	384
ngas	-0.033	-0.096	7.136	-6.940	1.319	0.701	11.971	384

Table 1.8: Descriptive Statistics

for p_t the EUA first log-differenced price series, all energy price series computed as forecast errors. $spot/dec06pr$ is the premium between EUA prices and Futures prices of Delivery December 2006, $spot/dec07pr$ the premium between EUA prices and Futures prices of Delivery December 2007, $spot/dec08pr$ the premium between EUA prices and Futures prices of Delivery December 2008, $dec06/dec07pr$ the premium between Futures prices of Delivery December 2006 and December 2007 and $dec07/dec08pr$ the premium between Futures prices of Delivery December 2007 and December 2008. SE stands for standard errors, $Skew.$ the skewness, $Kurt.$ the kurtosis and N the number of observations.

Chapter 2

The price fundamentals of carbon allowances

Introduction

This chapter aims at characterizing the daily price fundamentals of European Union Allowances traded since 2005 as part of the EU ETS, and is organized in three sections. In the first section, 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 allows to isolate distinct fundamentals evolving overtime. The results extend previous literature by showing that spot prices react not only to energy prices forecast errors, but also to unanticipated temperatures changes during colder events. Besides, the sub-period decomposition of the pilot phase gives a better grasp of institutional and market events that drive allowance price changes. The second section critically examines the impact of industrial production for sectors covered by the EU ETS on emissions allowance spot prices during Phase I (2005-2007). Using sector production indices and CO_2 emissions compliance positions defined by a ratio of allowance allocation relative to verified emissions, we show that the effect of industrial activity on EU carbon price changes shall be analysed in conjunction with production peaks and compliance net short/long positions at the sector level. The results extend previous literature by showing 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. The third section extends the analysis of the previous section at the country level. We capture statistically signficant effects of industrial production variation EUA price changes in Germany, Poland, Spain and the UK for the combustion and iron sectors, and confirm the central role played by German power producers on the EU ETS.

2.1 Price Drivers and Structural Breaks in European Carbon Prices 2005-07

Since January 1, 2005 each ton of carbon emitted in Europe by around 10,600 energy intensive plants has been priced. The 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 2008-12. 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 combustion entities manage their compliance between their allocation and annual verified emissions by buying or selling European Union Allowances to emit a ton of carbon[1]. 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 leading to effective emissions abatements.

---

[1] Concerning firms' decision making, note that firms continuously monitor their own emissions. Thus, they know their compliance position and decide on allowance purchases/sales in real time. However, due to the institutional design of the EU ETS, this behavior may only be captured empirically during the yearly compliance event imposed by the EC which provides us with a snapshot of the market at a given point in time.

Yet the first disclosure of 2005 verified emissions on April, 2006 revealing the net short/long position[2] of each plant was accompanied by a sudden allowance price collapse. Then from October, 2006 to the end of 2007 CO_2 prices tend towards zero following the European Commission announcement of stricter Phase II allocation (see Figure 2.1). This price pattern therefore suggests that allowance trading was based on heterogeneous anticipations prior to information disclosure. Within 2005-07, different fundamentals seem to co-exist *before* and *after* periods of structural breaks. The first 2005 compliance break highlights that when the cap is not set *below* business-as-usual emissions, allowance trading does not necessarily guarantee a carbon price high enough to provide incentives to reduce CO_2 emissions. Indeed, during Phase I of the EU ETS, the stringency of the cap did not appear sufficient for market agents, and consequently the allowance price collapsed. 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 Allowance?

This first section analyses the EU ETS during its pilot phase (2005-07) by focusing on the empirical relationship between CO_2 price changes[3] and its main fundamentals. The review of theoretical models by (141) and (41) lead to the identification of carbon prices main drivers being policy issues, energy prices, temperatures events and economic activity. While allowance supply is fixed by each Member States through National Allocation Plans[4] (NAPs), allowance demand is function of the level of CO_2 emissions which depends on a large number of factors such as fuel (brent, coal and natural gas) and power (electricity) prices[5], weather

---

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

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

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

[5] The electricity price constitutes an important determinant of the CO_2 price given the proportion of allowances distributed to the power sector and the arbitrages being made by producers concerning their energy-mix including the CO_2 costs. Moreover, the Granger causality test is inconclusive regarding a potential bias arising from the inclusion of the electricity price as an

conditions (temperatures, rainfall and wind speed). These potential impacts are analysed in this paper. Furthermore, to our best knowledge, empirical studies have not yet studied the effects of the arrival of new information on this newly created market. As soon as first 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[6] 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.

Compared to previous literature, our contribution is threefold. First, we show statistical evidence of two structural changes on April, 2006 and October, 2006[7] following the disclosure of new information regarding the European environmental policy. Second, this article extends, among other contributions, (114) by emphasizing that carbon price changes react not only to energy prices with forecast errors, but also to unanticipated temperatures changes during colder events. Third, this article shows evidence that those fundamentals vary between the periods defined by the two structural breaks, 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 Phase I.

The first section is organized as follows. Section 2.1.1 reviews the main drivers of EUA prices. Section 2.1.2 estimates the relationship between the daily carbon price changes and energy commodities, meteorological factors and institutional design issues. Section 2.1.3 presents the results.

---

independent variable to explain CO_2 price changes.

[6] The reason behind the fall are announcements from the Walloon Region of Belgium, France and Spain that their total verified emissions for 2005 are lower than expected. This followed similar announcements from the Netherlands and Czech Republic.

[7] Indeed, we show evidence in the paper of a second structural break on October 26, 2006 following EC annoucements of stricter NAPs II validation.

2.1.1 Main drivers of EUA prices

New commodity markets generally need time to achieve real price discovery. As shown in Figure 2.1, the EUA price pattern experienced strong price changes 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 realised 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 strongly correlated whereas EUA Futures prices for delivery in Phase II are totally disconnected since October, 2006.

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)). 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 to the difference between them. The dark spread represents 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

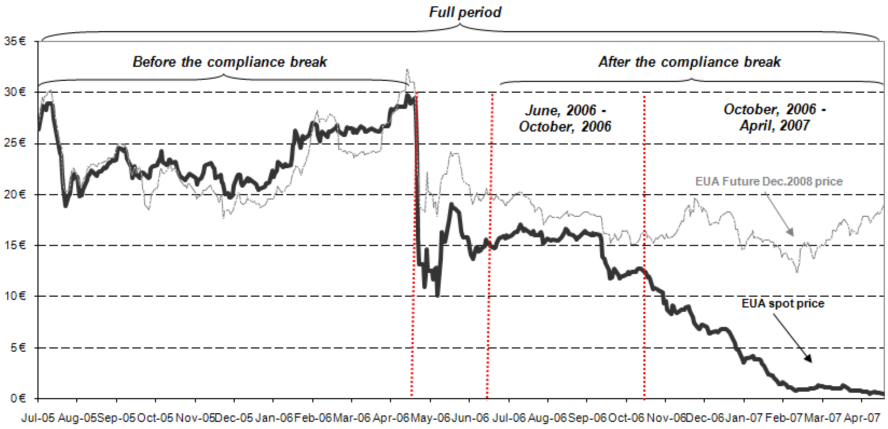

Figure 2.1: EUA Price Development from July 1, 2005 to April 30, 2007 from Bluenext

dark and clean spark spreads[8]. The equilibrium between these 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 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 more sensitive to natural gas price changes than to coal prices changes (Kanen, 2006). These three profitability indicators are used to determine the preferred fuel used for power generation.

By influencing energy demand, weather conditions may have an impact on EUAs. To our best knowledge, only Mansanet-Batallet 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[9].

---

[8] As calculated by the Caisse des Dépôts–Climate Task Force for Tendances Carbone. The methodology is available at *http://www.caissedesdepots.fr/spip.php?article659*.

[9] For an extensive literature review on this topic, see Li and Sailor (1995) and Springer (2003).

These studies indicate the relationship between temperatures and electricity demand is non-linear. Indeed, only both temperatures increases and decreases, beyond certain thresholds, may lead to increases in power demand[10]. With respect to seasonal average, 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 increase (decrease) their CO_2 emissions which should in return increase (decrease) the demand for allowances.

Some factors are missing in the recent empirical literature of carbon price fundamentals. Political and institutional decisions on the overall cap stringency, which is function of initial allocation, may have an 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 *long* positions caused a sharp fall in carbon prices. On October, 2006 announcements by the EC to validate stricter NAPs during Phase II reinforced this depressive effect on prices.

Section 2.1.2 details how to capture those relevant determinants in our model.

2.1.2 Data and Econometric Specification

The data common to Chapters 1 and 2 for carbon, energy prices and weather events is detailed in the introductory Chapter. We detail below the tests for structural breaks used in order to identify the sub-periods during which the EUA price fundamentals seem to change. Then, the econometric specification is detailed.

Structural breaks

As explained above, the EUA price break occurred on April, 2006 following the report of 2005 verified emissions. On April, first disclosures by the Netherlands, Czech Republic, France, and Spain revealing long positions caused the sharp price break. On May 15, 2006 the EC confirmed verified emissions were about 80 million

---

[10] On this topic, see also Bessec and Fouquau (2008).

tons or 4% lower than yearly allocation (Ellerman and Buchner (2007)). 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)[11] 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[12]. We therefore statistically identify two main periods in our dataset: "*before* the compliance break" and "*after* the compliance break".

Second, the unit root test by Lee and Strazicich (2001) with one structural break[13] has been run. It proves statistically the EUA price adjustment that occurred when the EC announced the stricter validation of NAPs II on October, 2006[14]. That is why we also identify two sub-periods "*after* the compliance break": "June 2006 - October 2006" and "October 2006 - April 2007". Thus, this statistical analysis conducts to the identification of one structural break on April, 2006 as commented by market observers, and brings new insights with the presence of a second structural break on October, 2006. 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

---

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

[12] Even in the presence of a structural break, the CO_2 time series has a unit root when taken in log first-difference.

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

[14] The EU Environment Commissionner, Stavos Dimas, on 23 October 2006, said that "According to the EC's calculations, the first 17 NAPs for Phase II notified to us propose an emissions cap that is about 15% above the actual emissions level in those Member States last year. I have said repeatedly that the Commission will be tough but fair in our evaluations of the NAPs. It is clear that we will need to be" [EC SPEECH/06/624] available at
http://europa.eu/rapid/pressReleasesAction.do?reference
=SPEECH/06/624&format=HTML&aged=1&language=EN&guiLanguage=en,
accessed on September, 2007.

period after the EUA price adjustment on October, 2006[15].

These breakdowns by main periods on the one hand and sub-periods on the other hand are summarized in Figure 2.1.

Econometric specification between carbon prices, energy prices and temperatures variables

The role played by energy variables on EUA price changes is estimated using energy prices with forecast errors. Following the discussion presented in Section 3.1.4., two distinct specifications are introduced to estimate the influence of temperatures on carbon price changes: extreme temperatures variables and temperatures deviations from seasonal average.

First specification with energy and extreme temperatures variables

The first specification (eq.(2.1)), summarizes the methodology followed by Mansanet-Bataller et al. (2007) including extreme temperature dummy variables with upper and lower quintiles:

$$\begin{aligned} p_t = \alpha_i &+ \beta_i(L)p_t + \chi_i break_1 + \delta_i break_2 + \phi_i(L)brent_t + \varphi_i(L)ngas_t \\ &+ \gamma_i(L)coal_t + \eta_i(L)switch_t + \iota_i(L)elec_t + \kappa_i(L)clean\ dark_t \\ &+ \lambda_i(L)clean\ spark_t + \Theta_i Temp + \mu_i Tempext5 + \nu_i Tempex95 + \epsilon_{i,t} \end{aligned} \tag{2.1}$$

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, $brent_t$ denotes 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,

---

[15] Note that, even if we adequately capture the institutionnal events, these results need to be interpreted with care given the limited number of observations.

$cleandark_t$ is the Clean Dark price series, $cleanspark_t$ 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 in Section 3.1.3. 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. Concerning temperatures data, $Temp$ 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.

Second specification with energy variables and temperatures deviations from seasonal average

Second, an alternative specification is introduced to take account of temperatures events. We choose to depart from previous literature by introducing interaction variables as explained in Section 3.1.4. Consequently, the following equation is introduced:

$$\begin{aligned} p_t = {} & \alpha_i + \beta_i(L)p_t + \chi_i break_1 + \delta_i break_2 + \phi_i(L)brent_t + \varphi_i(L)ngas_t \\ & + \gamma_i(L)coal_t + \eta_i(L)switch_t + \iota_i(L)elec_t + \kappa_i(L)clean\ dark_t \\ & + \lambda_i(L)clean\ spark_t + o_i Jul05 + \theta_i Win06 + \vartheta_i Jul06 \\ & + \rho_i Sepoct06 + \sigma_i Win07 + \epsilon_{i,t} \end{aligned} \tag{2.2}$$

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.(2.1).

The next section presents estimates of these two specifications. As shown in Section 3.1.2., the carbon price pattern is characterized by two structural breaks during 2005-07 which correspond to institutional events and therefore need to be analyzed *before* and *after* the corresponding breaks. These two breakpoints lead us to distinguish two main periods and two sub-periods during the EU ETS Phase I. The two main periods correspond to the "Before the compliance break" and "After the compliance break" periods (i.e. before and after the $break_1$ variable). Within the "After the compliance break" period, the two sub-periods correspond to "June-October 2006" and "October 2006-April 2007" (i.e. before and after the $break_2$ variable). Therefore, results are first exposed for the full period (July 2005-April 2007) and then decomposed by main and sub-periods (see Figure 2.1).

2.1.3 Results and Interpretation

Full period results for eq.(2.1) and (2.2) are first commented followed by subsequent main periods and sub-periods results. Descriptive statistics may be found in the Appendix (Table 2.1).

The quality of regressions is verified through the following diagnostic tests and statistics: 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 ($White\ test$), the Akaike Information Criterion (AIC) and the Schwarz Criterion (SC). When there is evidence of 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[16].

---

[16] When necessary, robustness GARCH estimates may be found in Table 2.6.

Full period

Table 2.3, regressions (1) and (2) shows the results for eq.(2.1). Note that regression (2) is the reduced form of eq.(2.1) estimates because neither $Tempext5$ nor $Tempext95$ are significant at the 10% significance level (regression (1)). Thus, only results of regression (2) are commented. 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 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. The LM test does not reject at the 10% significance level the null hypothesis of no residual autocorrelation for this model.

Brent and *switch* variables are not statistically significant at the 10% significance 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 like coal and natural gas and may be explained by a multicollinearity problem.

First, among significant fuel variables, *natural gas* and *clean spark* positively impact EUA price changes, whereas *coal* and *clean 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 the 1% significance level. High levels of natural gas lead power operators to realise a switch in fuel utilization from gas to coal. The natural gas price got higher from October 2005 to April 2006 and thereby positively influenced the EUA price. *Clean spark* affects EUA price changes with a positive coefficient significant at the 10% significance level. During the two years, *clean dark* stays above *clean spark* indicating burning coal is more profitable than natural gas, which increases allowances demand. Since the beginning of 2007, the difference between clean dark and clean spark spreads has been narrowing. This situation encourages consequently electric companies to decrease the use of coal to the profit of natural gas. As the most CO_2-intensive variable, *coal* plays a *negative* role on carbon price changes at the 5% significance level. 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 was also the most constrained sector during the allocation process. Some power producers are *net buyers* of allowances, which impacts *positively* EUA price changes.

Second, concerning structural change dummies, only the April, 2006 structural break (*break1*) is statistically significant at the 10% level. 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 during the full period.

Concerning temperatures variables, neither *Tempext5* nor *Tempext95* are statistically significant (regression (1)), as stressed above. It seems to indicate that there is no effect of extremely cold or hot days on CO_2 price changes, which is surprising when compared with previous literature[17]. 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). Eq. (2.2) estimates (regression (3)) provide first elements of explanation. Only *win*07 is significant and its coefficient is *negative*. Note that the coefficient of *win06* is not significant at the 10% level. In relation to eq.(2.1) (regression (2)), the adjusted R-squared increases from 34.17% to 35.58%; the AIC and the SC both decrease. Therefore, the inclusion of temperatures variables appears more relevant to explain CO_2 price changes. Note that, among other temperatures variables that are not significant at the 10% level, extremely hot days do not seem to impact allowance price changes[18]. Moreover, each of the five temperatures series has been

---

[17] We may refer to the literature on threshold models previously discussed: when temperatures are extremely cold, even colder temperatures do not impact energy consumption, *i.e.* there exists a threshold below which temperatures changes have no effect.

[18] The same effect from threshold models applies here with extremely hot days.

included as likely regressors and none of them were statistically significant. We also tried to replace the *win*06 variable (the *win*07 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 the 10% level. By combining these two remarks, 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 extremely cold days but not for extremely hot days.

As the April, 2006 structural change is significant in this section, we turn to the analysis of the two main periods below.

Before the compliance break (July 2005 - April 2006)

Results of eq.(2.1) and (2.2) are presented in Table 2.4 (regression (4) and (5)). The adjusted R-squared are respectively equal to 10.47% and 10.72%. All diagnostic tests are validated for both estimates. *ngas*, *coal*, *clean spark* and *clean dark* are not significant whereas *brent*, *electricity* and *switch* are significant and positive. Both *brent*[19] and *electricity* are significant at the 5% level. The sign of *switch* 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. Note the stability of energy variables coefficients between the two models prove the robustness of our results. This comment applies in the remainder of the section.

Compared to 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 *ngas* and

---

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

the non significance of their equivalent *switch* variable. Yet, since the coal price series is relatively stable over the time period considered, having *switch* significant and not *ngas* carries the same information as having *ngas* significant only. We find overall the same energy fundamentals as Mansanet-Bataller et al. (2007) during the "before the compliance break" period[20].

Compared to full period estimates, $Tempext95$ remains not significant (eq.(2.1), regression (4)). On the contrary, $Tempext5$ becomes significant and its sign is positive: the *cooler* the weather, the higher the effects of temperatures on EUA price changes.

Concerning results of eq.(2.2) (regression (5)), $Win06$ becomes significant. Its positive sign is consistent with previous literature concerning extremely cold events.

After the compliance break (June 2006 - April 2007)

Results of eq.(2.1) and (2.2) are presented in Table 2.5 (respectively regression (6) and (7)). The adjusted R-squared are respectively equal to 21.88% and 23.53%.

Compared to the full period, *ngas* and *coal* become not statistically significant, whereas *switch* becomes positive and significant. Energy fundamentals are similar between these two periods since *switch* may be interpreted as a shadow price of natural gas and coal. Besides, *electricity*, *clean spark* and *clean dark* remain significant with the same sign and *brent* becomes a positive determinant of EUA price changes.

On the contrary, CO_2 price changes have more energy fundamentals 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. 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. This dummy variable is now significant and negative in eq.(2.1) (regression (6)). Losing significance on the structural

---

[20] Their study indeed covers the period going from January 1, 2005 to November 30, 2005.

break dummy (*break 2*) in eq.(2.2) (regression (7)) suggests the $Win07$ variable contributes to a sharper explanation of carbon price changes[21].

More specifically, concerning eq.(2.1) estimates, only $Tempext5$ is significant and its sign is negative (regression (6)). Results of eq.(2.2) estimates indicate only $Win07$ is significant and its sign is also negative (regression (7)). Comparing results of eq.(2.1) during the "before the compliance break" period and the "after the compliance break" period *a priori* may lead to conclude to the non-robustness of the sign of extremely cold events. Actually, the analysis of eq.(2.2) 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 hotter 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. Thus, unanticipated temperatures changes seem to matter more than temperatures themselves during extremely cold events when one tests for the influence of climatic events on CO_2 price changes.

As the October, 2006 structural change is significant in Section 2.4.3, we turn below to the analysis of the two sub-periods.

---

[21] Note also that the *Clean spark* variable loses significance at the 11% level. However, we choose to keep this variable because first removing *clean spark* does not change signs and significance of other variables in regression (7) and second we want to compare the results in regression (7) with those in regression (6). The same comment applies for regression (10).

June 2006 - October 2006

EUA prices are disconnected from almost all types of fundamentals during this specific sub-period. Results of eq.(2.1) and (2.2) - presented in Table 2.5 (regression (8)) because none specification of temperatures variables is significant - highlight market participants' wait-and-see behaviour since no energy variables, except *brent*, influence EUA price changes. They are integrating in their expectations the revelation of the global net *long* position of the allowance market. Furthermore, they are expecting stricter 2008-12 NAPs validation by the EC. Market agents are sensitive to the diffusion of this new information.

October 2006 - April 2007

Results of eq.(2.1) and eq.(2.2) are presented in Table 2.5 (respectively regressions (9) and (10)). After the first compliance and EC announcements on the restriction of 2008-12 allocation, EUA price changes respond to the same energy variables as during the "after the compliance break" period (regressions (6) and (7)) 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. Moreover, 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 $Win07$ suggests it is not temperatures themselves but unanticipated temperatures changes which have an impact on CO_2 price changes during extreme weather events.

The three most important results featured in this first section may be summarized as follows. We first generalize to the full Period of our dataset all energy drivers stressed by Mansanet-Bataller et al. (2007) which do have an impact on EUAs price changes. Second, our main result shows evidence that carbon price fundamentals change over 2005-07 following two structural breaks statistically identified and the subperiods under consideration which occur due to the arrival of new information. The first break that occurred on April, 2006 following the disclosure of 2005 verified emissions emphasizes that carbon price changes react to different fundamentals as a consequence of the revelation of institutional information. These results suggest that before the disclosure of the net short/long emission position by country on April, 2006 allowance trading was based on heterogeneous anticipations since EUA prices do react to some, but not all, mechanisms that have been highlighted during the full period. The presence of a second structural break on October, 2006 as a consequence of EC announcements regarding the restriction of 2008-12 allocation confirms this agents' behavioral change. Finally, compared to previous literature, the analysis on temperatures influences is extended by considering not only extreme temperatures, but also unanticipated temperatures changes by market agents. We retrieve previous literature results by showing the non-linearity of the relationship between temperatures and carbon price changes. We take this analysis one step further by showing evidence that unanticipated temperatures changes matter more than temperatures themselves on CO_2 price changes during extreme weather conditions. Note that these concluding remarks do not hold for extremely hot events but only for extremely cold events.

In the next section, we examine the effects of the variation of industrial production as a potential fundamental of EUA prices. These effects have been suggested by the professional literature, but have received little attention in the academic literature so far.

2.2 Disentangling the Effects of Industrial Production and CO_2 Emissions on Carbon Prices

This second section 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[22] and economic activity in sectors included in the scheme. 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

---

[22] 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.

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[23] and counterfactual CO_2 emissions resulting from business-as-usual production growth forecasts. Thus, EU alowance (EUA) price changes may be affected by economic activity[24] 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[25]. Second, according to many market observers, industrials have hedged their allowances based on actual production during 2005-2007.

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, two distinct strands of literature deal with the relationships between carbon prices and industrial production. On the one hand, the literature on the impact of EUA prices on product prices and industrial production levels raises issues concerning the level of pass-through and competitiveness. The pass-through estimation link EUA prices and sales prices[26]. Competitiveness issues (such as the links between EUA prices and production costs, market share, production volume,

---

[23] 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.

[24] 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.

[25] 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.

[26] In the German and Dutch electricity sector, Sijm et al. (2006) observe high pass through rates ranging between 40 and 120% of CO_2 costs. In the EU cement sector, Walker (2006) tests the validity of cost pass-through abilities, but finds results to be inconclusive. In the iron and steel sector, Smale et al. (2006) estimate that manufacturers are able to pass on 65% of their marginal cost increases to consumers.

etc.) are detailed by Reinaud (2007) in the power sector, Demailly and Quirion (2008a) in the iron and steel sector[27] and Demailly and Quirion (2008b)[28] in the cement sector. On the other hand, the literature on the impact of industrial production volumes on EUA prices raises the issue of the estimation of CO_2 emissions following industrial production based on a decomposition analysis (Diakoulaki et al. (2007)). Thus, in this section we analyze *ex-post* the relationships between industrial production, the compliance position and carbon price changes for all sectors at the EU 27 level.

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 ratio of actual allocation relative to baseline emissions, to capture the extent to which each sector records a net short/long position. 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

---

[27] In the iron and steel sector, studies quantifying the impacts of CO_2 costs on competitiveness estimate limited short-run impacts(Carbon Trust (2004,2005), Smale et al. (2006), Demailly and Quirion (2008a), McKinsey and Ecofys (2006)). Despite being relatively more exposed to international trade than the cement industry, product differentiation allows for price differentiation to a certain degree. Smale et al. (2006) model that at an allowance price of 15 €/ton CO_2, short-run marginal production cost increase by 8%, while production output will decrease by 2.1%.

[28] Demailly and Quirion (2008b) study the EU ETS impact on the European cement industry, taking into account foreign competition and transport costs. While they support the conclusion that cement manufacturers profit from grandfathered allowances, they also address the dynamic tension between profit maximisation in the short-run and losing market shares to imports in the long run. This study explores output based allocation as an alternative approach to addressing competitiveness issues.

production index for each sector.

Compared to previous literature, this article extends (114) and (2) 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[29], 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[30].

The remainder of this section is organized as follows. Section 2.2.1 details the empirical relationship tested between the variation of industrial production in EU ETS sectors, emissions caps and carbon price changes. Section 2.2.2 presents the data and the econometric specifications. Section 2.2.3 contains the empirical results and a discussion.

2.2.1 Industrial Production and Emissions Compliance: Potential Impacts on Carbon Price Changes

Let us recall that 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

---

[29] The combustion sector was defined in a different way by each MS and contains too many subactivities. Trotignon and McGuiness (2007) and Trotignon et al. (2008) classify between large electricity production plants, district heating facilities (cogeneration when details were available) and other installations.

[30] Let us recall that power producers are the major players on the EU ETS: their trading activity and abatement potential are central to the achievement of effective emissions CO_2 reductions. Without these players, the EU ETS would be void in terms of delivering an efficient outcome. Thus, our regressions are not biased by the inclusion of the combustion sector, since we aim at detailing the effects of economic activity on EUA price changes based on the respective share of each sector included in the EU ETS in terms of allocation.

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.

As developped in the preceding section, 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 activity 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.*

Industries covered by 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.

Classification of Industries

Over 2005-2007, the EU ETS covers large CO_2-intensive emitting plants from nine industrial sectors accross its 27 MS. 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 20 MWh, mineral oil refineries, coke ovens, iron and steel and factories producing cement, glass, lime, brick, ceramics, pulp and paper. Table 2.8 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.

Evolution 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. Figures 2.6 and 2.7 display the evolution of monthly industrial production by sector at the EU 27 level. Table 2.9 details industrial production growth rates for those sectors in 2005-2006. In Figure 2.6, 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 second and third quarters 2005 and a strong recovery until the end of 2006. In Figure 2.6, 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.

Emissions Cap and Compliance of EU ETS 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.

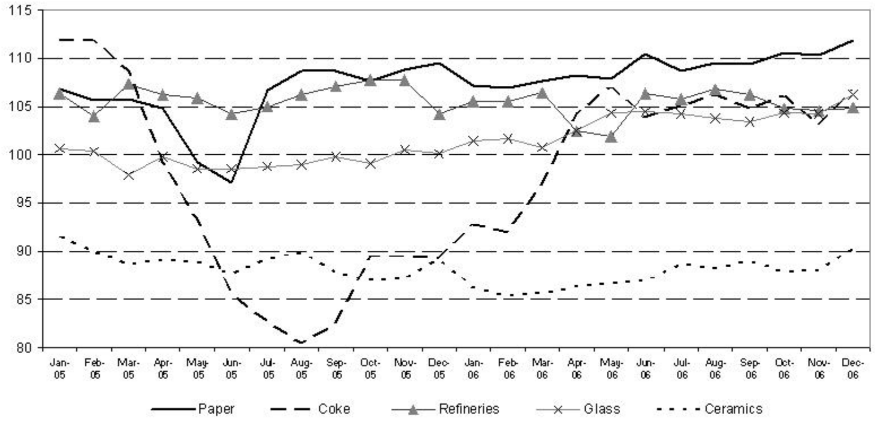

Figure 2.2: Evolution of Monthly Industrial Production Indices in Paper, Coke, Refineries, Glass and Ceramics Sectors in 2005 and 2006 based on the Classification NACE Rev.1 C-F from Eurostat

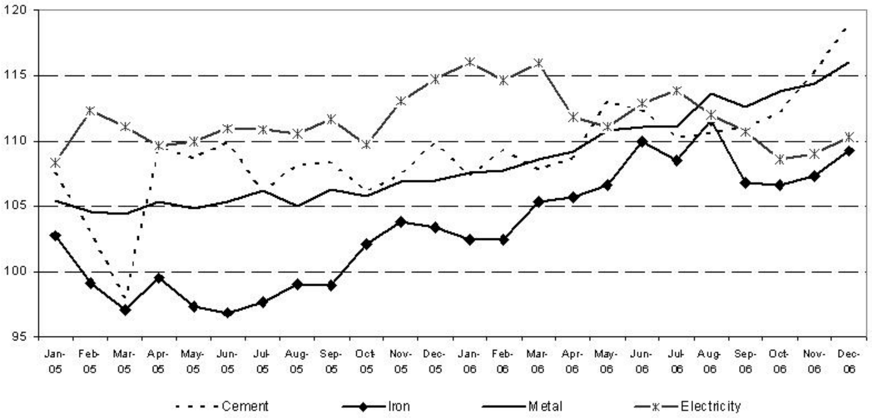

Figure 2.3: Evolution of Monthly Industrial Production Indices in Cement, Iron, Metal and Electricity Sectors in 2005 and 2006 based on the Classification NACE Rev.1 C-F from Eurostat

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 Agreement. 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[31]. Before the launch of the EU ETS on January 1, 2005 the NAPs from 25 MS[32] 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[33]. Leseur et al. (2007), Ellerman et al. (2008) provide a detailed analysis of NAPs during 2005-2007.

MS have distributed allowances to installations based on guidelines provided by the EC[34]. The allocation process has thus followed a top-down structure in three layers:

1. 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 Agreement and the validation by the EC.

2. 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

---

[31] See Ellerman (2008) for a detailed analysis of new entrants and closure provisions.

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

[33] The Greek NAP was the last approved by the EC on June 2005.

[34] 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.

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.

3. 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 2.8 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. Figure 2.9 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.

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,

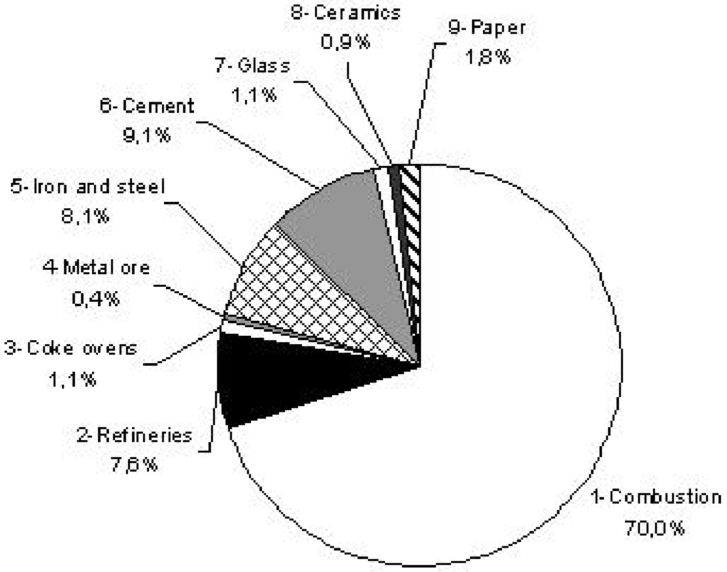

Figure 2.4: Breakdown of Allowance Allocation by Industry in 2006 from the CITL, Trotignon *et al.* (2008)

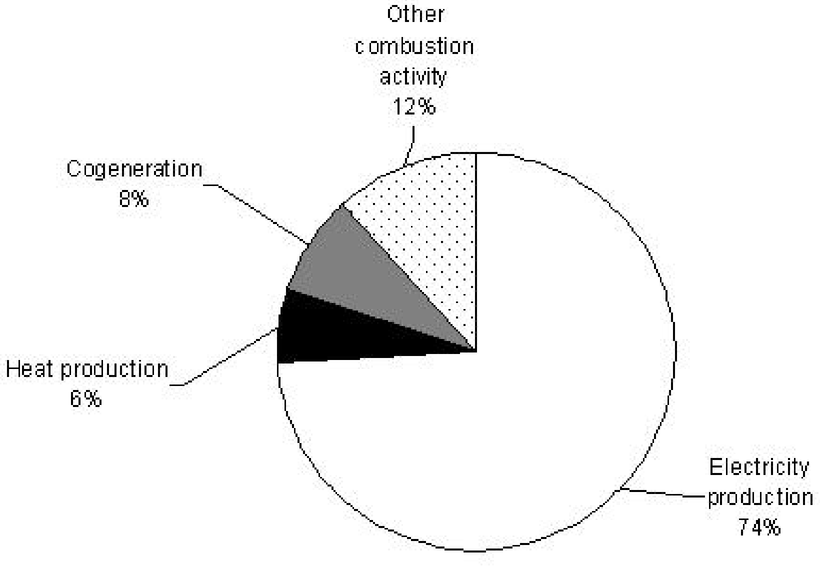

Figure 2.5: Characteristics of the Combustion Sector in the EU ETS from the CITL, Trotignon *et al.* (2008)

a short (long) installation need (not) additional allowances to cover its emissions level and achieve its compliance. A short (long) installation may buy (sell) allowances to achieve its compliance (make profits), either by trading with other market participants or by pooling allowances within the company between its different installations[35]. Thus, short (long) installations become potential buyers (sellers).

Figure 2.10 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. 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 $MtCO_2$) 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.

Figure 2.11 shows 2005 and 2006 compliance results for combustion subactivities agreggated from seven countries : Austria, France, Germany, Italy, Poland, Spain and the United Kingdom (Trotignon et al. (2008)). 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 2.10 details allocation and emissions volumes expressed in $MtCO_2$. The combustion sector and its power sector sub-

---

[35] This logic is further explained in Chapter 3.

activity dominates 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[36]. 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 the evolution of industrial production on carbon price changes in the next section.

Linking the Potential Impacts of Industrial Production and Yearly Compliance Results on Carbon Price Changes

The purpose of this section consists in detailing 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[37]. Thus, we attempt to capture the emissions-cap effects on EUA price changes *ex-post* by introducing

---

[36] See Chapter 3 for a more complete description of the several cases that apply.

[37] 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.

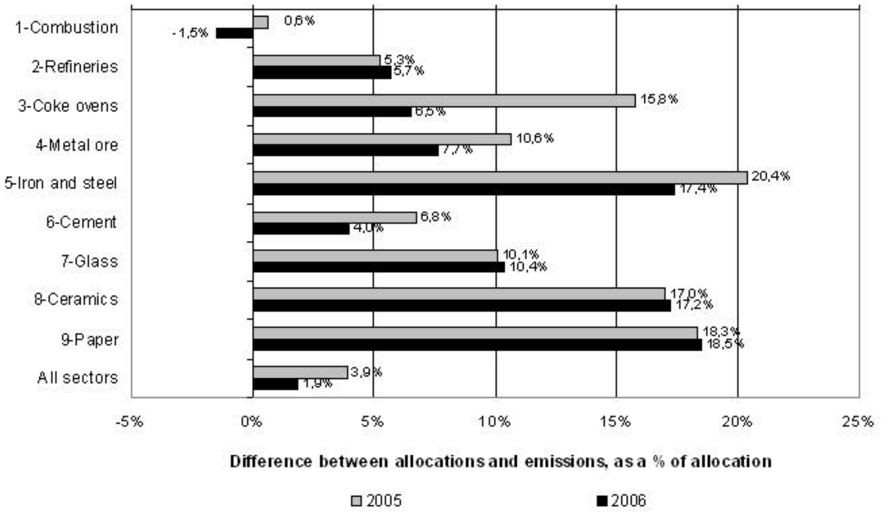

Figure 2.6: Emissions Compliance Positions by EU ETS sectors during 2005-2006 from Trotignon *et al.* (2008)

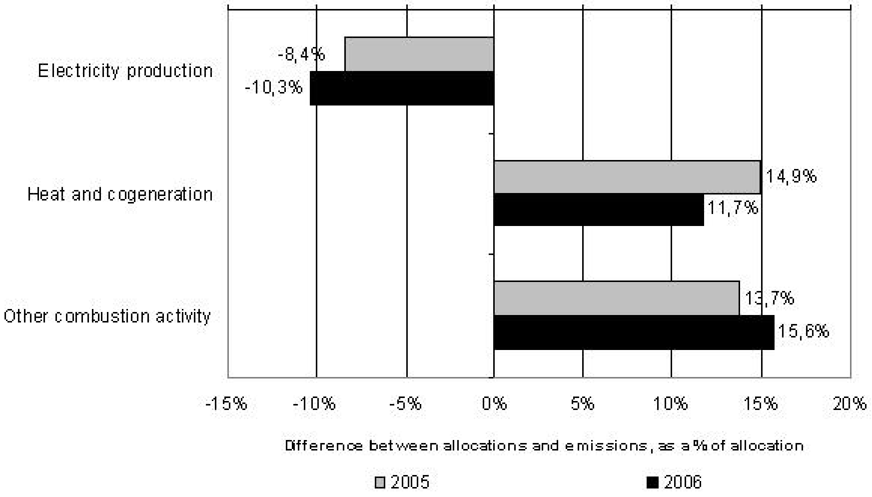

Figure 2.7: Emissions Compliance Position in the Combustion Sector during 2005-2006 from Trotignon *et al.* (2008)

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, Tables 2.9 and 2.10 presents the net compliance and the annual production growth rate recorded in each sector during 2005-2006.

From Figures 2.12 and 2.13, EU ETS sectors may be categorized in four groups:

1. one group with an *increasing* variation of industrial production and a net *long* compliance position;
2. one group with an *increasing* variation of industrial production and a net *short* compliance position;
3. one group with a *decreasing* variation of industrial production and a net *long* compliance position;
4. one group 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)[38].

---

[38] For instance, according to Figure 2.12, 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.

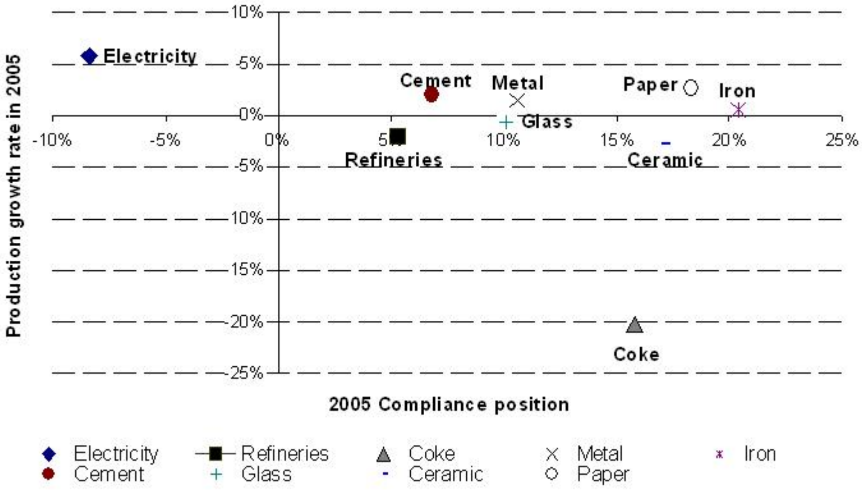

Figure 2.8: Emissions Compliance Positions and Production Growth Rates of EU ETS Sectors in 2005 from Eurostat, the CITL and Trotignon *et al.* (2008)

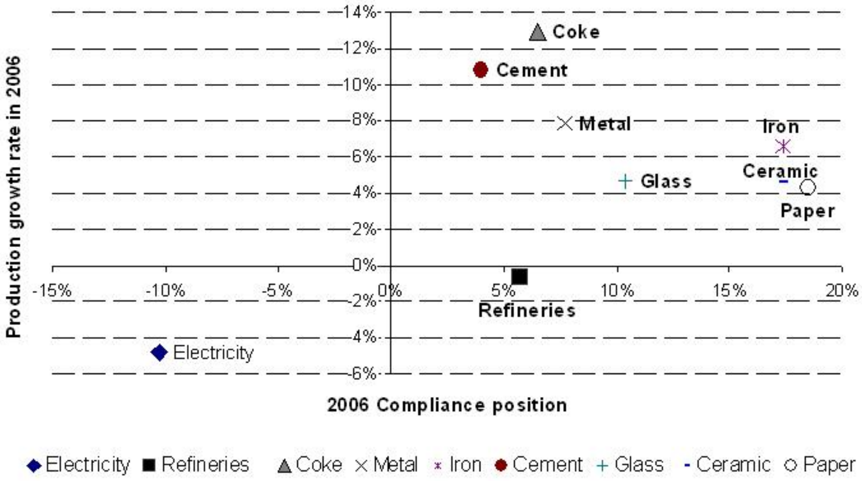

Figure 2.9: Emissions Compliance Positions and Production Growth Rates of EU ETS Sectors in 2006 from Eurostat, the CITL and Trotignon *et al.* (2008)

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?

2.2.2 Data and Econometric Specification

The data concerning the carbon price drivers regarding energy prices, temperature events and compliance breaks have been presented in the previous section. Here, we introduce the data that allows us to disentangle the potential effects of the variation of industrial production on carbon price changes: sector production indices and dummy variables representing production peaks, compliance results and the allowance squeeze probability around yearly compliance events. Then, we detail our econometric specifications.

Data

Sector Production Indices
Since CO_2 emissions levels are not directly observable at the installation level[39], monthly industrial production indices are collected by Eurostat (2007) at the aggregated EU 27 level using the Classification NACE Rev.1 C-F (see Table 2.11).

According to the decomposition of sectors required by the CITL, the following industrial production indices are collected: paper and board; iron and steel; coke ovens; refineries; ceramics; glass; cement; metal and combustion. 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 index has a base 100 in 2000 and is seasonally adjusted by Eurostat. These data are then resampled to convert monthly indices to daily frequency[40] (see IEEE (1979) for reference).

---

[39] See (59) for an extensive discussion.

[40] The Matlab function by L. Shure performs linear interpolation so that the mean square error

Let us discuss some preliminary concerns with the use of industrial 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[41]. 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[42]. Finally, according to the matrix of cross-correlations between sector variables reported in Table 2.13, no simple correlation is over around 60% in absolute value. Since it is possible to have low correlations together with colinearity, we have investigated the presence of multicolinearity by comptuting the inflation of variance between explanatory variables. These calculations did not reveal serious problematic multicolinearities.

As detailed in Section 2.2.2, two main reasons may explain the likely influence of industrial production on carbon price changes: 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 each yearly compliance. Thus, the dummy variable *sectcompl*[43] equals 1 if the sector is in an annual net *short* position and 0 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 industrial production index under

---

between the original data and their ideal values is minimized.

[41] 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 (2008a) and (2008b)).

[42] For instance, the electricity price does not appear to be correlated with the combustion production index since it covers 1/3rd of other sub-activities as explained in Section 2.2.2.

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

consideration[44]. Thus, the dummy variable *sectpeak*[45] 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, $sectcomplpeak = sectcompl * sectpeak$ is the product of the dummy variables characteristic of the annual net *short* positions and *positive* monthly production peaks in a given sector.

Similarly to the previous section, sector indices have been transformed to "one-step ahead" forecast errors. 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)).

Allowance Squeeze Probability

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[46], *i.e.* about fifteen days before the official EC announcement[47], and

---

[44] This threshold has been fixed considering the average level of monthly variation of production over 2005-2006. 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.

[45] *Sect* refers to the same sectors under consideration.

[46] 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 ocurred starting on April 24, 2006.

[47] 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).

zero otherwise. The information embeded 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: $psq = difsq * sq$.

Econometric Specification

The role played by the variation of 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.

Does the Variation of Industrial Production in EU ETS Sectors Impact EUA Price Changes?

On top of energy variables, temperatures events and compliance breaks that were previously identified as carbon price drivers in the preceding section[48], 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.

The estimated model is:

---

[48] Recall that on the full period the brent price affects EUA price changes through the natural gas price.

$$
\begin{aligned}
p_t = {} & \alpha + \beta(L)p_t + \delta break + \nu psq_{i,t} + \varphi(L)ngas_t + \gamma(L)coal_t \\
& + \iota(L)elec_t + \kappa(L)dark_t + \lambda(L)spark_t + \sigma\ Win07 \\
& + \varsigma(L)cement_t + \tau(L)refin_t + \upsilon(L)coke_t + \omega(L)comb_t + \xi(L)glass_t \\
& + \psi(L)metal_t + \zeta(L)paper_t + \rho(L)ceram_t + \chi(L)iron_t + \epsilon_t
\end{aligned}
\tag{2.3}
$$

For sector variables in the EU 27, $cement_t$ is the cement production index; $refin_t$ the production index in the refineries sector; $coke_t$ the production index in the coke ovens sector; $comb_t$ the production index in the combustion sector; $glass_t$ the glass production index; $iron_t$ the production index in the iron and steel sector; $metal_t$ the production index in the metallurgy sector; $ceram_t$ the production index in the ceramics sector; and $paper_t$ the production index in the paper and pulp sector.

As explained in Section 2.2, this first specification allows us to identify three sectors covered by the EU ETS whose variations of industrial production significantly affect EUA price changes: combustion, iron and paper. Thus, we take our analysis one step futher by investigating in the next section why those sectors impact EUA price changes. Two main reasons were highlighted above, *i.e.* the influence of production peaks and compliance positions.

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 industrial 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.(2.3). We then estimate 3 equations which may be summarized as:

$$\begin{aligned} p_t = {} & \alpha + \beta_i(L)p_t + \delta break_1 + \nu psq_{i,t} + \varphi(L)ngas_t + \gamma(L)coal_t \\ & + \iota(L)elec_t + \kappa(L)dark_t + \lambda(L)spark_t + \sigma\ Win07 \\ & + \omega\ sect_{i,t} + \emptyset\ sectpeak_{i,t} + \vartheta\ sectcompl_{i,t} \\ & + \eta\ sectcomplpeak_{i,t} + \epsilon_t \end{aligned} \tag{2.4}$$

where $sectpeak_{i,t}$ is a dummy variable capturing *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* production peaks and a net short compliance position in the sector under consideration. $psq_{i,t}$ is the allowance squeeze probability for $i = \{1, 2\}$ referring to the 2005 and 2006 compliance results. Other variables are explained in eq.(2.3).

Estimation results of eq.(2.3) and eq.(2.4) are provided in the next section.

2.2.3 Results and Discussion

As highlighted by Seifert et al. (2008), 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. Taking into account this quite dynamic behavior for EU allowance prices, and the dependence of the variability of the time series on its own past, Borak et al. (2006) and Benz and Truck (2006) 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 $(p_t)_{t\geq 0}$, but also on a moving average of past conditional variances which better fits the data. Paolella and Taschini (2008) conclude that the GARCH specification[49] that provides the best likelihood-based goodness-of-fit for the EUA return series is a GARCH(1,1) model with a generalized asymmetric t innovation distribution. Thus, they justify

---

[49] Even if the VAR forecasts based on this specification do not provide fully satisfactory results.

to work at least with an asymmetric GARCH to characterize EUA price series returns.

Concerning our sample, we depart from Paolella and Taschini (2008) by choosing an asymmetric TGARCH(p,q) model[50] (Zakoian (1994)) with a Gaussian innovation distribution. The TGARCH(1,1) model estimated in Table 3.14 may be written as:

$$\sigma_t = \alpha_0 + \alpha^+ \ (L) \ \epsilon_t^+ - \alpha^- \ (L) \ \epsilon_t^- + \beta \ (L) \ \sigma_t \tag{2.5}$$

where:

$$\begin{cases} \epsilon_t^+ = max(\epsilon_t, 0) \\ \epsilon_t^- = min(\epsilon_t, 0) \end{cases}$$

ϵ_t^+ et ϵ_t^- allow to take into account the asymmetric effects concerning volatility described earlier. The effect of a shock ϵ_{t-i} on the conditional variance depends both on the magnitude and the sign of this shock.

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)).

This specification fits well with descriptive statistics of EUA price changes displayed in Table 2.12. 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 2.14 (see the Appendix B). The quality of regressions is verified through the following diagnostic tests and statistics: the simple R-squared, the adjusted R-squared, the p-value of the F-test statistic

---

[50] TGARCH stands for Threshold GARCH.

($F - stat$), the Ljung-Box Q-test statistic, the ARCH Lagrange Multiplier test ($ARCHLM$), the Akaike Information Criterion (AIC) and the Schwarz Criterion (SC).

The Effects of Sector Industrial Production Indices

Compared to the previous section, the point here is to test whether industrial production indices significantly impact EUA price changes besides other drivers highlighted in regression (1a), Table 2.14. We have selected the same lag operators on the dependent variable as in the preceding section. Results of eq.(2.3) are presented in Table 2.14, regression (1b). We only present the reduced form estimate of eq.(2.3)[51]. 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. 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. We do not comment here the results obtained concerning the variables for energy prices and temperatures, given the stability of the coefficients obtained compared to previous section estimates, which confirms the robustness of our results.

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 industrial 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,

---

[51] 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.(2.3).

is significant at 1% level. Its positive sign reflects a strong allowance demand from installation operators before the 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. Those comments apply to the remainder of the section.

Second, among the nine sectors included in the EU ETS, three sectors are statistically significant at 1% level: combustion, iron and paper[52]. As shown in Figure 2.8, combustion and iron gather around 78% of allowances allocated, with respectively 70% and 8% of distributed allowances. 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[53].

In Figure 2.7, 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 2.6 and 2.7, 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

---

[52] According to the Klein test, the comparison of the squared correlation between each of these exogenous variables (Table 3.13) and the R-squared of regression (1b) (Table 3.14), does not reveal any problematic colinearity.

[53] The economic logic behind this presumed pooling behavior is further explained in Chapter 3.

the next section by disentangling the effect of production peaks and compliance positions on EUA price changes.

The Effects of Production Peaks and Compliance Positions

As explained in Section 2.2.2, we now estimate eq.(2.4) for each of the three sectors which were significant in eq.(2.3) (regression (1b), Table 2.14): combustion, iron and paper sectors.

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 alternance of a net long position (+0.6% in 2005) and a net short position (-1.5% in 2006).

In Table 2.14, regressions (2a) and (2b) show the results of eq.(2.4) for the combustion sector. All diagnostic tests are validated for these estimates. The regression (2a) contains *combcompl* and *combpeak* whereas regression (2b) contains these latter dummy variables as well as the interaction variable, *combcomplpeak*. The *comb* coefficient remains negative in both estimates. The coefficients of *combcompl* and *combpeak* are both positive and significant at 1% level. The sign of these two dummy variables is conform to arguments presented in Section 2.2.2. In regression (2a), with no interaction effects, the growth rate of EUA prices is *higher* (by about 0.5%) when the combustion sector record a *short* allowance position *ceteris paribus*. The growth rate of EUA prices is *higher* (by about 2%) when the combustion sector encounters a *positive* production peak *ceteris paribus*. 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. The *negative* coefficient of *comb* remains even after taking into account the positive effect of production peaks and may be explained by the *decreasing* evolution of activity in the combustion sector in 2006, which decreases both CO_2 emissions and allowances demand, and ultimately has a *negative* impact on EUA price changes.

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.(2.4) estimates (regression (2a)) with those of the same equation (regression (2b)) 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. 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) *ceteris paribus*. This result lies 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.

Analysis of the Iron and Paper Sectors

In this section, we detail the results for both iron (regression (3), Table 2.14) and paper (regression (4), Table 2.14) 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 and the paper sector total respectively 8% and 1.80% of EU allowance allocation in 2005-2006.

It is worth underlining the lowest value of the the adjusted R-squared statistic 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. The *negative* sign of *iron* and *paper* variables is not explained by their increasing variation of production[54], but ultimately by their net *long* position on the whole period. Indeed, both iron and paper sectors record by far the *highest net long* positions with respectively 20.4% and 18.3% in 2005 as shown in Figure 2.8. Thus, they are potential net *sellers* of allowances, which has a *negative* impact on EUA price changes. 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* and *paper*. Similarly, the significant effect of *paper* on EUA price changes may not be explained by its low share in terms of allocation in the EU ETS, but rather by the fact that it records one of the longest position during compliance events. The reason behind the positive sign of *paperpeak* and *ironpeak* is similar to what has been explained 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.

The two most important results of this second section may be summarized as follows. First, we show evidence that 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 and shows the central role by the power sector on this market. 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. In the next section, we extend to the *country-level* our analysis

---

[54] 2.61% in 2005 and 4.31% in 2006 for *iron*, and 0.62% in 2005 and 4.31% in 2006 for *paper*.

on the relationship between the evolution of industrial production and EUA price changes.

2.3 EU Emissions Compliances and Carbon prices: A Country Specific Analysis of Industrial Sectors

In this section, we choose to focus on the combustion and iron sectors only, based on their share of total allocation in the EU ETS[55]. Following the same methodological approach as in the preceding section, we extend our analysis to six main countries covered by the scheme: Germany, Spain, France, Italy, Poland and the UK.

2.3.1 Evolution of Industrial Production at the Country Level in 2005-2006 in the Combustion and Iron Sectors

Figures 2.14 and 2.15 display the evolution of industrial production by country for the combustion and iron sectors during 2005-2006. As shown also in Table 2.15, we observe very different patterns depending on the country under consideration. The combustion sector recorded in 2005 a growth of +2.24% in the UK and +12.95% in Italy. In 2006, the sector recorded a negative growth from -1.83% in Spain to -9.36% in Italy. Besides, the iron and steel sector exibited contrasted growth rates. In 2005, it increased in Spain (+0.99%), Germany (+1.65%) and the UK (+7.54%), whereas it decreased in three main countries, Italy(-0.24%), France (-3.46%) and Poland (-3.81%). In 2006, the iron and steel production decreased only in Spain (-0.13%), while it increased in five countries from +2.29% in France to +17.75% in Poland.

---

[55] The combustion and iron sectors gather respectively 70% and 7% of allocation at the EU 27 level.

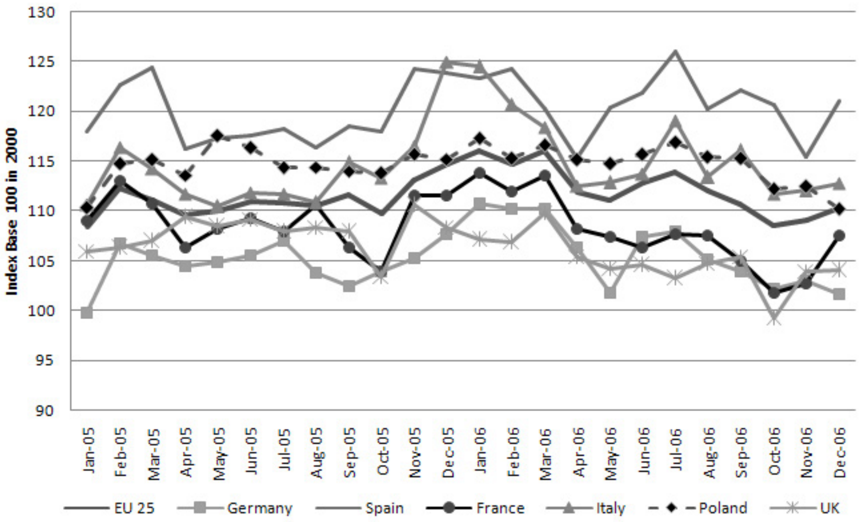

Figure 2.10: Evolution of Industrial Production in the Combustion Sector for Germany, Spain, France, Italy, Poland and the UK in 2005 and 2006 based on the classification NACE Rev.1 C-F from Eurostat

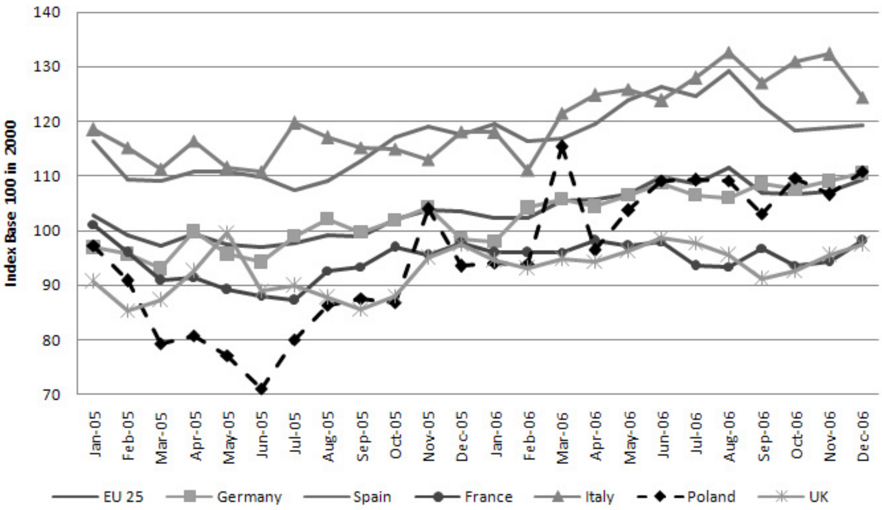

Figure 2.11: Evolution of Industrial Production in the Iron & Steel Sector for Germany, Spain, France, Italy, Poland and the UK in 2005 and 2006 based on the classification NACE Rev.1 C-F from Eurostat

2.3.2 Emissions Cap and Compliance Positions at the Country Level in 2005-2006 in the Combustion and Iron Sectors

Figures 2.16 and 2.17 provide the repartition by country of allocation to the combustion and iron sectors in 2005-2006. In the combustion sector, we observe that the largest countries in terms of allocation are Germany (27%), Poland (14%) and the UK (11%). In the iron sector, we observe that the largest countries in terms of allocation are Germany (20%) and France (17%).

Figures 2.18 and 2.19 provide a breakdown by country of the 2005 and 2006 compliance results in the combustion and iron sectors. These figures indicate by country the number of installations that are net short/long of allowances, and the global net short/long position of each sector. Table 2.15 is also used for our analysis.

In 2005, the combustion sector recorded a net long compliance position at the EU 27 level (+0.55%). The picture is different at the country-level: the sector recorded a short position in Italy (-8.01%), in Spain (-16.08%) and in the UK (-24.30%). In the iron and steel sector, most countries recorded a net long position from +0.08% in UK to +60,60% in Poland.

In 2006, the combustion sector recorded a net short compliance position at the EU 27 level, with its verified emissions being 2.42% *higher* than allocated allowances. At the country level, Italy, Spain and the UK recorded a net short compliance by respectively -20.25%, -19.90% and -29.74% of their allowances allocation. Conversely, France, Germany and Poland presented a net long position, from +2.21% in Poland to +26.61% in France. In the iron and steel sector, five countries revealed a net long position from +1.32% in the UK to 51.88% in Poland, whereas Italy disclosed a net short position of -9.47%.

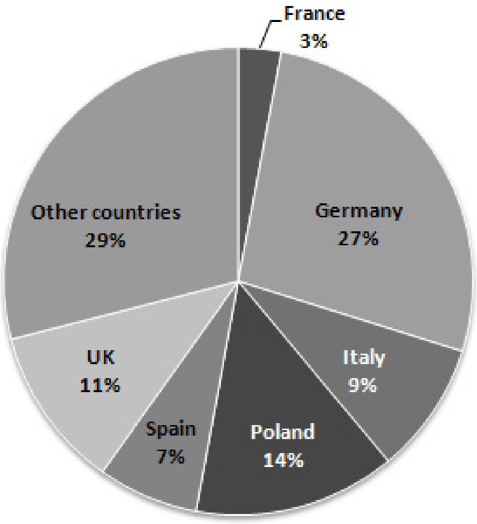

Figure 2.12: EUA allocation by Country in the Combustion Sector in 2005-2006 from the CITL, Trotignon *et al.* (2008)

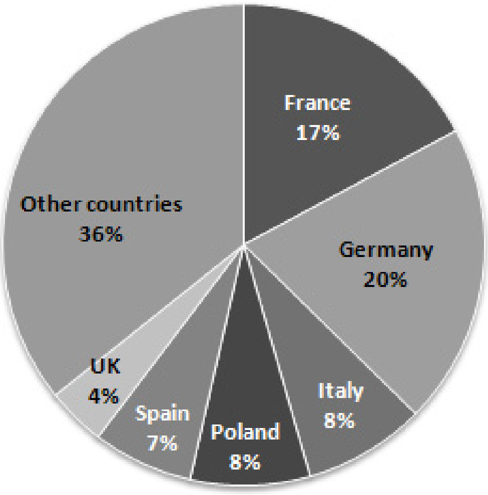

Figure 2.13: EUA allocation by Country in the Iron & Steel Sector in 2005-2006 from the CITL, Trotignon *et al.* (2008)

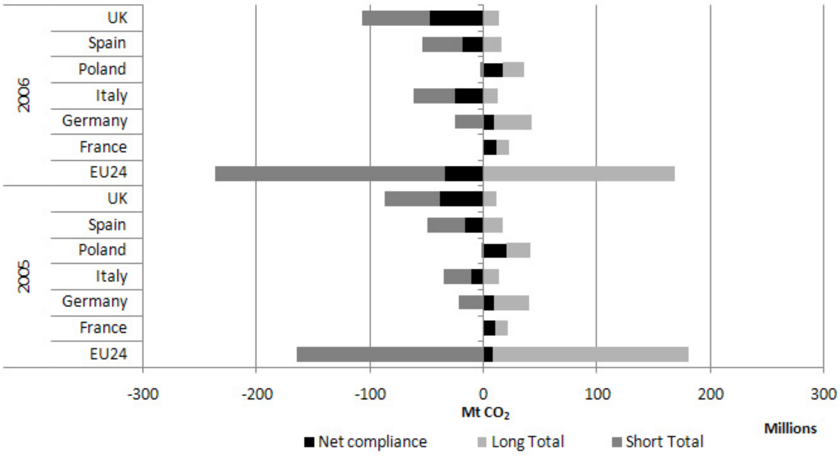

Figure 2.14: Emissions Compliance Positions in the Combustion Sector in 2005-2006 from the CITL, Trotignon *et al.* (2008)

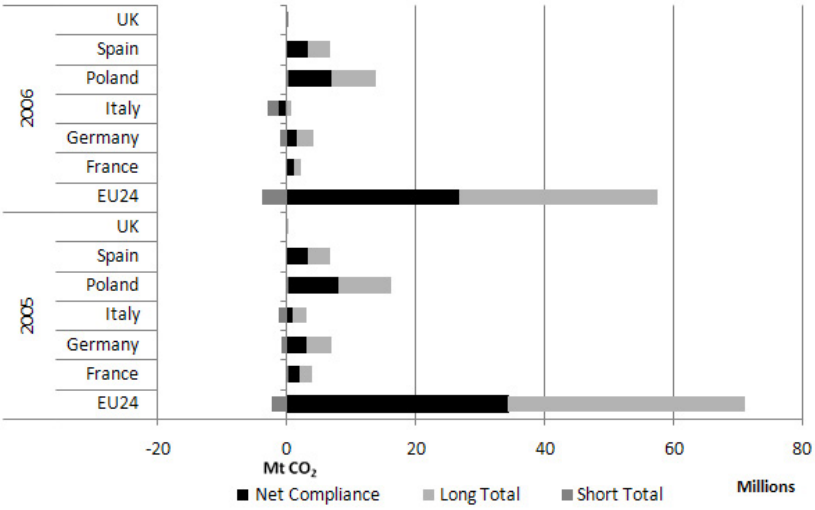

Figure 2.15: Emissions Compliance Positions in the Iron & Steel Sector in 2005-2006 from the CITL, Trotignon *et al.* (2008)

2.3.3 Data and Econometric Specification

Data

We use the same data for energy prices, temperatures variables and institutional events as detailed in the preceding Sections. At the country level, industrial production indices are gathered from Eurostat for combustion and iron in France, Germany, Italy, Poland, Spain and the UK according to the classification NACE Rev.1 C-F.

Econometric Specification

Following the discussion presented in Section 2.2.2, our econometric specification aims at capturing country-specific effects of production peaks and compliance net short/long positions in the combustion and iron sectors:

$$\begin{aligned} p_t = {} & \alpha + \beta_i(L)p_t + \delta break_1 + \nu psq_{i,t} + \varphi(L)ngas_t + \gamma(L)coal_t \\ & + \iota(L)elec_t + \kappa(L)dark_t + \lambda(L)spark_t + \sigma\ Win07 \\ & + \omega\ sect_{i,j,t} + \emptyset\ sectpeak_{i,j,t} + \epsilon_t \end{aligned} \tag{2.6}$$

where $sect_{i,j}$ is the industrial production index of the sector under consideration, $i = \{\text{comb, iron}\}$ corresponds either to the combustion and iron sectors and j=$\{de, es, fr, it, pl, uk\}$ corresponds either to Germany, Spain, France, Italy, Poland or the UK. $sectpeak_{i,j,t}$ is a dummy variable capturing positive monthly production peaks [56]. Note we cannot instrument the dummy variable *sectcompl* nor the interaction variable *sectpeakcompl* at the country level since we do not observe an alternance of net short and long compliance positions between 2005 and 2006. Other variables are explained in eq.(2.3). Estimation results of eq.(2.6) are provided in the next section.

---

[56] A production peak is defined with the variation of +2.5% of the sector production index under consideration.

2.3.4 Results and Discussion

We choose the same asymmetric TGARCH(p,q) model with a Gaussian innovation distribution as in Section 2.2.2, estimated by PML with the BHHH algorithm. This specification fits well with descriptive statistics of EUA price changes displayed in Table 2.16. From the matrix of cross-correlation between sector variables in Table 2.17, our analysis based on the inflation of the variance between explanatory variables does not reveal problematic multi-collinearities. As explained in Section 2.3.2, estimation results of eq.(2.6) in each country for the combustion and iron sectors which were significant in eq(2.3) are presented in Tables 2.18 and 2.19 (see the Appendix B). We use the same diagnostic tests as in Section 2.2.5.

Comments of energy prices, extreme temperatures events, structural breaks variables have been developed in Section 2.1.4. Comments of industrial production indices, production peaks and compliance positions variables at the EU 27 level have been developed in Section 2.2.5.

Country Specific Analysis of the Combustion Sector

In Table 2.18, regressions (3),(4),(5) and (6) show the results of eq.(2.6) for the combustion sector at the country specific level. More precisely, these regressions correspond to the combustion sector respectively in Germany, Spain, Poland and the UK.

Among the six countries studied in this section, four are statistically significant, which total 59% of allowances allocated in the combustion sector. Thus, both the combustion sectors in France and Italy do not have a statistically significant impact on EUA price changes[57].

As a first comment, the variable *break* is statistically significant in regressions (4),(5) and (6) but not in regression (3). Losing significance on *break* in regression (3) suggests that the influence of the combustion sector in Germany contributes to

---

[57] In Figure 2.8, we observe that the combustion sector in France and Italy is characterized by an alternance of net short and net long installations. Allowances pooling may occur between these installations, which explains why we do not observe a statistically significant effect. This logic is further explained in Chapter 3.

a sharper explanation of carbon price changes than in Spain, Poland and the UK. This result is confirmed by the fact that the German power sector totals 27% of allocated allowances in the EU. Thus, the central role played by power producers in the EU ETS concerning trading activity and the achievement of effective CO_2 emissions reductions targets fits well the case of Germany, which has some major companies such as E.ON or RWE.

Second, for all countries, the coefficients of *comb* and *combpeak* has the expected sign as explained in Section 2.2.2. Note the negative sign of *combde* in regression (3), and *combuk* in regression (6) may be explained by the decreasing variation of industrial production of the combustion sector in these two countries as displayed in Figure 2.14.

Country Specific Analysis of the Iron Sector

In Table 2.19, regressions (8), (9), (10) and (11) show the results of eq.(2.6) for the iron sector, respectively in Germany, Spain, Poland and the UK. The four countries which appear to be statistically significant are the same than for the combustion sector and total 39% of allocated allowances in the iron sector. Similarly, the iron sectors in France and Italy do not have a statistically significant impact on EUA price changes.

Compared to the country-specific analysis of the combustion sector, the variable *break* is statistically significant in all regressions ((8) to (11)), which strenghtens our earlier argument concerning the central role played by German power producers in the EU ETS. The *negative* sign of *iron* for all countries in regressions (8) to (11) may not be explained by a decreasing variation of industrial production. As displayed in Figure 2.15, the variation of industrial production was rather increasing in all countries during 2005-2006. Thus, the negative sign may be explained by the predominance of the net *long* compliance position of the iron sector in these countries as displayed in Figure 2.19. This explanation is conform to Section 2.2.5. However, we cannot instrument *sectcompl* here since we cannot observe an alternance of net short/long positions between 2005 and 2006 at the country level.

The coefficients of *ironpeakes* (regression (9)), *ironpeakpl* (regression (10)) and *ironpeakuk*(regression (11)) have the expected positive sign. The logic to comment these coefficients is the same as developed in Section 2.2.2. Conversely, we observe a negative sign for the coefficient of *ironpeakde* (regression (8)). According to Figures 2.18 and 2.19, the German iron sector is characterized by an increasing variation of industrial production and a net long position in 2005-2006. As evoked in Section 2.2.2, this specific case highlights that our disentangling analysis may lead to intermediate cases where the effect of industrial production on EUA price changes is more ambiguous. The German combustion sector is indeed net *long* by 2% during 2005-2006. This situation does not reflect necessarily the situation of major power producers on this sector, such as E.ON or RWE, which recorded a net *short* position as we will detail in Chapter 3. Our analysis thus needs to be complemented by the investigation of trading activity at the firm-level.

Conclusion

The EUA price collapse that occurred on April, 2006 showed evidence that when the cap is not stringent enough, emissions trading schemes do not necessarily guarantee a carbon price high enough to provide incentives to reduce CO_2 emissions. Indeed, during Phase I of the EU ETS, the stringency of the cap did not appear sufficient for market agents, and consequently the price collapsed. This particular episode of the EU ETS highlights the necessity to understand the underlying mechanisms of carbon price changes. Theoretical studies clearly identified three types of carbon price fundamentals: institutional design issues, energy prices and temperatures events. The empirical analysis of the daily spot carbon price conducted in this Chapter evaluates the impact of these fundamentals during the EU ETS pilot phase (2005-07), and besides the influence of the institutional context.

We have identified in the first section that energy prices, temperatures events and institutional information variables as EUA carbon price drivers during 2005-2007. We have highlighted that the influence of these fundamentals varies between the time periods under consideration, *i.e. before* and *after* two structural breaks statistically identified.

The analysis of EU ETS price drivers is taken one step further in the second section 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. To our best knowledge, this second section constitutes the first attempt to test the empirical relationship between the evolution of industrial production and EUA price changes. After having detailed both the expected effect of the variation of industrial production in EU ETS sectors and emissions compliance on EUA price changes, we have shown that at the aggregated EU 27-level, the variation of industrial production for three among nine sectors had a significant effect on EUA price changes from July 1, 2005 to April 30, 2007. These sectors are combustion, iron and paper and total 78% of allowances allocated.

The third section investigates *at the country-level* the effects of the variation of industrial production on EUA price changes. Our econometric specification captured the effects of production peaks and compliance positions in two sectors that were significant at the EU 27 level, *i.e.* combustion and iron. This study confirms the impact of the variation of industrial production on EUA price changes in four countries (Germany, Spain Poland and the UK), and underlines the central role played by German power producers on the EU ETS.

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).

Linked to the influence of political, energy, climatic and economic uncertainties on EUA price changes developed in Chapter 2, we study in Chapter 3 risk-hedging strategies on the EU ETS.

Appendix to Chapter 2

Appendix B

2.1 Price Drivers and Structural Breaks in European Carbon Prices 2005-07

Full Period	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
Clean Dark	0.01	-0.07	16.05	-11.70	2.09	1.09	19.83	483
Clean Spark	0.01	0.15	13.56	-19.34	3.18	-0.99	10.89	483

Table 2.1: Descriptive Statistics

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
Energy model[a]	0.0000	112.1917
"After the compliance break" period	Probability	F-statistic
Energy model[b]	0.0316	16.8623

Table 2.2: Chow Breakpoint Test statistics

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

[b]: Results for breakpoint on October 25, 2006.

	Full Period		
	Eq.(2.1)	Eq.(2.1)	Eq.(2.2)
	(1)	(2)	(3)
Constant	0.0013	0.0006	0.0005
	(0.0026)	(0.0023)	(0.0024)
Break 1	-0.0175***	-0.0165***	-0.0125***
	(0.0057)	(0.0054)	(0.0049)
Break 2	-	-	-
Brent	-	-	-
Natural Gas	0.0732**	0.0730***	0.0736**
	(0.0305)	(0.0300)	(0.0306)
Coal	-0.0978**	-0.0999**	-0.1018**
	(0.0470)	(-0.0471)	(0.0471)
Switch	-	-	-
Electricity	0.0082***	0.0083***	0.0079***
	(0.0027)	(0.0027)	(0.0027)
Clean Dark	-0.0527***	-0.0525***	-0.0526***
	(0.0148)	(0.0146)	(0.0148)
Clean Spark	0.0396**	0.0394**	0.0398**
	(0.0169)	(0.0167)	(0.0170)
Tempext5	-0.0097		
	(0.0068)		
Tempext95	0.0056		
	(0.0663)		
Win06			-
Win07			-0.0074**
			(0.0035)
R-squ.	0.3560	0.3543	0.3694
Adj. R-squ.	0.3407	0.3417	0.3558
F-Stat	0.0000	0.0000	0.0000
D.W.	1.8944	1.8892	1.8900
LM test	0.1277	0.1155	0.1472
White test	0.0002	0.0001	0.0000
AIC	-3.2974	-3.3030	-3.3226
SC	-3.1920	-3.2153	-3.2260
Procedure	NW OLS	NW OLS	NW OLS

Table 2.3: Full Period Results

*** indicates significance at 1%, ** at 5% and * at 10%. Standard errors in parenthesis. The values reported for F-stat are the p-values. The procedure NW OLS means an estimation by ordinary least squares using the Newey West Heteroscedastic Consistent Covariance Matrix (HCCM), which corrects residuals to adjust for both heteroskedasticity and autocorrelation.

	"Before the break" Period	*compliance*
	Eq.(2.1) (4)	Eq.(2.2) (5)
Constant	-0.0004	-0.0005
	(0.0018)	(0.0018)
Brent(-1)	0.0030**	0.0030**
	(0.0015)	(0.0015)
Natural Gas	-	-
Coal	-	-
Switch	0.0004**	0.0004**
	(0.0002)	(0.0002)
Electricity	0.0013**	0.0013**
	(0.0005)	(0.0005)
Clean Dark	-	-
Clean Spark	-	-
Tempext5	0.0073**	
	(0.0037)	
Tempext95	-0.0018	
	(0.0064)	
Win06		0.0018*
		(0.0011)
R-squ.	0.1346	0.1327
Adj. R-squ.	0.1047	0.1072
F-Stat	0.0000	0.0000
D.W.	1.9404	1.9257
LM test	0.4861	0.2906
White test	0.1635	0.1513
AIC	-4.6703	-4.6777
SC	-4.5433	-4.5665
Procedure	NW OLS	NW OLS

Table 2.4: "Before the compliance break" Period Results

*** indicates significance at 1%, ** at 5% and * at 10%. Standard errors in parenthesis. The values reported for F-stat are the p-values. The procedure NW OLS means an estimation by ordinary least squares using the Newey West Heteroscedastic Consistent Covariance Matrix (HCCM), which corrects residuals to adjust for both heteroskedasticity and autocorrelation.

	"After the compliance break"	
	Eq.(2.1) (6)	Eq.(2.2) (7)
Constant	-0.0040	-0.0094**
	(0.0031)	(0.0038)
Break 2	-0.0129*	-
	(0.0068)	
Brent	0.0107***	0.0106***
	(0.0035)	(0.0034)
Natural Gas	-	-
Coal	-	-
Switch	0.0089*	0.0090*
	(0.0051)	(0.0054)
Electricity	0.0089***	0.0079***
	(0.0024)	(0.0022)
Clean Dark	-0.0293***	-0.0283***
	(0.0103)	(0.0108)
Clean Spark	0.0169*	0.0173
	(0.0103)	(0.0110)
Tempext5	-0.0302***	
	(0.0090)	
Tempext95	-0.0031	
	(0.0060)	
Win06		-
Win07		-0.0042**
		(0.0017)
R-squ.	0.2586	0.2673
Adj. R-squ.	0.2188	0.2353
F-Stat	0.0000	0.0000
D.W.	1.9829	1.9735
LM test	0.9962	0.9570
White test	0.0005	0.0003
AIC	-2.9672	-2.9975
SC	-2.7803	-2.8418
Procedure	NW OLS	NW OLS

Table 2.5: "After the compliance break" Period Results

*** indicates significance at 1%, ** at 5% and * at 10%. Standard errors in parenthesis. The values reported for F-stat are the p-values. The procedure NW OLS means an estimation by ordinary least squares using the Newey West Heteroscedastic Consistent Covariance Matrix (HCCM), which corrects residuals to adjust for both heteroskedasticity and autocorrelation.

	Jun06-Oct06	*Oct06-Apr07*	
	Eq.(2.1,2.2)	Eq.(2.1)	Eq.(2.2)
	(8)	(9)	(10)
Constant	-0.0021	-0.0149**	-0.0117*
	(0.0021)	(0.0070)	(0.0070)
Brent	0.0072**	0.0139**	0.0137**
	(0.0033)	(0.0058)	(0.0056)
Natural Gas	-	-	-
Coal	-	-	-
Switch	-	0.0100**	0.0097*
		(0.0051)	(0.0053)
Electricity	-	0.0110***	0.0095***
		(0.0030)	(0.0029)
Clean Dark	-	-0.0300***	-0.0279***
		(0.0103)	(0.0106)
Clean Spark	-	0.0144*	0.0144
		(0.0085)	(0.0090)
Tempext5	-	-0.0269***	
		(0.0096)	
Tempext95	-	-	
Win07	-		-0.0035*
			(0.0018)
R-squ.	0.1532	0.2544	0.2656
Adj. R-squ.	0.1336	0.1975	0.2096
F-Stat	0.0000	0.0000	0.0000
D.W.	1.9745	1.9641	1.9604
LM test	0.2951	0.9600	0.7492
White test	0.0358	0.4850	0.4262
AIC	-4.7598	-2.4968	-2.5119
SC	-4.6759	-2.2734	-2.2891
Procedure	NW OLS	NW OLS	NW OLS

Table 2.6: Sub-Periods Results

*** indicates significance at 1%, ** at 5% and * at 10%. Standard errors in parenthesis. The values reported for F-stat are the p-values. The procedure NW OLS means an estimation by ordinary least squares using the Newey West Heteroscedastic Consistent Covariance Matrix (HCCM), which corrects residuals to adjust for both heteroskedasticity and autocorrelation.

	Full Period		*”After the compliance break” Period*
	Eq.(2.1)	Eq.(2.2)	Eq.(2.2)
Constant	-0.0095***	-0.0095***	-0.0070***
	(0.0004)	(0.0005)	(0.0025)
Break 1	0.0081***	0.0084***	
	(0.0026)	(0.0010)	
Break 2	-	-	-
Brent	-	-	0.0056***
			(0.0019)
Natural Gas	0.1345***	0.1349***	-
	(0.0050)	(0.0033)	
Coal	-0.1928***	-0.1929***	-
	(0.0077)	(0.0108)	
Switch	-	-	0.0137***
			(0.0012)
Electricity	0.0010***	0.0011***	0.0067***
	(0.0004)	(0.0004)	(0.0021)
Clean Dark	-0.0761***	-0.0763***	-0.0377***
	(0.0025)	(0.0014)	(0.0039)
Clean Spark	0.0748***	0.0750***	0.0283***
	(0.0027)	(0.0018)	(0.0025)
Tempext5			
Tempext95			
Win06		-	
Win07		-0.0069**	-0.0083***
		(0.0030)	(0.0032)
R-squ.	0.1397	0.1782	0.2065
Adj. R-squ.	0.1173	0.1549	0.1598
F-Stat	0.0000	0.0000	0.0000
D.W.	1.4389	1.4979	1.7372
AIC	-4.2763	-4.2815	-3.4599
SC	-4.1621	-4.1586	-3.2574
Procedure	GARCH	GARCH	GARCH

Table 2.7: Robustness GARCH(1,1) Estimates

*** indicates significance at 1%, ** at 5% and * at 10%. Standard errors in parenthesis. The values reported for F-stat and ARCH LM test are the p-values.

2.2 The EU Emissions Trading Scheme: Disentangling the Effects of Industrial Production and CO_2 Emissions on Carbon Prices

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 sulphide 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.

Table 2.8: The Decomposition of Industrial Sectors in the EU ETS from the EU Directive 2003/87/CE, Annex I

CITL Activities	Annual growth rate in 2005	Annual growth rate in 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%

Table 2.9: Industrial Production Growth for EU ETS Sectors in 2005-2006 from Eurostat

CITL Activities	Allowances in 2005	Emissions in 2005	Compliance in 2005†	Allowances in 2006	Emissions in 2006	Compliance in 2006†	Number of installations in 2006
1. Combustion	1465.6	1456.9	0.6%	1438.3	1459.8	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 steel	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

Table 2.10: Total Allowance Allocations ($MtCO_2$), Emissions Level ($MtCO_2$) and Compliance Positions (in %) on the EU ETS during 2005-2006 from the CITL, National Registries, NAPs, Trotignon et al. (2008)

* 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)).

†The compliance ratio (in %) is computed as $\frac{Allowances_j - Emissions_j}{Allowances_j}$ where $j = \{2005, 2006\}$.

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

Table 2.11: EU ETS Sector Decomposition and NACE Rev.1 C-F Classification System from Eurostat

	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
Obs.	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	-0.0965	-0.0889
Kurt.	2.5970	3.2708	3.0847	2.5930	6.4709	3.8076	3.0601	2.6643	3.4918
Obs.	481	481	481	481	481	481	481	481	481

Table 2.12: Descriptive Statistics

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

	Elecsect	Iron	Paper	Ceramics	Refineries	Cement	Glass	Metal	Coke
Elecsect	1								
Iron	0.0747	1							
Paper	0.2250	0.4628	1						
Ceramics	0.2307	0.0148	0.4086	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 2.13: Matrix of Cross-Correlations Between Sector Production Variables

	(1a)	(1b)	(2a)	(2b)	(3)	(4)
Constant	-0.0104***	-0.0104***	-0.0131***	-0.0132***	-0.0108***	-0.0083***
	(0.0006)	(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)		
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***
						(0.0014)
R-squ.	0.1746	0.1796	0.1394	0.1851	0.1143	0.0625
Adj. R-squ.	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

Table 2.14: Results of eq.(2.3),(2.4) Estimates for the TGARCH(1,1) Model

*** indicates significance at 1%, ** at 5% and * at 10%. Standard errors in parenthesis. The values reported for F-stat and ARCH LM test are the p-values. The model TGARCH(1,1) estimated is:
$\sigma_t = \alpha_0 + \alpha^+ \ (L) \ \epsilon_t^+ - \alpha^- \ (L) \ \epsilon_t^- + \beta \ (L) \ \sigma_t$, with $\epsilon_t^+ = max(\epsilon_t, 0)$ and $\epsilon_t^- = min(\epsilon_t, 0)$. ϵ_t^+ and ϵ_t^- allow to take into account asymmetric effects.

2.3 EU Emissions Compliances and Carbon prices: A Country-specific Analysis of Industrial Sectors

		Combustion		Iron	
		2005	2006	2005	2006
EU 25	Allowances[a]	68,70%	68,41%	8,01%	8,02%
	Compliance[a]	0,55%	-2,42%	20,48%	16,29%
	Production[b]	5,87%	-4,93%	0,62%	6,64%
Germany	Allowances[c]	27,00%	27,00%	20,00%	20,00%
	Compliance[d]	2,28%	2,21%	9,16%	4,65%
	Production[a]	7,92%	-8,13%	1,65%	12,72%
Spain	Allowances	7,00%	7,00%	7,00%	7,00%
	Compliance	-16,08%	-19,90%	29,39%	29,11%
	Production	4,90%	-1,83%	0,99%	-0,13%
France	Allowances	3,00%	3,00%	17,00%	17,00%
	Compliance	23,37%	26,61%	6,66%	3,75%
	Production	2,39%	-5,54%	-3,46%	2,29%
Italy	Allowances	9,00%	9,00%	8,00%	8,00%
	Compliance	-8,01%	-20,25%	6,26%	-9,47%
	Production	12,95%	-9,36%	-0,24%	5,42%
Poland	Allowances	14,00%	14,00%	8,00%	8,00%
	Compliance	9,87%	8,28%	60,60%	51,88%
	Production	4,44%	-6,05%	-3,81%	17,75%
UK	Allowances	11,00%	11,00%	4,00%	4,00%
	Compliance	-24,30%	-29,74%	0,08%	1,32%
	Production	2,24%	-2,82%	7,54%	3,03%

Table 2.15: Industrial Production Growth for the Combustion and Iron Sectors in 2005-2006

[a]: Figures of Allowances and Compliance are computed in 2005 and 2006 at the level of EU 25 (Romania and Bulgaria came in the EU ETS in 2007).

[b]: The growth rate of sector production is computed at the EU 25 level.

[c]: Allowances are the national share in the total Allowances Allocated (in Mt CO_2) at the sector in the EU 25.

[d]: The compliance ratio (in %) is computed as $\frac{Allowances_j - Emissions_j}{Allowances_j}$ where $j = 2005, 2006$.

	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
Obs.	481	481	481	481	481	481

	Combde	*Combes*	*Combfr*	*Combit*	*Combpl*	*Combuk*
Mean	-0.0001	0.0311	-0.0249	0.0099	0.0173	-0.0059
Median	-0.0037	0.0232	-0.0070	0.0254	0.0092	-0.0055
Max	0.3492	0.3698	0.3775	0.4012	0.2577	0.3131
Min	-0.3037	-0.3269	-0.4534	-0.2906	-0.1383	-0.2768
Std. Dev.	0.1351	0.1882	0.1678	0.1562	0.0833	0.1164
Skew.	0.1650	0.0523	-0.1617	0.2094	0.6397	0.2433
Kurt.	3.0654	2.0194	3.0986	2.5803	3.3615	3.5986
Obs.	481	481	481	481	481	481

	Ironde	*Irones*	*Ironfr*	*Ironit*	*Ironpl*	*Ironuk*
Mean	0.0060	-0.0181	-0.0005	-0.0238	-0.0228	0.0053
Median	0.0264	-0.0022	-0.0047	-0.0275	-0.0525	-0.0068
Max	0.2856	0.2927	0.2066	0.5622	1.1582	0.4569
Min	-0.3480	-0.3994	-0.2647	-0.4912	-1.1954	-0.4469
Std. Dev.	0.1265	0.1606	0.1074	0.2247	0.4427	0.1737
Skew.	-0.4136	-0.2432	-0.3145	0.0664	0.2067	0.1333
Kurt.	3.2094	2.4634	2.5366	2.8674	3.3914	3.0447
Obs.	481	481	481	481	481	481

Table 2.16: Descriptive Statistics

p_t is the first log-differenced EUA price series, all energy variables and sector production indices transformed in forecast errors, $StdDev.$ the standard deviation, $Skew.$ the skewness, $Kurt.$ the kurtosis and N the number of observations.

	Combde	*Combes*	*Combfr*	*Combit*	*Combpl*	*Combuk*	*Ironde*	*Irones*	*Ironfr*	*Ironit*	*Ironpl*	*Ironuk*
Combde	1											
Combes	-0.0801	1										
Combfr	0.0432	-0.0602	1									
Combit	0.2990	0.5215	0.2662	1								
Combpl	0.4486	0.3464	-0.1204	0.3746	1							
Combuk	0.1839	0.0126	0.6482	0.1747	0.2719	1						
Ironde	-0.0818	0.1920	-0.0562	-0.4216	0.1138	0.3357	1					
Irones	-0.0719	-0.3094	0.3853	-0.1246	-0.1844	0.0963	-0.2087	1				
Ironfr	-0.0813	0.0055	0.1124	0.0369	-0.1823	-0.1309	0.1261	0.1507	1			
Ironit	-0.0604	-0.6104	0.1245	-0.0997	-0.1195	-0.0075	-0.5787	-0.2901	0.3416	1		
Ironpl	-0.0924	0.0929	0.5003	-0.0994	0.0364	0.6073	0.3063	0.0613	-0.2603	0.2039	1	
Ironuk	0.6408	0.0218	-0.0445	0.1615	0.3265	0.2732	0.0668	-0.0245	-0.1590	-0.0342	0.0020	1

Table 2.17: Matrix of Cross-Correlations Between Sector Production Variables Transformed To Forecast Errors in the Combustion and Iron Sectors for Germany, Spain, France, Italy, Poland and the UK

	(1)	(2a)	(2b)	(3)	(4)	(5)	(6)
Constant	-0.0105***	-0.0131***	-0.0132***	-0.0076***	-0.0099***	-0.0116***	-0.0135***
	(0.0007)	(0.0006)	(0.0006)	(0.0005)	(0.0006)	(0.0007)	(0.0006)
Break	-	-	-	-	-0.0024**	0.0091***	0.0100***
					(0.0011)	(0.0013)	(0.0014)
Psq	0.0003***	0.0004***	0.0004***	0.0005***	0.0008***	0.0014***	0.0005***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
Natural Gas	0.1309***	0.1343***	0.1344***	0.1418***	0.1344***	0.1433***	0.1388***
	(0.0027)	(0.0029)	(0.0030)	(0.0024)	(0.0028)	(0.0033)	(0.0036)
Coal	-0.1795***	-0.1840***	-0.1842***	-0.1922***	-0.1912***	-0.2052***	-0.1956***
	(0.0087)	(0.0076)	(0.0077)	(0.0093)	(0.0111)	(0.0100)	(0.0065)
Electricity	0.0011***	0.0008***	0.0010***	0.0009**	0.0017***	0.0017***	0.0009**
	(0.0004)	(0.0003)	(0.0003)	(0.0004)	(0.0004)	(0.0004)	(0.0004)
Clean Dark	-0.0740***	-0.0756***	-0.0758***	-0.0789***	-0.0769***	-0.0818***	-0.0782***
	(0.0013)	(0.0014)	(0.0015)	(0.0011)	(0.0011)	(0.0017)	(0.0016)
Clean Spark	0.0730***	0.0749***	0.0749***	0.0790***	0.0744***	0.0800**	0.0775***
	(0.0015)	(0.0016)	(0.0017)	(0.0014)	(0.0016)	(0.0018)	(0.0020)
Win07	-0.0059***	-0.0263***	-0.0259***	-0.0046*	-0.0168***	-0.0094*	-0.0080***
	(0.0023)	(0.0018)	(0.0017)	(0.0027)	(0.0019)	(0.0028)	(0.0028)
Combustion	-0.0548***	-0.0671***	-0.0678***				
	(0.0058)	(0.0057)	(0.0060)				
Iron	-0.0302***						
	(0.0057)						
Combpeak		0.0195***	0.0513***				
		(0.0019)	(0.0021)				
Combcompl		0.0051***	0.0063***				
		(0.0012)	(0.0012)				
Combpeakcompl			-0.0345***				
			(0.0029)				
Combde				-0.0250***			
				(0.0048)			
Combpeakde				0.0102***			
				(0.0015)			
Combes					0.0131***		
					(0.0035)		
Combpeakes					0.0288***		
					(0.0019)		
Combpl						0.1285**	
						(0.0068)	
Combpeakpl						0.0068**	
						(0.0015)	
Combuk							-0.0215***
							(0.0039)
Combpeakuk							0.0089***
							(0.0013)
R-squ.	0.2060	0.1394	0.1851	0.1544	0.2034	0.1464	0.1611
Adj. R-squ.	0.1782	0.1073	0.1529	0.1248	0.1737	0.1146	0.1298
F-Stat	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Log-Likelihood	1058.415	1091.737	1104.632	1045.744	1065.211	1057.119	1059.990
ARCH LM Test	0.3020	0.3812	0.4285	0.6016	0.3644	0.5402	0.2001
AIC	-4.3942	-4.5305	-4.5807	-4.3407	-4.4186	-4.3845	-4.3966
SC	-4.2449	-4.3725	-4.4139	-4.1915	-4.2606	-4.2264	-4.2386

Table 2.18: Results of eq.(2.3),(2.4),(2.5) Estimates for the Combustion Sector at Country-Level

	(7)	(8)	(9)	(10)	(11)
Constant	-0.0108***	-0.0039***	-0.0135***	-0.0116***	-0.0109***
	(0.0008)	(0.0004)	(0.0009)	(0.0007)	(0.0008)
Break	-	0.0021*	0.0064***	0.0048***	0.0036***
		(0.0012)	(0.0014)	(0.0011)	(0.0014)
Psq	0.0005***	0.0005***	0.0011***	0.0004***	0.0008***
	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0001)
Natural Gas	0.1371***	0.1368***	0.1403***	0.1353***	0.1352***
	(0.0026)	(0.0023)	(0.0035)	(0.0031)	(0.0028)
Coal	-0.1872***	-0.1911***	-0.2111***	-0.1877***	-0.1952***
	(0.0062)	(0.0054)	(0.0078)	(0.0089)	(0.0090)
Electricity	0.0010***	0.0010***	0.0014***	0.0008**	0.0014***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Clean Dark	-0.0776***	-0.0773***	-0.0801***	-0.0761***	-0.0770***
	(0.0013)	(0.0011)	(0.0019)	(0.0015)	(0.0013)
Clean Spark	0.0765**	0.0764***	0.0780***	0.0756***	0.0752***
	(0.0014)	(0.0013)	(0.0020)	(0.0017)	(0.0015)
Win07	-0.0266*	-0.0080***	-0.0062***	-0.0067*	-0.0204***
	(0.0062)	(0.0029)	(0.0024)	(0.0029)	(0.0019)
Iron	-0.0226***				
	(0.0062)				
Ironpeak	0.0085***				
	(0.0008)				
Ironde		-0.0322***			
		(0.0040)			
Ironpeakde		-0.0132***			
		(0.0008)			
Irones			-0.0180***		
			(0.0041)		
Ironpeakes			0.0073***		
			(0.0010)		
Ironpl				-0.0040***	
				(0.0009)	
Ironpeakpl				0.0095***	
				(0.0009)	
Ironuk					-0.0226***
					(0.0047)
Ironpeakuk					0.0123***
					(0.0014)
R-squ.	0.1143	0.1940	0.1709	0.1913	0.1800
Adj. R-squ.	0.0832	0.1639	0.1400	0.1611	0.1494
F-Stat	0.0000	0.0000	0.0000	0.0000	0.0000
Log-Likelihood	1069.825	1055.716	1058.288	1065.738	1068.094
ARCH LM Test	0.5576	0.4741	0.3419	0.4527	0.2374
AIC	-4.4423	-4.3786	-4.3894	-4.4208	-4.4308
SC	-4.2931	-4.2205	-4.2314	-4.2628	-4.2723

Table 2.19: Results of eq.(2.3),(2.4),(2.5) Estimates for the Iron Sector at EU 25 and Country-Level

Chapter 3

Risk hedging strategies

Introduction

Chapter 3 deals with risk hedging strategies, based on political, economic or financial uncertainties. Since January 1, 2005 investors need to manage the risk of holding of allowance of CO_2 on the European carbon market among a portfolio of diversified investment. Investors naturally attempt at hedging against a variation of the risk attached to allowance trading, especially given the institutional features of this market.

In the first section, we evaluate the impact of the 2006 compliance event on changes in investors' risk aversion on the European Carbon Market using the newly available option prices dataset. Thus, we aim at capturing the specific event that occurred on April 2007 as the European Commission disclosed the 2006 verified emissions data. Following the methodology existing for stock indices, we recover empirically risk aversion adjustments on the period 2006-2007 by estimating first the risk-neutral distribution from option prices and second the actual distribution from futures on the European Climate Exchange. Our results show evidence of a dramatic change in the market perception of risk around the 2006 yearly compliance event that has not been assessed yet.

The second section stems from the view that the well known economic advantage of tradable permits over command and control obviously vanishes if firms do not trade because of regulatory uncertainty. In fact, uncertainty about political decision changes in the permits program could make firms reluctant to participate in tradable permits markets. With reference to the insights developed in Chapter 1, our results suggest that the banking provisions may be used as a tool of policy risk control and that it is possible to define optimal risk sharing rules in order to respond to political decision changes. Finally, our empirical discussion attempts to put the theoretical results concerning firms' banking and pooling behaviors in the context of the recent development of the EU ETS.

3.1 Risk Aversion and Institutional Information Disclosure on the European Carbon Market: a Case-Study of the 2006 Compliance Event

We focus in this first section on the role of information revelation by the regulator, and its role in the formation of investors' anticipations. The EU ETS Review[1] indeed pointed out the necessity for the EC to act more as the central authority entitled to set firmly emissions caps for Phase II and to restore the scarcity of allowances equally among sectors, including the sectors that will be included in the scheme in Phase III[2].

The role of coordinator, educator and enforcer played by the EC is central to the analysis of investors' risk aversion developed in this section. At the start of the EU ETS, most of the information available for trading was deemed as speculative. Consequently, we attempt to characterize investors' hedging strategies for this new carbon commodity by asking the following central question: can we statistically identify a shift in investors' risk aversion around the 2006 yearly compliance event imposed by the EC? The publication of 2006 emissions data by the EC is indeed central to the analysis developed in this paper since it constitutes

---

[1] Available at *http : //ec.europa.eu/environment/climat/emission/reviewen.htm*. Cited February, 2008.

[2] More particularly, the aviation and petro-chemicals sectors as of 2013.

the only observable compliance event to date since the launch of carbon derivatives products[3].

To our best knowledge, this analysis constitutes the first tentative assessment of risk behavior on the EU ETS since it is based on newly available plain vanilla European option prices data which transfer the risk of financial exposure between market agents. (146) describe extensively derivative instruments on the EU carbon market based on qualitative surveys. (38) provide an application of CO_2 price dynamics modelling to option pricing, but their empirical application is only based on numerical simulations. Our study gathers a sample of option prices and futures going from October, 2006[4] to November, 2007 from the European Climate Exchange.

We retrieve empirically investors' risk aversion on the EU carbon market based on the relationship that exists with the risk-neutral and historical probabilities as detailed by (89)[5]. We base our analysis on non-parametric kernel regression ((1), (43)) to estimate the risk-neutral probability distribution and on an asymmetric GARCH model to estimate the historical probability distribution ((131)). Such an approach proved to be useful in documenting changes in implied risk aversion for major equity indices.

Our results may be summarized as follows. First, we uncover a shift in the level of risk aversion on the EU ETS following the publication of 2006 verified emissions data by the EC on April 30, 2007. Second, we observe lower levels of volatility for contracts of maturity December 2008 and December 2009 during the time period after the 2006 compliance event. This latter result suggests that institutional information disclosure has a strong market effect. Third, our results indicate periods of increasing markets coincide with periods of higher volatility.

---

[3] Note that, due to to data limitation, the early publication of 2007 compliance data by the EC on April 2, 2008 does not constitute a possible event to investigate. Indeed, we need a sample of several months after this result to adequatly capture the changes in risk aversion related to the compliance event.

[4] *i.e.* at the start of this carbon derivatives trading on this platform.

[5] Note our methodology to recover risk aversion from option and futures prices slightly differs from (89). Indeed, in the latter paper, the analysis is carried out on a monthly basis. Since our dataset covers 13 months, we prefer to work instead with a daily frequency.

This inverted leverage effect reveals that, contrary to equity markets, the risk is associated with *increasing* allowance prices when trading carbon derivatives *after* the 2006 compliance event. This situation may be explained by the context of a low environmental constraint (and associated low allowance prices) on the EU ETS.

Expectation building is becoming more efficient on the EU carbon market since market agents gradually integrate accurate information published by the EC concerning the level of CO_2 emissions compared to allocated allowances, be it at the installation or aggregated levels. Thus, we highlight the role played by the regulator during the 2006 compliance event in changing market participants' expectations concerning amendments of the scheme.

The remainder of the paper is organized as follows. Section 3.1.1 discusses the expected investors' risk perception with respect to institutional design features of the EU ETS. Section 3.1.2 details the estimation methodology to recover the risk-neutral and historical probabilities from option and futures prices. Section 3.1.3 discusses the empirical results.

3.1.1 Risk Behavior on the EU Carbon Market

The characterization of risk behavior and risk management strategies on the emerging EU carbon market constitutes an important field of research for several reasons.

First, the rents distributed to existing incumbents on a "first-come, first-served" basis represents a market value of €40 billion that was created at the same time as CO_2 emissions were capped. This allocation methodology, also known as grandfathering, is the most frequently observed since the market determines the size and nature of property rights and there are less political pressures to implement the scheme. Its main benefits lie in the fact that it recognizes incumbents and specific non-deployable investments, rewards first-movers and economizes transaction costs. Since January 1, 2005 carbon allowances therefore form another asset in commodities against which industrials and brokers need to hedge. As the volume of transaction on the EU ETS has been increasing steadily from 262 million tons in 2005 to 1,443 million tons in 2007, this trading activity reflects market participants' progressive learning of this new financial market. Thus, we are interested in examining closely the formation of investors' risk appetite related to the diffusion of institutional information.

Second, during Phase I of the EU ETS (2005-2007), spot prices experienced a high level of volatility around each compliance event. Since industrial installations have the obligation to surrender to the EC the exact number of allowances that matches their verified emissions each year around end of March, this institutional compliance event may be used as the cornerstone of each major change in investors' risk aversion. The official report by the European Commission is disclosed by mid-May[6], but installation operators have already a fair amount of information between the publication of their own report and the compilation of verified emissions by the EC to approximate the global level of emissions relative to allowances allocated and to adjust their anticipations. The visual inspection of the data in Figure 3.1 reveals a sharp price break for spot and futures price series of all maturities during the 2005 compliance event[7]. As displayed in Figure 3.1, by the end of April 2006, this price correction of 54% within four days followed the announcement by the EC that CO_2 emissions were approximately 3% lower than the allocated allowances during the 2005 compliance period ((59)).

This particular kind of institutional event led to abrupt changes in investors' preferences and risk hedging strategies that we aim at capturing in this paper. Since the recent creation of the EU allowance market on January 2005, the 2006 compliance event constitutes the only observable compliance event to date. Indeed, the European Climate Exchange launched on October 2006 derivatives products trading carbon allowances as the underlying asset.

---

[6] Indeed, the EC is bound by law to publish the compliance result on May 15 of each year at the latest (see Directive 2003/87/CE)This time to maturity has been chosen in order to make the results comparable for the December 2008 and December 2009 contracts. We tested for other values of τ and our results remained qualitatively unchanged. Thus, we decided to stick to this approach to ease the presentation of the results. Note smaller values of τ should not be used because of the average maturity of the options in the dataset.

[7] Note we carry in Section 3.1.4 a more rigorous statistical analysis based on tests of structural breaks in the data.

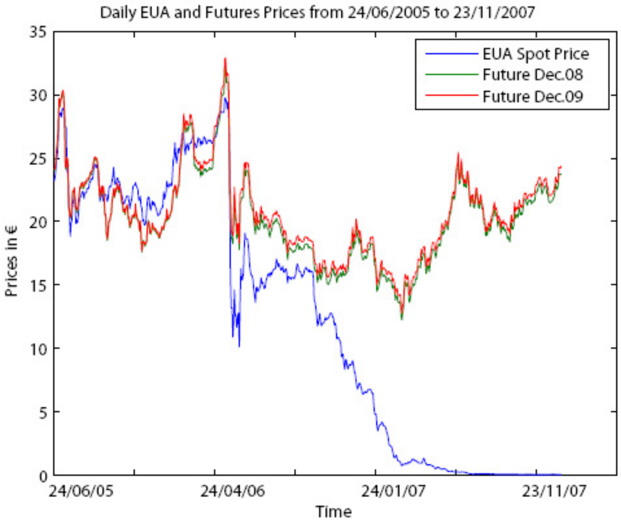

Figure 3.1: Daily EUA Prices, Futures Dec.08 and Dec.09 Contracts from June 24, 2005 to November 23, 2007 from BlueNext and the European Climate Exchange

Third, carbon allowances exhibit strong characteristics of being a nonstandard commodity ((122)), since installations do not need to physically hold allowances to produce but only to match them with verified emissions for their yearly compliance report to the EC. Consequently, the probability of a potential illiquidity trap exists if market participants face a market squeeze during the compliance event. Another specificity of emission allowances may be highlighted: compared to stocks which are valid during the entire lifetime of the firm, emissions allowances are vintaged for a given compliance year and cannot be used for future compliance periods, unless intertemporal flexibility mechanisms are authorized. During Phase I of the EU ETS, the inter-period transfer of allowances has been restricted by all Member-States[8]. These specificities of EU allowances, as well as the potential high level of uncertainty attached to the trading of such a new commodity, add another line of argument to justify our specific interest in the formation of risk aversion and purchasing strategies by market participants around the 2006 compliance event.

It appears interesting to highlight for the purpose of this study that, around

---

[8] See Alberola and Chevallier (2007) for an extensive discussion on this topic.

each yearly publication of verified emissions results by the EC, investors' anticipations with respect to risk are changing. Indeed, despite its recent creation, (136) emphasize that most market agents[9] are attempting to estimate accurately CO_2 emissions levels and abatement efforts on the EU ETS. In what follows, we test the hypothesis that strong reversals in investors' anticipations occur during the 2006 compliance event[10]. Moreover, we expect the level of volatility to decrease after the diffusion of information by the EC which tends to dissipate previously misleading trading information on this new market.

In this section, the discussion on EU allowance characteristics in terms of trading patterns and price developments leads us to argue that institutional information disclosure by the EC has a clear effect on adjustments in risk behaviors since it provides reliable market updates on agents' positions in terms of actual CO_2 emissions with respect to allocated allowances. In the next section, our estimation strategy is detailed to identify statistically those changes in investors' risk aversion that are expected to occur around the 2006 compliance event.

3.1.2 Estimation Methodology

As presented in (15), there are several ways to deal with the risk aversion estimation problem. Absolute risk aversion can be expressed in terms of the historical and risk-neutral probability distributions ((1), (89), (131))[11]:

$$RA(x) = \frac{f'(x)}{f(x)} - \frac{q'(x)}{q(x)} \tag{3.1}$$

where $q(x)$ is the risk neutral density, and $f(x)$ is the historical density across states. It is easy to see that once two of them are known, the third one is readily available as a by-product. Here, we have at hand enough data to estimate both

---

[9] And not only large market players such as power producers, who were more constrained.

[10] Note that it is not possible to test for shifts in investors' risk aversion during the 2005 compliance event due to data limitation on the availability of option prices, but we expect lower effects on April 2007 compared to the magnitude of EUA price changes on April 2006.

[11] See the Appendix C for a review of the relationships between risk aversion and the risk-neutral and historic distributions in the literature on pricing kernels.

the risk neutral and historical distributions without making assumption about the shape of investors' risk appetite. Thus, risk aversion will be deduced from our estimation of the risk neutral and historical probability measures. Following the terminology established in (15), this approach fits the "Risk-Neutral Constrained Direct Modelling" strategy, *i.e.* we make limited assumption on the risk neutral and historical distributions and no assumption on the pricing kernel. For estimation purposes, we need to keep in mind that this pricing kernel usually depends on numerous state variables, such as consumption, industrial production or more specific economic aggregates. Given this possible very high number of state variables, the usual approach to pricing kernel estimation dwells on the selection of a single appropriate state variable. This variable is selected for its explanatory power: the projection of any relevant factor in the subspace spanned by this variable should maintain as much information as possible regarding risk aversion. The usual variable that is retained now in the literature is the stock index itself whose dynamics actually reveals a lot about the changes in market sentiments. The estimated pricing kernel is then referred to as the "projected pricing kernel"[12]. On this point, see (42) and the discussion supplied in (131). Here, we thoroughly follow this approach.

Following (1), we estimate the risk neutral distribution non-parametrically, while the historical distribution is recovered from a semi-parametric GARCH procedure ((9), (131)). As explained above, from these estimates we will deduce an empirical estimate of risk aversion. This methodology will then allow us to investigate the empirical characteristics of investors' risk aversion on the European carbon market, along with its potential shifts around the 2006 compliance event.

Let us first detail how to recover both the risk-neutral and historical probability distributions.

---

[12] See also a review in the Appendix C.

Risk Neutral Probability Distribution

Under no arbitrage restrictions, the price of an European call is:

$$C(\tau, K) = B(\tau) \int_{-\infty}^{+\infty} (S_T - K)\ q(S_T)\ \mathrm{d}S_T = B(\tau)\ \mathbb{E}^Q\ [(S_\tau - K)^+] \tag{3.2}$$

where $C(\tau, K)$ is the premium for a call option of time to maturity τ and strike price K, S_T is the underlying asset price at the maturity date, and r is the risk-free interest rate. $B(\tau)$ is the price of a zero coupon bond with maturity τ, and represents the corresponding discount factor, *i.e.* $B(\tau) = e^{-r\tau}$. $\mathbb{E}^Q[.]$ denotes the expectation computed using the risk-neutral distribution. Following (34), we have:

$$\frac{\partial^2 C(\tau, K)}{\partial K^2} = B(\tau)\ q(S_T | S_T = K). \tag{3.3}$$

Equation (3.3) describes the formal relationship between the second derivative of the call price with respect to the strike price and the risk-neutral density. Since we are mostly interested in recovering the "average" pricing kernel in the option market, we propose to use (1) non parametric estimator to the risk neutral density. This estimator uses the link between implied volatility and the risk-neutral distribution: since both implied volatility and risk neutral distribution depend on the moneyness, it is possible to infer the risk neutral distribution from implied volatilities series. When $\sigma(K)$ is a function of the strike that is twice differentiable, using the Black-Scholes model and eq.(3.3) result, (5) showed that:

$$\begin{aligned} q(S_\tau | S_\tau = K) &= e^{r\tau} \frac{\partial^2 C}{\partial K^2} && (3.4) \\ &= \left(\frac{1}{\sigma(K) K \sqrt{\tau}} + \left(\frac{2d_1}{\sigma(K)} \right) \frac{\partial \sigma}{\partial K} + \left(\frac{d_1 d_2 K \sqrt{\tau}}{\sigma} \right) \left(\frac{\partial \sigma}{\partial K} \right)^2 + K\sqrt{\tau} \frac{\partial^2 \sigma}{\partial K^2} \right) N(d_1) && (3.5) \end{aligned}$$

For $\sigma(\tau, K)$ to be expressed as a function of the strike price, it may be estimated either parametrically with a polynomial[13] or non-parametrically. (1) recommend the use of a non parametric estimator of the volatility surface (see also (43)). This

---

[13] See (5) and (29).

estimator is particularly adapted to situations where we do not need a day-by-day estimator of this probability density function, but an estimator of the average risk neutral distribution over a large time period. This approach is close to what may be found in (89). We propose to use the non-parametric approach that also offers the advantage to be more robust to market anomalies which are very likely to occur on such a new commodity market. Thus, we introduce a non-parametric Nadaraya-Watson estimator with $k = \frac{K}{S}$ defined as the moneyness and τ fixed as in (43):

$$\sigma(k,\tau) = \frac{\sum_{i\ j} K\left(\frac{\tau-\tau_i}{h_1}\right)\ K\left(\frac{k-k_j}{h_2}\right)\ \sigma(\tau_i,k_j)}{\sum_{i\ j} K\left(\frac{\tau-\tau_i}{h_1}\right)\ K\left(\frac{k-k_j}{h_2}\right)} \tag{3.6}$$

with

$$K(x) = \frac{1}{\sqrt{2\pi}}\ e^{-\frac{1}{2}x^2} \tag{3.7}$$

the Gaussian kernel. $\{h_1, h_2\}$ are bandwidth parameters that determine the degree of smoothing. As pointed out by (43), too small values will lead to a bumpy surface while too large ones will smooth away important details. The method developed by (30) is used to obtain an optimal bandwith h. Once we have this non parametric estimator of implied volatility, we are able to derive it with respect to the strike price and then use it in eq. (3.5) to finally recover the risk neutral distribution for a given horizon τ. It is noteworthy to remark that this methodology imposes martingality restrictions as a by-product. These restrictions are essential to recover the risk neutral distribution ((93)).

We recall now how to obtain implied volatility series from option prices. Building on the previous notation, $C(\tau,K)_{obs}$ is the observed call option price and $C(\tau,K,\sigma)_{BS}$ is the Black-Scholes (BS) price computed using the implied volatility σ. By definition, we have $C(\tau,K)_{obs} = C(\tau,K,\sigma)_{BS}$. The implied volatility of the strike price is obtained by numerically inverting the BS formula, which can be done by solving:

$$\min_{\sigma} \left(C(\tau,K)_{obs} - C(\tau,K,\sigma)_{BS}\right)^2 \tag{3.8}$$

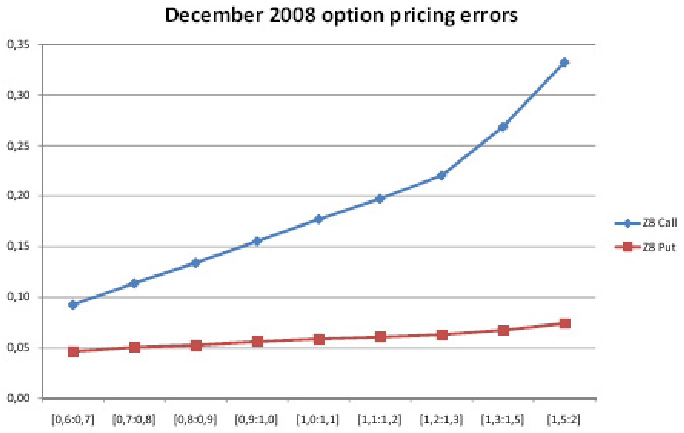

Figure 3.2: Option mispricing errors between the carbon market and the benchmark Black-Scholes option pricing model for December 2008 contract

Then, allowing σ to be a function of the strike price, we may use eq.(3.3) to recover the risk-neutral distribution.

Finally, we discuss the differences between actual market prices and prices calculated from Black-Scholes. Figures 3.2 and 3.3 display a comparison between option prices of maturity December 2008 and December 2009 exchanged on the carbon market, and the benchmark Black-Scholes option pricing model[14]. We compare the real market quotes with the Black-Scholes price computed using the at-the-money implied volatility. Figures 3.2 and 3.3 present the average absolute relative mispricing error obtained following this methodology[15]. We follow here the criterion presented in Barone Adesi et al. (2008). Let $C(t,K)$ be the real option price and $C(t,K)_{BS}$ be the corresponding Black Scholes price. Then, the Average Absolute Relative Mispricing Error (AARME) criterion presented here is:

$$AARME(K) = \sum_{t} \frac{|C(t,K) - C(t,K)_{BS}|}{C(t,K)} \qquad (3.9)$$

for a given moneyness K. The main intuition behind Figures 3.2 and 3.3

---

[14] Using the Average Absolute Relative Mispricing Error (AARME) criterion.

[15] The horizontal and vertical scales display, respectively, the moneyness and the AARME criterion as a function of moneyness.

Figure 3.3: Option mispricing errors between the carbon market and the benchmark Black-Scholes option pricing model for December 2009 contract

is that option prices on the carbon market lead to pricing errors that are usual for commodity or equity markets (see the results obtained by Barone Adesi et al. (2008)). The mispricing errors are mainly driven by the well-known smile problem that we are going to discuss below. We observe that the mispricing error increase with the moneyness. One interesting feature of these option pricing errors is that put deviations from Black-Scholes are less important than for calls. As we discuss it later, the main fear in the carbon market is that prices increase. On such a market, the easiest way to hedge again this risk is by selling calls: call option prices are more actively traded than puts. This situation is reflected in this deviation measure from the Black-Scholes model.

Next, we present our methodology to recover the historical distribution.

Historical Probability Distribution

There exists an emerging body of literature on the spot-futures parity in the EU ETS. (136) reveal a very steep spot price volatility increase when coming toward the end of the 2005 compliance period. (23) also pointed out that the term structure for allowance prices changed from initial backwardation to contango[16] and is

---

[16] Recall that a situation where futures prices are above current spot prices is called *contango*, and it is normally associated to a market where the supply is plentiful relative to demand.

subject to abrupt changes of expectations. As shown in Figure 3.1, this situation provides a first element of justification to use futures instead of spot prices series in our dataset.

On October 2006, following multiple EC announcements[17] to tighten allocation caps for Phase II, we observe a divorce between the EUA spot and futures price series as shown in Figure 1[18]. While the EUA spot price pattern was decreasing towards zero until December 2007, the EUA futures price series stabilized around €20 per ton. This price signal is currently sustained on the medium-term by the decision of the European Council to maintain the European carbon market at least until 2020. Thus, the futures price series seems to reflect better the dynamics behind investors' anticipations and hedging strategies, which explains why we have decided to work with futures instead of spot prices.

Since this divorce between spot and future price series, the *cash-and-carry* rationale based on the storage theory ((65), (66), (28), (127)) linking futures and spot prices does not seem to hold. To this purpose, we compute the spread between December 2008 and December 2009 futures contracts, discounted at the one year swap risk free rate, in Figure 3.4. This premium between the two futures contracts is not linear, but also subject to abrupt variations. This visual inspection of the data suggests that futures have a distinct behavior from spot prices.

This intuition is confirmed by a statistical test of the no-arbitrage relationship that should hold between spot and futures prices[19]. In Table 3.1 (see the Appendix C), the test statistics for the futures premium reveal that the null hypothesis of no spread between the December 2008 and December 2009 contracts is rejected at 1% significance level. This result proves statistically that the carry relationship does not hold and further strenghtens our approach to use futures instead of spot

---

Conversely, the situation where futures prices are below spot prices is known as *backwardation*, and it is generally associated to a market with a low supply.

[17] See for instance EC SPEECH/06/624 available at *http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/06/624&format=HTML&aged=1&language=EN&guiLanguage=en*. Cited January 2008.

[18] We provide a statistical analysis for this divorce between spot and futures price series in Section 3.1.2.

[19] See the Appendix C for a detailed explanation of this test.

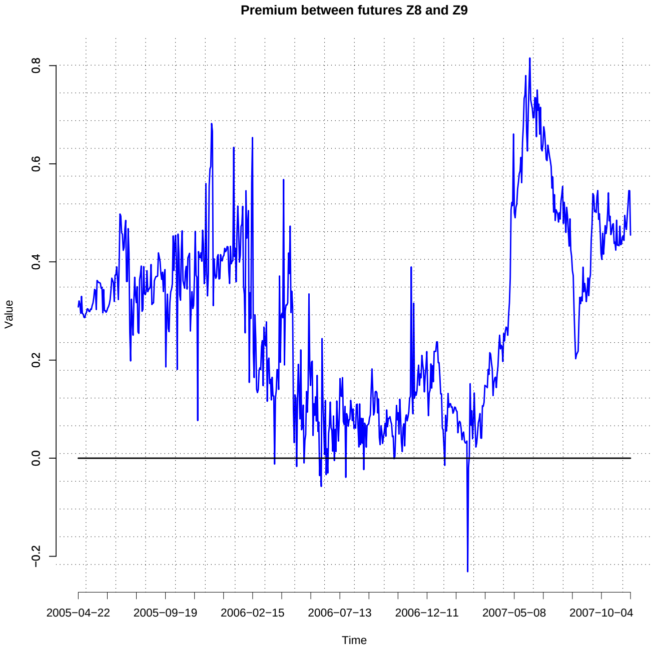

Figure 3.4: Premium Between December 2008 and December 2009 Contracts

prices. Since futures prices behave quite differently than spot prices during the time period under consideration, we are left with two possibilities: either consider separately the contracts of maturity December 2008 and December 2009, or find a consistent model for futures pricing. Without a consistent model for the term structure of futures prices, we choose to work with future price series of maturities December 2008 and December 2009.

(87) add another line of argument to justify the choice of our data price series for the historical distribution: due to infrequent trading of spot prices, we prefer using future prices which reflect more accurately agents' trading anticipations and hedging allowance strategies. This approach is also in line with (122) who argue that the study of spot price dynamics is inadequate due to early political uncertainties on the allowance market. That is why we prefer to consider futures contract prices of maturity December 2008 and December 2009[20]. As for the estimation

---

[20] Note we rule out contracts that are not liquid such as the contract of maturity December 2007.

methodology, (12) and (122) strongly support the use of GARCH specifications to model the returns of CO_2 emission allowances which is also developed below.

Following the literature dedicated to the stock market[21], we choose to model the historical distribution using a semi-parametric asymmetric GARCH(p, q) model as in (9). We discuss the goodness of fit of the chosen model compared to other specifications for the CO_2 return series in the next section. Note the methodology adopted by (89) is not applicable because the monthly frequency used in the latter paper would lead to few observations in our paper. Besides, it is worth underlining that unlike (131) and (89) we use longer term option prices with a 1.3-years investor horizon[22] to display our results.

The estimated model is:

$$\begin{aligned} r_t &= \mu + \sigma_t \epsilon_t \\ \sigma_t^2 &= \omega_0 + \omega_1 I_t + \alpha (r_{t-1} - \mu)^2 + \beta \sigma_{t-1}^2 + \delta \max(0, -(r_{t-1} - \mu))^2 \end{aligned}$$

with $\epsilon_t \sim \mathcal{N}(0,1)$. If $\delta > 0$, we have $Cov(r_t - r_{t-1}, \sigma_{t-1}^2 - \sigma_{t-2}^2) < 0$ to take into account the asymmetry, also known as the skewness effect in stock price dynamics and the leverage effect in financial economics. The model is estimated in a Pseudo Maximum Likelihood (PML) framework by assuming returns are Gaussian. As (71) put it, estimating by PML will lead to unbiased estimates even if the probability distribution function does not necessarily contain the true distribution. (9) and (131) proved the robustness of this approach. The estimates covariance matrix is estimated using the BHHH matrix (see (14)). We then recover the estimated residuals and bootstrap them to simulate sampled paths for any maturity of interest. Using these simulated returns, we estimate the conditional historical

---

[21] We use the stock market as a benchmark that has been extensively used and researched in the financial economics literature. We found no (or few) relevant academic references in the commodity and fixed income markets literature.

[22] As explained in (43), this investor horizon has been identified as the best fit in our dataset. Note that this choice does not affect the robustness of the results.

distribution density using the following Gaussian kernel:

$$f(S) = \frac{\sum_j K\left(\frac{S_j - S}{h}\right) S}{\sum_j K\left(\frac{S_j - S}{h}\right)}. \tag{3.10}$$

As in (89), we select the following bandwidth parameters:

$$h = \frac{1.8\sigma}{\sqrt[5]{n}} \tag{3.11}$$

where S is a point of the future value of the asset price support, h is the kernel bandwidth, σ is the standard deviation of the sample returns and n is the number of observations. Using this methodology, we intend to cope with the non normality of future returns as diagnosed in the next section. Thus, our results will not be tainted by any ill-chosen distribution assumption.

The next section presents the results of our estimation strategy.

3.1.3 Estimation Results and Discussion

This section briefly summarizes the data used, and then discusses the results.

Data

The dataset gathers daily observations for futures and option prices from the European Climate Exchange (ECX), the most liquid trading platform for carbon derivatives with approximately 86.5% of the total exchange-based trades of allowances.

The data used include plain vanilla European option closing prices in € of maturity December 2008 and December 2009 traded from October 1, 2006 to November 23, 2007. Tables 3.2 and 3.3 display the number of available observations for each contract and the average volume for each strike of option prices in the dataset[23]. The data for the risk neutral distribution covers a sample of 570 option

---

[23] Note in Table 3.3 the volume associated to each contract and each trading day is not always available in the dataset.

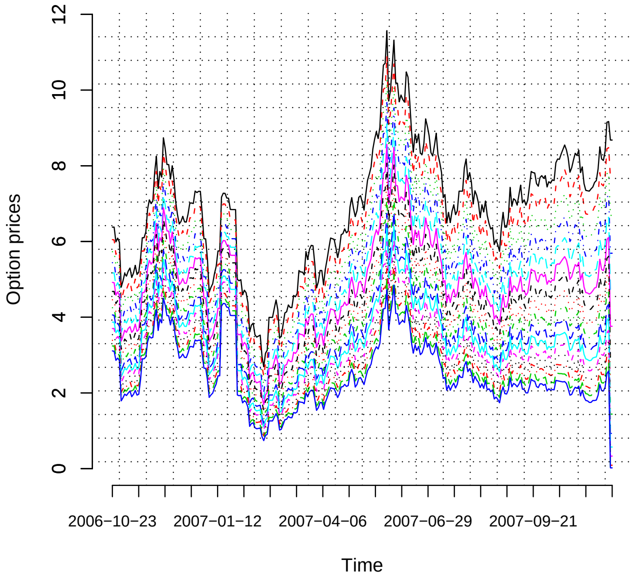

Figure 3.5: Option prices available along with several strikes from ECX

prices for the December 2008 contract and 494 option prices for the December 2009 contract. With 18 strikes for each contract, the sample totals 10,260 and 8,892 observations respectively. Figure 3.5 gives us an illustration of option prices available along with several strikes.

Descriptive statistics regarding each contract may be found in Tables 3.4 (see the Appendix C). For both contracts, the negative skewness indicates a distribution with an asymmetric tail extending towards more negative values. The positive excess kurtosis suggest a fat tailed empirical distribution and the presence of extreme observations. Thus, as stated by the Jarque Berra test statistics, residuals are not Gaussian which is characteristic of financial time-series. The p-value of the Box Pierce test statistic reveals residuals are not autocorrelated. To remove unreliable observations characterized by a low volume and a low sensitivity to volatility, we only consider options of moneyness included between 0.5 and 1.5.

We also use futures prices drawn from ECX for contracts with the same maturities[24]. The underlying asset of the contracts are first and second period spot prices. The risk free rate is the one year swap rate in € commonly used by market agents. The choice of futures prices over spot prices as already been motivated in Section 3.2. Thus, the data for the historical distribution covers a daily sample of futures prices ranging from October 1, 2006 to November 23, 2007, *i.e.* more than 400 observations for each contract.

In Figures 3.6 and 3.7, the visual inspection of the data reveals strong reversals of the futures price series depending on the time period, *i.e.* before and after the 2006 compliance event. Statistical tests have been run on each futures first natural logarithm price series and confirm the presence of one structural break around March 1, 2007[25].

Over the period going from October 1, 2006 to November 23, 2007, we choose to split our dataset before and after the yearly compliance event imposed by the EC to evaluate investors' changes in anticipations. Installations need to report by the end of March their verified emissions that occurred during the preceding year. For instance, CO_2 emissions at the installation level for the calendar year 2006 were reported on March 30, 2007. Then, the information becomes publicly available when the EC officially publishes its report between the end of April and mid-May. Thus, to reflect these institutional events and to capture the state of information available to all market participants with most accuracy, the sample has been split in two sub-samples on April 30, 2007, *i.e.* at the time where the EC issued its official report for the verified emissions of the 2006 compliance period[26]. We therefore identify Sample #1 as being "October 1, 2006 - April 30, 2007".

---

[24] We do not include futures prices of maturity December 2007 in our sample since this contract has less observations and is less liquid.

[25] The unit root test by (101) with one structural change in the intercept and trend slope reveals that the endogenous structural break occurs on March 1, 2007 for both contracts of maturities December 2008 and December 2009. This result is further proved by Chow's breakpoint test statistics. A journal of those tests may be obtained upon request to the authors.

[26] Note the choice of the sample splitting date between end of March and end of April does not affect the stability of the results. For instance, the results are not qualitatively different if we eliminate the whole range of dates where the information is not clear, *i.e.* March, April and May.

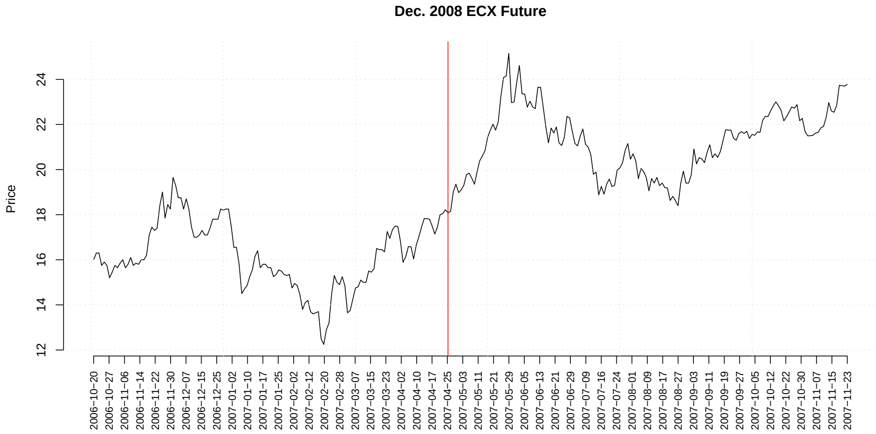

Figure 3.6: Historical price of the ECX future for December 2008 contract

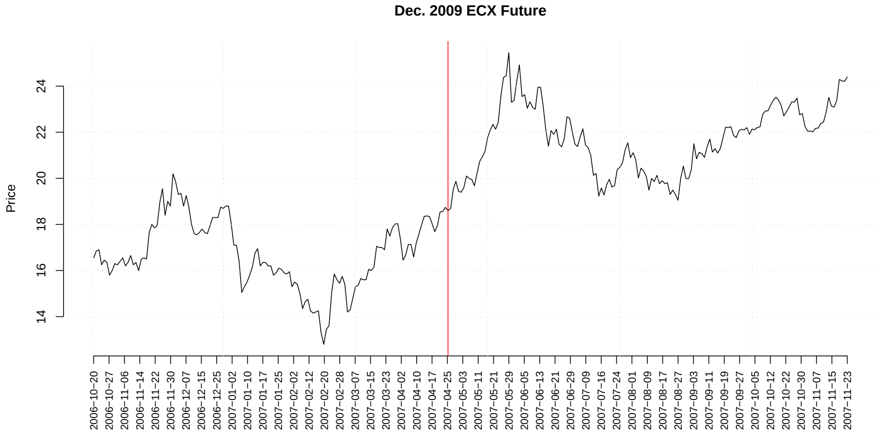

Figure 3.7: Historical price of the ECX future for December 2009 contract

Sample #2 is defined as being "May 1, 2007 - November 23, 2007". This division by sub-samples is the same for each contract of maturity December 2008 and December 2009.

During both periods, we assume the risk-neutral and historical distributions to be sufficiently stable[27] to use market prices and recover both of them. This methodology only provides us with estimates of average risk-aversion on the time periods under consideration[28]. As a final assumption, we choose to work with an average time to maturity of $\tau = 1.3$ on annual basis in our dataset[29].

Estimation Results

Let us briefly summarize the estimation methodology developed in this paper. First, the risk neutral distribution is recovered from ECX option prices. Second, the historical distribution is approximated by the historical return distribution of futures allowance prices. Thus, over the entire dataset from October 1, 2006 to November 23, 2007 we estimate the historical and risk neutral distributions. Third, as detailed in eq. (3.1), we infer from these probability distributions the absolute risk aversion functions for a representative investor with a 1.3-years investor horizon[30].

As for the historical probability distribution, Table 3.5 indicate the best model is the asymmetric GARCH(1,1)-GJR to accommodate the leverage effect (see the Appendix C). The result of the likelihood ratio test confirms the GARCH GJR is the best fit for the historical distribution. The chosen model is the GJR-GARCH

---

[27] As highlighted above, over the two studied sub-samples, we ran unit root tests with endogenous structural breaks in the mean of the time series used in the article. We concluded with the fact that no break could be detected in the sub-samples.

[28] See (131) on this specific point.

[29] This time to maturity has been chosen in order to make the results comparable for the December 2008 and December 2009 contracts. We tested for other values of τ and our results remained qualitatively unchanged. Thus, we decided to stick to this approach to ease the presentation of the results. Note smaller values of τ should not be used because of the average maturity of the options in the dataset.

[30] The choice of this investment horizon has been discussed in the previous section.

model of (67) that we re-state below for the ease of the presentation:

$$
\begin{aligned}
&r_t = \mu + \sigma_t \epsilon_t \\
&\sigma_t^2 = \omega_0 + \omega_1 I_t + \alpha (r_{t-1} - \mu)^2 + \beta \sigma_{t-1}^2 + \delta \max(0, -(r_{t-1} - \mu))^2 \\
&\epsilon_t \sim \mathcal{N}(0, 1),
\end{aligned}
$$

with r_t the one-day logarithmic return at time t and $I_t = 1$ if t is in Sample #2 (after the compliance event) and 0 for Sample #1 (before the compliance event). We are especially interested in the fact that ω_1 is statistically different from zero and *negative*: the European carbon market is characterized by *more* volatility *before* the compliance event on April, 2007 than after the compliance event. This finding is consistent with what we expected in Section 3.2, *i.e.* that information disclosure is due to reduce uncertainty and thus volatility on financial markets. Figures 3.8 and 3.9 display the historical volatility for both contracts estimated from this asymmetric GARCH(1,1) model.

Compared to previous literature, our estimates strongly depart from the usual equity-based results. First, while the constant term ω_0 and the ARCH term α are higher than the values found in (131) and (9), the GARCH term β is systematically lower. However, the degree of persistence of the conditional variance as measured by $(\alpha + \beta)$ is close to the values in the previously cited papers. Second, and most interestingly, δ is *negative*: periods of *increasing* market coincide with periods of higher volatility. This increasing feature is the exact opposite of the usual leverage effect found on equity markets[31]. In a context of a low environmental constraint on the carbon market, the risk associated to the option contract consists in *increasing* allowance prices *after* the 2006 compliance event which is the opposite of a standard commodity market[32]. Thus, beyond the information disclosure effects that led to a lower average volatility in the globally increasing Sample #2, the volatility during increasing periods has been higher than during decreasing periods. Thus,

---

[31] Recall that the leverage effect implies a higher level of volatility associated to *decreasing* prices.

[32] This logic is conform to the disconnection between first and second period allowance prices described earlier, *i.e.* investors expect increasing allowance prices in a context of increasing allowance scarcity overtime.

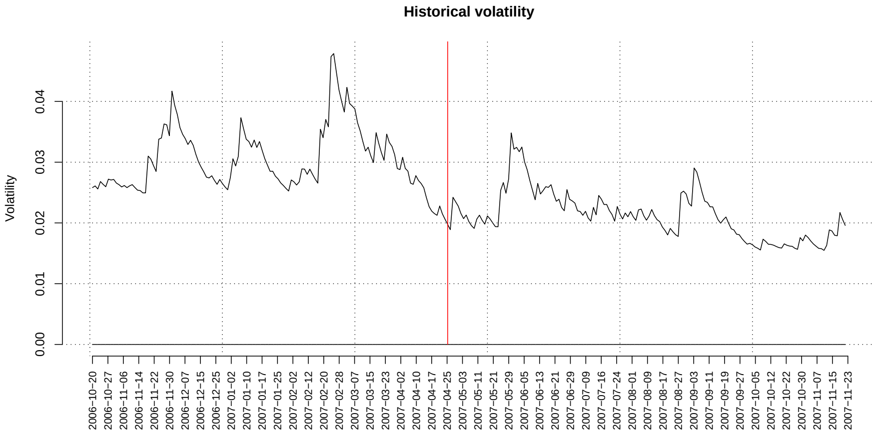

Figure 3.8: Historical volatility estimated from asymmetric GARCH(1,1) model for December 2008 contract

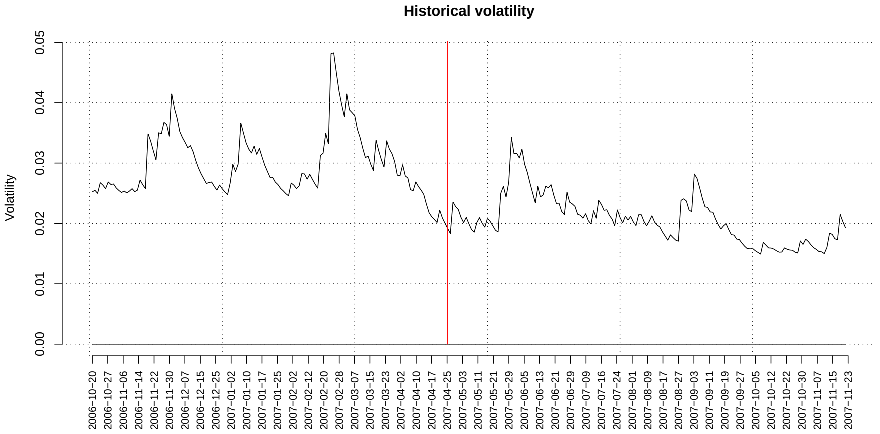

Figure 3.9: Historical volatility estimated from asymmetric GARCH(1,1) model for December 2009 contract

we are able to disentangle two different asymmetric volatility effects, the first being dependent on information disclosure and the second being an uncovered feature on this new market. However, as explained below when investigating implied volatility, the first effect usually dominates the other.

The rationale behind the second effect may be stated as follows. As shown in Figures 3.10 and 3.11, the implied volatilities exhibit smiles with a dramatically different slope depending on the sample considered. For both contracts December 2008 and December 2009, the smile observed in Sample #1 (displayed in blue) is skewed to the right which suggests operators anticipated a *decrease* of the carbon price *before* the release of 2006 verified emissions. For Sample #2 (displayed in red), the smile displays a leftward asymmetry which suggests operators anticipated an *increase* of the carbon price *after* the 2006 compliance event. The logic at stake to comment the level of implied volatilities obtained is the following. When investors anticipate a sharp price decline, the rationale behind option pricing consists in buying puts with strikes lower than the underlying asset spot value and selling calls with higher strikes. Given the one-to-one relation between option prices and implied volatility, this results in a low implied volatility for low levels of moneyness compared to higher ones. Thus, the implied volatility is lower for levels of moneyness strictly superior to one indicating these declining trends. At every point of the asset price support, the lower the implied volatility, the higher the probability of occurrence of the event. This relationship also explains the changes in the skewness of the risk neutral distribution. Between the two contracts, our analysis finds a level of implied volatility in the range of 0.8-0.9 for the second contract of maturity December 2009, which is higher than the values obtained for the first contract of maturity December 2008 comprised between 0.6-0.8. This result may be explained by the fact that the average time to maturity for option prices in the dataset is higher for the second contract compared to the first contract.

Therefore, we uncover a dramatic shift in investors' anticipation around the 2006 compliance event. We expect this result to be of lower magnitude than during the 2005 compliance event[33]. On April 2007, the EC revealed that verified

---

[33] As stated earlier, option prices are not available to capture the magnitude of this effect.

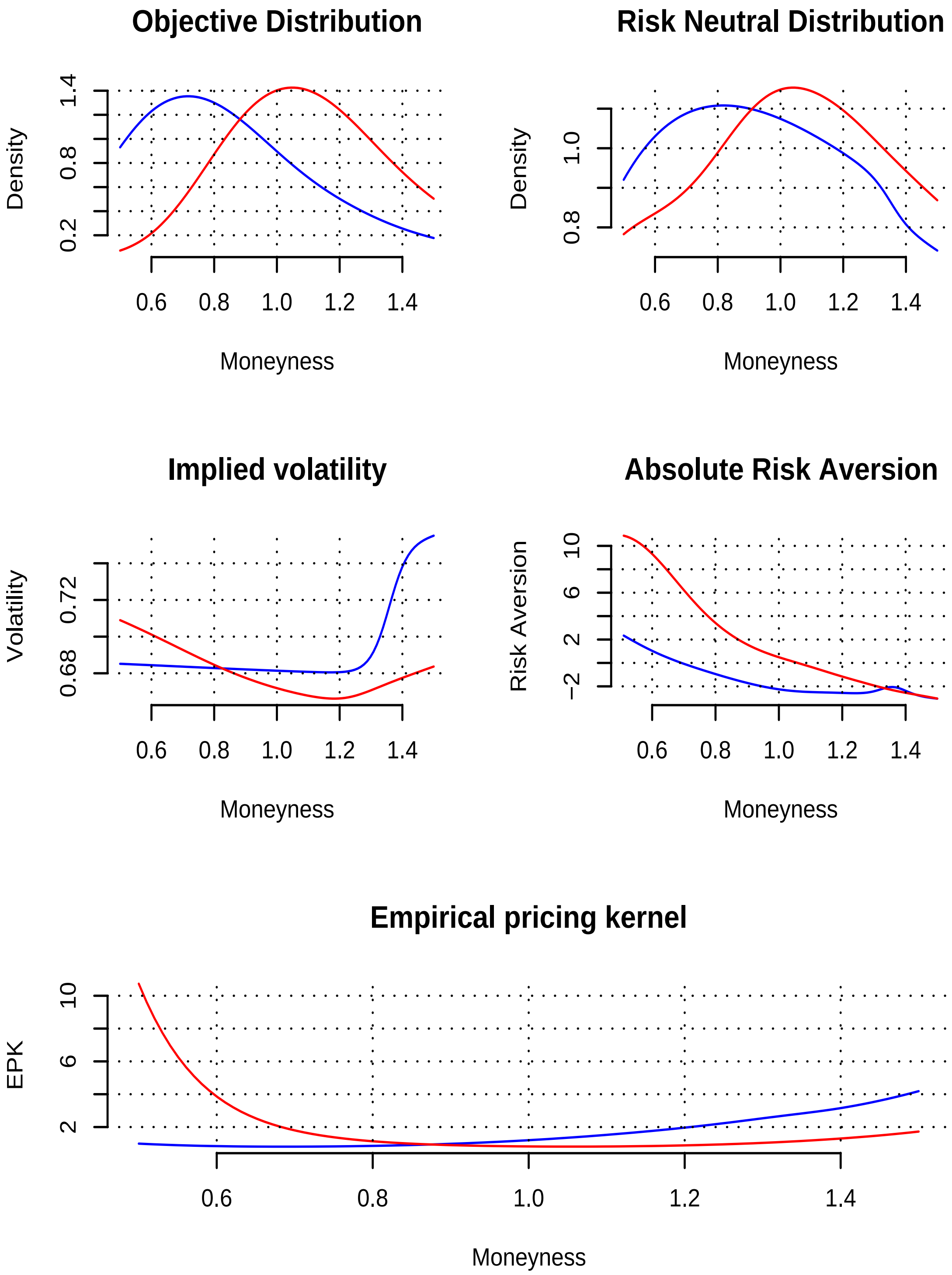

Figure 3.10: Estimation results for December 2008 contract with $\tau = 1.3$
The blue line denotes the Sample #1. The red line denotes the Sample #2.

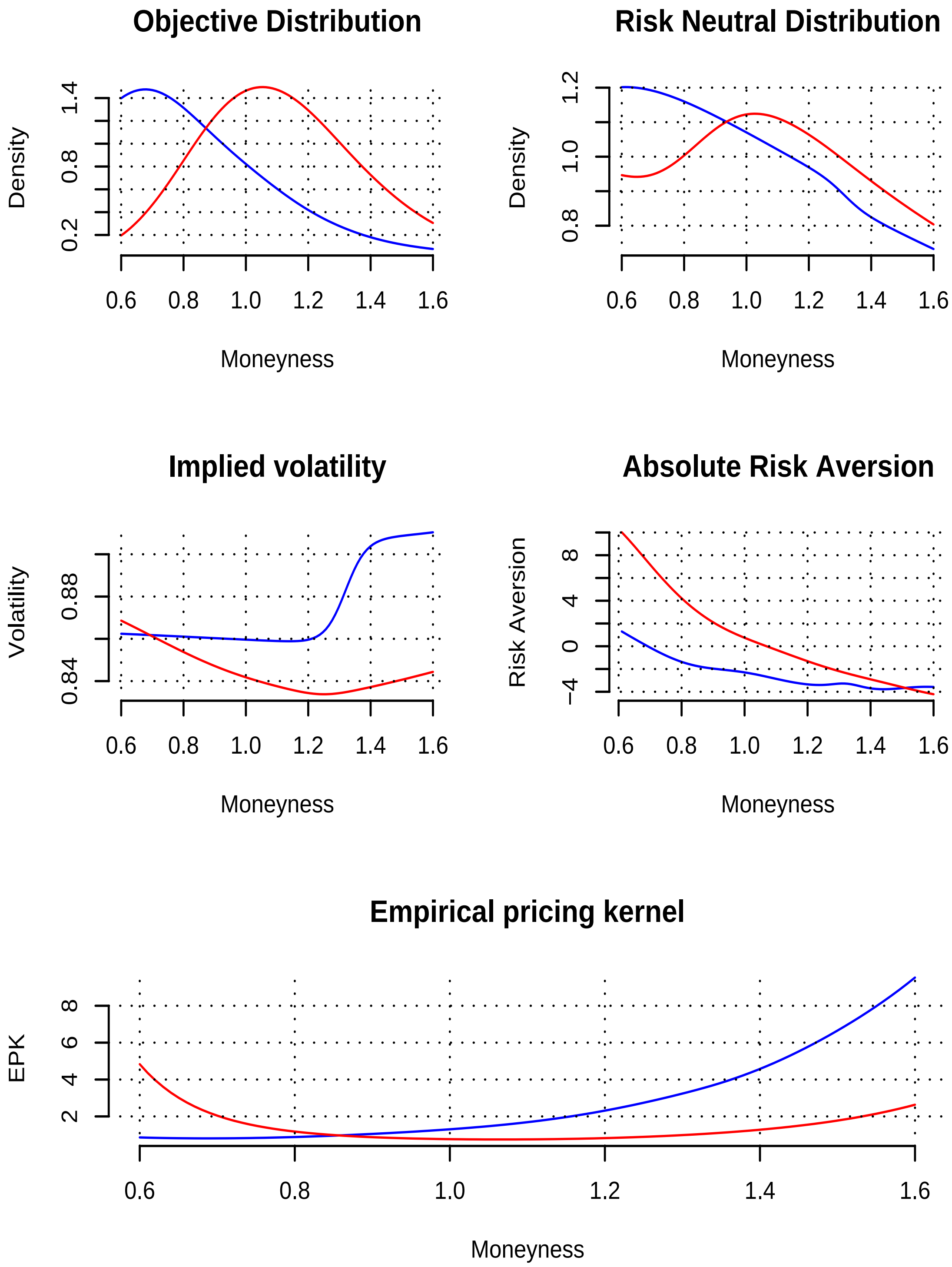

Figure 3.11: Estimation results for December 2009 contract with $\tau = 1.3$
The blue line denotes the Sample #1. The red line denotes the Sample #2.

emissions were about 30 million tons or 1.45% lower than the 2006 allocation[34]. Two distinct messages are embedded in this diffusion of institutional information. First, the EC confirmed that allocated allowances were higher than the actual level of CO_2 emissions. This first element may explain why market agents were expecting a drop in the carbon price before the 2006 compliance event. Second, the EC revealed that verified emissions were lower than allocated allowances by only 1.45% for the 2006 compliance event, which corresponds to a thinner margin than for the 2005 compliance result[35]. Thus, market agents have adapted the financial risk of being exposed to a situation of allowance shortage, which may explain why they were expecting an increase in the carbon price after the 2006 compliance event. As developed in Section 3.1.1, this futures dynamics is sustained by further EC announcements to restrict allocation and to rely on auctioning during Phase II which have a positive effect on the expected allowance scarcity. As a final line of argument, the decision to maintain the EU ETS at least until 2020 may also contribute to this increasing futures price pattern. On a broader scale, the substantial uncertainties associated with the 2006 reported emissions are therefore captured through volatility. Primarily options prices, and to a lesser extent futures, are financial assets that vary greatly as a function of volatility and thus of uncertainty. It is well known that call and put options are increasing functions of uncertainty, even on the carbon market. The relationship between futures and uncertainty is less clear on the EU ETS. Our estimation results nevertheless reveal that investors' anticipations of strictly increasing allowances prices are correctly reflected in the futures' price trends.

The results obtained for the objective and risk neutral distributions confirm our intuitions. Recall that the objective distribution is the time series distribution of futures prices, whereas the risk neutral distribution is the pricing density used to give a fair price to any contingent claim asset. For the risk neutral distribution, in Figures 3.10 and 3.11, the blue line which denotes the risk neutral density for

---

[34] See the EU Environment DG at *http://ec.europa.eu/environment/press/index.htm.* Cited February 2008.

[35] Recall that verified emissions were lower than allocated allowances by 3% during the 2005 compliance period ((59)).

Sample #1 has a steeper slope than the red line for Sample #2, which induces more volatility. These results are therefore consistent with what we what we expected, *i.e.* to obtain lower levels of implied volatility after the EC annoucement. The results for the historical density yield the same asymmetries as for the risk neutral density for both contracts of maturity December 2008 and December 2009.

Turning our attention to risk aversion, the empirical pricing kernels present noticeable shapes that underline the dramatic change in the market risk aversion. We recall that the empirical pricing kernel is defined as $\frac{\hat{q}(x)}{\hat{f}(x)}$ for each point of the support of the asset price. Figures 3.10 and 3.11 clearly illustrate this point: before the yearly compliance event (# Sample 1), market agents expect a drop in the EUA price whereas after the yearly compliance event (# Sample 2) a sharp price increase is expected. From Figures 3.10 and 3.11, we may assert that the pricing kernel is countercyclical, *i.e.* it is inversely related to the current market trend. The pricing kernel is decreasing in the context of increasing markets and conversely, as pointed out by (131). These results should be compared to results obtained on equity markets, using comparable ranges of maturities and moneynesses. We use options with a longer time to maturity than (89) or (131) and our moneyness ranges are consequently wider than theirs. Only (9) present empirical results for a comparable range of strikes and maturities. Their estimates are ranging from 2 to 5. As shown in Figures 3.10 and 3.11, our estimates range from nearly 0 to 10. These considerably wider estimates suggest that the slope of the pricing kernel is steeper in our paper. This result applies especially for low moneynesses in Sample #2 for the contract of maturity December 2008 and high moneynesses in Sample #1 for the contract of maturity December 2009 . Similar comments arise for the graphs of risk aversion where a steep slope for the pricing kernel is associated with a high level of risk aversion. Thus, during the period under consideration, one may conclude that risk aversion on the European carbon market has been higher than the values typically found on equity markets. It appears consistent with the risk premium associated to the financial exposure on such a new carbon commodity market and the necessity to adopt accurate risk management strategies.

The *increasing* futures dynamics observed *after* the 2006 compliance result may be interpreted as an increasing awareness in terms of future tightened caps. As the EU ETS is confirmed to operate at least until 2020, investors are taking into account a medium-term carbon price signal. This trend will most likely be strenghtened by the recent EU ETS review which involves more sectors and an increasing reliance on auction mechanisms to allocate allowances as part of the global fight against climate change. These elements bring us in the second section of Chapter 3 to analyse in more details how agents may hedge against the risk of variation of political decisions, and how to reallocate allowances so as to share this risk.

3.2 Bankable Permits under Uncertainty and Optimal Risk Management Rules: Theory and Empirical Evidence

Emission permits are now widely considered as efficient instruments for regulating firms' emissions of pollutants. Their numerous advantages have been extensively discussed in the literature (Bohm and Russel (1985), Pearce and Turner (1990), Cropper and Oates (1992), Koutstaal (1997), Baumol and Oates (1998)). However, emission permits may also convey a high level of uncertainty with respect to political decisions. While in the case of a tax the political uncertainty concerns the level of the tax, in the case of an emission permit uncertainty depends not only on its price but also on the allocation rules enforced by the regulator.

Hence, the informational efficiency argument[36] in favor of emission permits compared to other classic instruments[37] vanishes given this potential higher level of uncertainty linked to the risk of political decision changes[38]. To cope with these political uncertainties, a number of firms may not participate in the permits market, and express their fear of an environmental regulation system dependent on such shifts in the regulatory environment (Wossink and Gardebroek (2006)).

---

[36] *i.e.* less information is needed concerning firms' depolluting costs.

[37] For instance, a tax or a lump sum.

[38] Be it concerning the global permits allocation, or its repartition between firms.

Hahn (1989) first stressed the potential negative effects of political uncertainties for emission permits systems. He emphasized that the advantages of permits schemes in terms of emissions control may be undermined by political uncertainties regarding banking and trading provisions. Leston (1992), Stavins (1995) and Ben-David et al. (1999) have also underlined that the performance of emission permits is critically linked to the clarity of political decisions.

In this section, we only examine firms' production decisions subject to the introduction of an emission permits market, and to the possibility to bank permits forward in a partial equilibrium framework. At the beginning of each period, firms receive an initial permits allocation. Without uncertainty on the next period allocation, firms smooth their emissions between trading periods as documented in previous literature (Rubin (1996), Kling and Rubin (1997), Leiby and Rubin (2001)). This banking behavior also changes the temporal pattern of emissions by decreasing the concentration of emissions on early periods[39]. Since it overcomes potential negative effects, the authorization of banking therefore appears as a decisive feature for the successful implementation of permits systems as an environmental regulation tool[40]. Departing from this benchmark case, the introduction of uncertainty on future allocation provides further incentives for firms to bank permits, and to consider collusion as a way of insurance (Von der Fehr (1993), Ehrhart et al. (2008))[41].

This section therefore addresses the following central questions: will an increase in the level of uncertainty concerning future allocation impact positively or negatively the amount of banking by firms? following a variation in the level of uncertainty, is it possible to identify an optimal risk sharing rule between firms? We aim at detailing firms' behavior, that is why we focus our analysis on the banking provisions, and consider that permits trading between firms has already occurred.

Compared to previous literature, the main theoretical results of this article are

---

[39] This behavior applies especially for firms with high abatement costs.

[40] See Bosetti et al. (2008) for an empirical discussion.

[41] Collusion may have several impacts on the permits market. See the above mentioned articles for a discussion.

twofold. First, we show that when firms face an increase in the level of risk, the variation of the amount of banked permits is linked to the third derivative of their production function with respect to emissions. Second, without uncertainty on the total number of permits allocated during the second period, an agency may introduce a Pareto-optimal permits re-allocation between firms. When the regulatory uncertainty concerns the number of permits available during the second period, an optimal risk-sharing rule needs to take into account the sensitivity of firms' marginal productivity to the number of permits, as well as the elasticity of the marginal productivity with respect to the stock of pollution. These results convey interesting policy implications concerning the use of banking as a risk-management tool linked to political uncertainty on an emission permits market. These results also underline the need to take into account the sensitivity of investors with regard to pollution choices (Etner and Jouvet (2000))

Finally, we provide empirical insights into these findings by investigating the banking behavior at the installation level, and the pooling behavior at the group level on the European carbon market. In this literature, we may already refer to the article by Ehrart et al. (2008), who have first studied the effects of allowance pooling in the EU ETS. We confirm the impact of different allocation rules and overall regulatory uncertainty on the variation of firms' banked permits, and the existence of risks-pooling by parent companies to save penalty and permits purchases costs.

The remainder of the section is organized as follows. Section 3.2.2 details the behavior of firms. Section 3.2.3 examines risk management strategies between firms, proposes an optimal risk sharing rule, and discusses policy implications. Section 3.2.4 provides an empirical discussion. Section 3.2.5 concludes.

3.2.1 Behavior of Firms

We analyze in this section the behavior of firms with a two-period time-horizon for production decisions. Since we focus on the effects of uncertainty on firms' banking behavior, we thus assume that permit trading between firms has already occurred. During the first period, t, firms receive a permits allocation noted $\bar{P}_t$.

This initial allocation may be used for production, but also banked for the next period. During the second period, firms receive a permits allocation noted $\bar{P}_{t+1}$.

During each period, each firm produces a good with a given production technology by using X_t input[42]and P_t permits. Thus, following the introduction of permits at time t, each firm uses a quantity of environment P_t additional to its input quantity X_t in order to produce a good Y_t:

$$Y_t = F(X_t, P_t) \tag{3.12}$$

The quantity of environment P_t simply states the number of permits needed by the firm to produce and cover its pollutant emissions level. The production function is strictly concave for each of its arguments and the second non-crossed derivatives are negative ($F_{ii} < 0$).

Behavior of Firms without Uncertainty

The firm maximizes its intertemporal profit as a function of its inputs, X_t and X_{t+1}, and the choice of using pollution permits P_t and P_{t+1}. Let $\bar{P}_t$ and $\bar{P}_{t+1}$ be the permits allocated to firms and S_t the permits bank computed as the difference between the initial permits endowment and the number of permits used by the firm[43], $S_t = \bar{P}_t - P_t$. During the second period, the firm may use its permits endowment plus its permits bank accumulated during the first period. Noting β the discounting factor used by the firm, the intertemporal profit may be written as:

$$\Pi_t = \pi_t + \beta\pi_{t+1}$$

with $\pi_t = F(X_t, P_t) - R_t X_t$ and $\pi_{t+1} = F(X_{t+1}, P_{t+1}) - R_{t+1}X_{t+1} + q_{t+1}(\bar{P}_{t+1} + S_t - P_{t+1})$ with R_t and R_{t+1} the inputs prices, q_t and q_{t+1} the permits prices.

---

[42] X_t can be a vector of inputs, *i.e.* $X_t = \{X_t^1, ..., X_t^k$ with $k \geq 1$. To ease the presentation, we consider the case where $k = 1$.

[43] In this article, we only consider the possibility to bank permits, *i.e.* at non-negative levels of S_t. If $S_t < 0$, then the firm would be allowed to borrow permits. Note that relaxing the non-negativity constraint on borrowing does not change qualitatively the results obtained.

The optimization program of the firm is :

$$\max_{X_t, X_{t+1}, S_t \geq 0, P_t, P_{t+1}} \left\{ \begin{array}{c} F(X_t, P_t) - R_t X_t \\ +\beta \left\{ F(X_{t+1}, P_{t+1}) - R_{t+1} X_{t+1} + q_{t+1}(\bar{P}_{t+1} + S_t - P_{t+1}) \right\} \end{array} \right\}$$

With $P_t = \bar{P}_t - S_t$, the first order conditions are:

$$F_{X_t}(X_t, P_t) = R_t \tag{3.13}$$

$$F_{X_{t+1}}(X_{t+1}, P_{t+1}) = R_{t+1} \tag{3.14}$$

$$F_{P_t}(X_t, P_t) - \beta q_{t+1} \leq 0 \; ; = 0 \; if \; S_t > 0 \tag{3.15}$$

$$F_{P_{t+1}}(X_{t+1}, P_{t+1}) - q_{t+1} = 0 \tag{3.16}$$

From eq.(3.15), we know that the firm will bank permits if the marginal cost of banking is inferior to the anticipated permits price. Combining eq.(3.15) and (3.16), we have:

$$F_{P_t}(X_t, P_t) = \beta F_{P_{t+1}}(X_{t+1}, P_{t+1}) \tag{3.17}$$

From eq.(3.13), (3.14) and (3.17), we obtain the effects of the variation of the number of permits allocated on the firm's banking behavior during either of the two trading periods. Banking is an increasing function of the first period permits allocation, $dS_t/d\bar{P}_t > 0$, and a decreasing function of the second period permits allocation, $dS_t/d\bar{P}_{t+1} < 0$. When the number of permits allocated during the first period increases, the firm may increase both the number of permits banked and used, thereby also increasing its present and future production levels. When the number of permits allocated during the second period increases, the firm may increase its production level during both trading periods by using more permits during the second period and banking less during the first period.

In this section, we have developed the basic model underlying our analysis. In the next section, we study the effects of introducing uncertainty on the number of permits allocated during the second period.

Behavior of Firms under Uncertainty

In this section, we assume a random second period permits allocation[44], noted $\tilde{P}_{t+1}$ with a probability distribution $G(.)$. The randomness reflects changing permits allocation rules by the regulator impacting the second period permits allocation. Only at the beginning of the second period does the firm know its permits allocation. Thus, at time $t+1$, the firm knows its amount of permits $\hat{P}_{t+1}$ endowed and may decide on its inputs uses, production level and associated emissions of pollutants. However, at time t, this amount is not known with certainty. We assume here that the firm anticipates an average amount of permits distributed during the second period equal to $\bar{P}_{t+1}$.

Thus, when there is uncertainty on the second period allocation, the expected intertemporal profit, $E\ \Pi_t = \pi_t + \beta E\ \pi_{t+1}$ is:

$$\Pi_t = \left\{ \begin{array}{c} F(X_t, P_t) - R_t X_t \\ +\beta E \left\{ F(X_{t+1}, P_{t+1}) - R_{t+1} X_{t+1} + q_{t+1}(\tilde{P}_{t+1} + S_t - P_{t+1}) \right\} \end{array} \right\}$$

The choice of the firm indeed follows two steps. In a first step, the firm chooses S_t and X_t by taking into account the uncertainty over the total number of permits distributed in the future. In a second step, the firm chooses X_{t+1} and P_{t+1} with $P_{t+1} \leq \hat{P}_{t+1} + S_t$ given its choices during the first period. Let us solve this program by backward induction.

Choice of X_{t+1} ***and*** P_{t+1} ***with*** S_t ***and*** $\hat{P}_{t+1}$ ***given***

$$\max_{X_{t+1}, P_{t+1}} \left\{ \ \pi_{t+1} = \beta \left\{ F(X_{t+1}, P_{t+1}) - R_{t+1} X_{t+1} + q_{t+1}(\hat{P}_{t+1} + S_t - P_{t+1}) \right\} \ \right\}$$

The first order conditions are:

---

[44] We denote a random variable with $\tilde{}$.

$$F_{X_{t+1}} - R_{t+1} = 0 \tag{3.18}$$

and

$$F_{P_{t+1}} - q_{t+1} = 0 \tag{3.19}$$

At period t, eq.(3.19) implies eq.(3.19)':

$$q_{t+1} = EF_{P_{t+1}}$$

We then obtain the level of profit during the second period, $\tilde{\pi}^{\star}_{t+1}$ as a function of the permits allocation $\hat{P}_{t+1}$ and the bank S_t:

$$\begin{aligned}\tilde{\pi}^{\star}_{t+1}(\hat{P}_{t+1}) = F(X^{\star}_{t+1}(\hat{P}_{t+1}, S_t), P^{\star}_{t+1}(\hat{P}_{t+1}, S_t)) - R_{t+1}X^{\star}_{t+1}(\hat{P}_{t+1}, S_t) \\ +q_{t+1}(\hat{P}_{t+1} + S_t - P^{\star}_{t+1}(\hat{P}_{t+1}, S_t))\end{aligned}$$

Choice of X_t and S_t with the introduction of a random permits allocation, $\tilde{P}_{t+1}$

$$\max_{X_t, S_t} \left\{ \; F(X_t, \bar{P}_t - S_t) - R_t X_t + \beta E \left\{ \tilde{\pi}^{\star}_{t+1}(\tilde{P}_{t+1}) \right\} \; \right\}$$

Using (3.19)', the optimality conditions are:

$$F_{X_t} = R_t \tag{3.20}$$

$$-F_{P_t}(X_t, \bar{P}_t - S_t) + \beta EF_{P_{t+1}}(X_{t+1}, \tilde{P}_{t+1} + S_t)) = 0 \tag{3.21}$$

We obtain an expected condition similar to the case without uncertainty, *i.e.* the firm's behavior is simply based on the expected profit, and we derive similar results to Section 2.1. Thus, it appears important to investigate the consequences of a change in the level of risk associated with the second period permits allocation. To this purpose, we consider an increase in risk in the sense of Rothschild and Stiglitz (1971), and study the effects of this change in the probability distribution on the firm's banking choices. The effects of the variation of the risk associated to the banking variable S lead to the following result:

Proposition 1 *For a given level of inputs, in response to an increase in risk in the sense of the mean preserving spread, the banking of pollution permits by the firm increases (decreases) if and only if the third derivative of the production function with respect to the emissions, F_{PPP}, is positive (negative).*

Proof. Considering a given level of inputs, $X_t^\star$, $X_{t+1}^\star$, from eq.(3.21) with the distribution of probability, $G(.)$, we obtain:

$$-F_{P_t}(X_t^\star, \bar{P}_t - S_t^G) + \beta E_G F_{P_{t+1}}(X_{t+1}^\star, \tilde{P}_{t+1} + S_t^G)) = 0 \equiv H^G(S_t^G)$$

Considering a distribution of probability $K(.)$, where $K(.)$ is a mean preserving spread of $G(.)$, eq.(3.21) gives:

$$-F_{P_t}(X_t^\star, \bar{P}_t - S_t^K) + \beta E_K F_{P_{t+1}}(X_{t+1}^\star, \tilde{P}_{t+1} + S_t^K)) = 0 \equiv H^K(S_t^K)$$

Using the second order condition of the optimization program, we have $S_t^K > S_t^G$ if and only if $H^K(S_t^G) > H^G(S_t^G)$ (Rothschild and Stiglitz (1971)).

Then, $S_t^K > S_t^G$ if and only if:

$$E^K h(S_t^G) > E^G h(S_t^G)$$

where $h(S) = F_{P_{t+1}}(X_{t+1}^\star, \tilde{P}_{t+1} + S)$. This inequality is verified if and only if $h(S)$ is convex:

$$h'(S) = F_{P_{t+1}P_{t+1}}$$

and

$$h''(S) = F_{P_{t+1}P_{t+1}P_{t+1}}$$

■

The conditions on the third derivative of the production function with respect to emissions indeed relate to the study of the concavity of this function. The intuition behind this result may be summarized as follows:

When facing a stronger (weaker) increase of their marginal productivity, firms tend to use less (more) permits, and thus are able to produce and bank more (less) permits.

In this section, we have demonstrated that the variations of a firm's banked permits depend on its production function with respect to concavity. Firms with heterogeneous characteristics on their third derivative may adopt dramatically different behaviors in terms of banked permits. We explore in the next section whether firms may pool permits through the intermediation of an agency. If such an option exists, then we investigate what may be the optimal risk-sharing rule between firms.

3.2.2 Risk Management Strategies

Let us detail first the risks pooling behavior and second the optimal risk-sharing rule between firms.

The Pooling Behavior

In order to study a risk sharing rule between firms, we assume that in partial equilibrium there exists N firms and Θ states of nature[45]. Note $\bar{P}^{i\theta}_{t+1}$ the permits allocation that firm i receives in the state of nature θ, $\underline{\theta} \leq \theta \leq \overline{\theta}$, with a realization probability μ_θ. The optimization program of firm i may be written as:

$$\max_{X_t, X_{t+1}, S_t, P_{t+1}} \left\{ \begin{array}{c} F^i(X^i_t, \bar{P}^i_t - S^i_t) - R_t X^i_t \\ +\beta \sum_{\theta=0}^{\Theta} \mu_\theta \left\{ F^i(X^i_{t+1}, P_{t+1}) - R_{t+1} X^i_{t+1} + q_{t+1}(\bar{P}^{i\theta}_{t+1} + S^i_t - P^i_{t+1}) \right\} \end{array} \right\}$$

The pooling behavior implies the introduction of a cooperation agency[46] between firms which is responsible to maximize the sum of firms' profits whatever

---

[45] By considering a partial equilibrium framework, we assume that the N firms constitute a sub-sample of the firms subject to the permits market.

[46] This agency may either correspond to a "parent agency" with N subsidiaries or to a centralization of production decisions. This latter type of pooling corresponds to common practices for consumers' mutual insurance companies (see Gollier (2001)).

their states of nature. This agency will thus take into account the sum of firms' permits allocations over the two periods:

$$\sum_{i}^{N} \bar{P}_t^i = \sum_i P_t^i + S_t \tag{3.22}$$

and

$$\sum_i \bar{P}_{t+1}^{i\theta} + S_t = \sum_i P_{t+1}^{i\theta},\ \forall\theta \in \Theta \tag{3.23}$$

Substituting S_t in eq.(3.22) and (3.23), we obtain the following constraint for the agency:

$$\sum_i [\bar{P}_t^i + \bar{P}_{t+1}^{i\theta}] = \sum_i P_t^i + \sum_i P_{t+1}^{i\theta} \equiv \bar{P}^\theta,\ \forall\theta \in \Theta \tag{3.24}$$

The agency's program consists in maximizing the sum of profits by choosing firms' inputs levels (X_t^i and $X_{t+1}^{i\theta}$) as well as the use of permits (P_t^i and $P_{t+1}^{i\theta}$) for all states of nature . As the agency takes into account the sum of firms' profits, and given that the sum of permits sales must be equal to the sum of permits purchases, the agency's program may be written as:

$$\max_{\{X_t^i, X_{t+1}^{i\theta}, P_t^i, P_{t+1}^{i\theta}\}_{i,\theta}} \sum_i \left\{ \begin{array}{c} F^i(X_t^i, P_t^i) - R_t X_t^i \\ +\beta \sum_{\theta=0}^{\Theta} \mu_\theta \left\{ F^i(X_{t+1}^{i\theta}, P_{t+1}^{i\theta}) - R_{t+1} X_{t+1}^{i\theta} \right\} \end{array} \right\}$$

subject to the constraint in eq.(3.24). Noting λ_θ the Lagrange multiplier of the constraint in the state θ, we obtain the following first order conditions for all i and for all $\theta \in [0, \Theta]$:

$$F_{X_t^i}^i(X_t^i, P_t^i) = R_t \tag{3.25}$$

$$F_{X_{t+1}^{i\theta}}^i(X_{t+1}^{i\theta}, P_{t+1}^{i\theta}) = R_{t+1} \tag{3.26}$$

$$F_{P_t^i}^i(X_t^i, P_t^i) = \sum_\theta \lambda_\theta \tag{3.27}$$

$$\beta\mu_\theta F^i_{P^{i\theta}_{t+1}}(X^{i\theta}_{t+1}, P^{i\theta}_{t+1}) = \lambda_\theta \tag{3.28}$$

and

$$\lambda_\theta \left\{ \sum_i [\bar{P}^i_t + \bar{P}^{i\theta}_{t+1}] - \sum_i P^i_t - \sum_i P^{i\theta}_{t+1} \right\} = 0 \tag{3.29}$$

We may identify Borch's condition applied to firms and the reciprocity principle. At the optimum, the marginal rates of technical substitution of firms i and j between two states of nature, θ_1 and θ_2, are equal:

$$\frac{F^i_{P^{i\theta_1}_{t+1}}(X^{i\theta_1}_{t+1}, P^{i\theta_1}_{t+1})}{F^i_{P^{i\theta_2}_{t+1}}(X^{i\theta_2}_{t+1}, P^{i\theta_2}_{t+1})} = \frac{F^j_{P^{j\theta_1}_{t+1}}(X^{j\theta_1}_{t+1}, P^{j\theta_1}_{t+1})}{F^j_{P^{i\theta_2}_{t+1}}(X^{j\theta_2}_{t+1}, P^{j\theta_2}_{t+1})} \; \forall i, j, \theta_1, \theta_2 \tag{3.30}$$

This condition is similar to Borch (1962) concerning agents' marginal rates of substitutions between two states of nature.

From the set of optimality conditions (eq. (3.25) to (3.29)), and by keeping the Borch's condition, we obtain an implicit function $\Gamma^{i\theta}$ between the number of permits allocated to each firm in a given state of nature and the total amounts of permits distributed for each of these states. We write the following reciprocity principle:

$$P^{i\theta}_{t+1} = \Gamma^{i\theta}(\bar{P}^1, \bar{P}^2, ..., \bar{P}^\theta, ..., \bar{P}^\Theta) \tag{3.31}$$

The permits distributed by the agency depend on the aggregated sum of permits available in the economy over the two periods. If a change arises in firms' permits allocation rules, and without uncertainty on the total number of permits allocated during the second period, we obtain the following result:

For any given set of decisions of the regulator concerning firms' permits allocation criteria during the second period, the re-allocation of permits by the agency is Pareto-optimal for firms.

This pooling behavior sharply departs from the "laissez faire" policy examined in Section 3.2.2. The expected firms' profits are similar to the case without uncertainty where the agency is in charge of redistributing the total number of permits available in the economy. If the agency only knows the total number of permits allocated during each period, $\bar{\bar{P}}_t = \sum_i \bar{P}_t^i$ and $\bar{\bar{P}}_{t+1} = \sum_i \bar{P}_{t+1}^i$, it will be able to redistribute the total number of permits , $\bar{\bar{P}}_t + \bar{\bar{P}}_{t+1}$, during each period for any change in permits allocation rules enforced by the regulator. In this context, the agency is able to smooth changes in permits allocation between the two periods instead of firms. When Borch's condition is met, this allocation is also Pareto-optimal.

However, as we detail in the next section, if the uncertainty concerns the total amount of permits distributed during the second period, then the risk-sharing agency will only be able to enforce an optimal risk-sharing rule associated with permits holdings.

The Optimal Risk-Sharing Rule

For a given state of nature , θ, we may deduce from the optimality conditions the equality of permits marginal productivity between firms:

$$F^i_{P^{i\theta}_{t+1}}(X^{i\theta}_{t+1}, P^{i\theta}_{t+1}) = F^j_{P^{j\theta}_{t+1}}(X^{j\theta}_{t+1}, P^{j\theta}_{t+1}) \tag{3.32}$$

Based on eq.(3.26), the inputs X during the second period may be expressed as functions of second period permits allocations:

$$X^{i\theta}_{t+1} = \Phi^i(P^{i\theta}_{t+1}) \tag{3.33}$$

Plugging these functions in eq.(3.32), we obtain a relationship between firms' final permits allocations taken pairwise:

$$F^i_{P^{i\theta}_{t+1}}(\Phi^i(P^{i\theta}_{t+1}), P^{i\theta}_{t+1}) - F^j_{P^{j\theta}_{t+1}}(\Phi^j(P^{j\theta}_{t+1}), P^{j\theta}_{t+1}) = 0 \tag{3.34}$$

In order to derive the optimal risk-sharing rule, we study the variations of firms' permits allocations as a function of the variation of the second period permits bank. We consider the permits allocation constraint in eq.(3.24) in two different states of nature θ_1 and θ_2:

$$\sum_i [\bar{P}_t^i + \bar{P}_{t+1}^{i\theta_1}] = \sum_i P_t^i + \sum_i P_{t+1}^{i\theta_1} \tag{3.35}$$

and

$$\sum_i [\bar{P}_t^i + \bar{P}_{t+1}^{i\theta_2}] = \sum_i P_t^i + \sum_i P_{t+1}^{i\theta_2} \tag{3.36}$$

with $\bar{\bar{P}}_{t+1}^{\theta_1} = \sum_i \bar{P}_{t+1}^{i\theta_1}$ and $\bar{\bar{P}}_{t+1}^{\theta_2} = \sum_i \bar{P}_{t+1}^{i\theta_2}$, the total allocation for each state of nature, and we obtain:

$$\bar{\bar{P}}_{t+1}^{\theta_1} - \bar{\bar{P}}_{t+1}^{\theta_2} = \sum_i P_{t+1}^{i\theta_1} - \sum_i P_{t+1}^{i\theta_2} \tag{3.37}$$

Using eq.(3.34) and the implicit function theorem, we define, for each state of nature, a relationship, $g(.)$, between firms' second period permits allocations taken pairwise. For each pair of firms i and j, we have:

$$P_{t+1}^{i\theta} = g_{ij}^{\theta}(P_{t+1}^{j\theta}) \tag{3.38}$$

Using equation (3.37) and (3.38), we get:

$$\frac{dP_{t+1}^{j\theta}}{d\bar{\bar{P}}_{t+1}^{\theta}} = \frac{1}{\sum_i g_{ij}'^{\theta}(P_{t+1}^{j\theta})} \tag{3.39}$$

with

$$g_{ij}'^{\theta}(P_{t+1}^{j\theta}) = \frac{\partial F_P^j/\partial P}{\partial F_P^i/\partial P}$$

Noting σ_j^θ the elasticity of the marginal productivity of the environmental variable as a function of firm's i production with respect to the variation of the number of permits:

$$\sigma_j^\theta = P \times \frac{\partial F_P^j/\partial P}{\partial F^j/\partial P},$$

we obtain the following proposition:

Proposition 2 *If the total permits bank during the second period is random, any optimal risk-sharing rule between firms is such that:*

$$\frac{dP_{t+1}^{j\theta}}{d\bar{\bar{P}}_{t+1}^{\theta}} = \frac{\sigma_j^\theta / P_{t+1}^{j\theta}}{\sum_i \sigma_i^\theta / P_{t+1}^{i\theta}}$$

When the initial global permits allocation in the state of nature θ increases, the final second period permits allocation in this state increases proportionally to the elasticity of the marginal productivity with respect to the environmental variable (the stock of pollution). This sharing condition also takes into account the sensitivity of the firm's marginal productivity to the number of permits.

Policy Implications

The policy implications of these theoretical results shall be analysed in conjunction with the well-known properties of banking for use on emission permits markets that we have detailed in Chapter 1. It is noteworthy to remark that emissions banking generally cannot be assumed to be socially efficient, and may introduce other sources of inefficiency. In this article, we are focusing on the analysis of the risk-management perspective attached to the banking mechanism that has attracted much less attention in previous literature.

We may derive from Proposition 1 that the regulator should strive to reduce or eliminate uncertainty in future permits allocation. More precisely, the task of the regulator consists in announcing and enforcing strict emissions target. If uncertainty arises concerning changes in allocation rules, firms may use banking in order to limit the level of risk attached to emissions trading. In absence of a credible commitment[47] from the regulator in terms of allocation targets for future periods, banking therefore appears as an adequate tool for policy risk control.

Besides, Proposition 2 raises the question of creating an agency at the *sector* level , since it appears missing from our previous analysis between the governement- and firm-levels. Such an agency may prove to be useful in order to pool allowances between firms with different technological characteristics. It therefore may be seen as an institutional "insurance" device against the variation of political decisions on emission permits markets.

Having detailed in Section 3.2.2 the consequences of uncertainty on firms' banking behavior, and in Section 3.2.3 the rationale for risk-sharing between firms, we

---

[47] We may also refer here to the notion of temporal consistency of public policies applied to the case of allowance trading. See Biglaiser et al. (1995) and Helm et al. (2003) for a discussion.

examine in the next section whether these theoretical predictions meet firms' actual behavior on the European carbon market.

3.2.3 Empirical Evidence

This section hinges on the recent development of the EU ETS during 2005-2007 to discuss empirically the main theoretical findings. The early experience of the world's largest greenhouse gases ETS to date indeed allows us to shed some light on *i)* the banking behavior at the installation level as detailed in Section 3.2.2, and *ii)* the permits pooling behavior at the group level as highlighted in Section 3.2.3.

We use Reuters Carbon Market Data[48] to provide a qualitative discussion of these theoretical findings. From the 800 companies included in this database, we identify seven companies that allow us to shed some light on the banking and pooling behaviors. Our case-studies are divided in three sub-samples: firms with the highest permits shortages at the group level, firms with the highest permits surpluses at the group level and the highest emitter of CO_2 on the market. We focus our comments on the number of allowances banked forward at the installation level and the presumed pooling behavior at the group level as detailed respectively in Sections 3.2.2 and 3.2.3.

The Banking Behavior at the Installation Level

On the EU ETS, the political uncertainty regarding the second period permits allocation is linked to the negotiation of NAPs II between Member States and the European Commission. This situation fits well the theoretical framework developed in Section 3.2.2. The uncertainty concerns indeed the exact amount of permits being allocated from 2008 onwards, since the EC announced during Phase I its will to enforce stricter allocation rules for Phase II.

---

[48] Available at *http://www.carbonmarketdata.com.* To the purpose of our empirical section, we exploit from the Reuters Carbon Market Data the compilation of 2005-2007 verified emissions between subsidiaries and parent companies that was accurate as of May 2008.

The variation of banked allowances between Phase I (2005-2007) and Phase II (2008-2012) corresponds to the 2008 compliance result which will be disclosed by the EC by mid-May 2009[49]. Thus, we choose to focus our comments on the variation of banked permits by firms linked to the variation of the global level of regulatory uncertainty during 2005-2007. By many aspects, Phase I may be considered as a "warm-up" period for the EU ETS since several key provisions[50] of this newly created market were characterized by abrupt decision changes. By using this approach, we intend to provide an empirical discussion of the theoretical results regarding the banking of permits that corresponds to the early development of the European carbon market.

The risk underlying permits trading on the European carbon market is linked to increasing permits prices against which installations need to form hedging strategies[51], and the firm's net short/long position that need to be carefully managed to save penalty costs (Buchner and Ellerman (2008)). If a firm encounters an uncertainty as modelled in Section 3.2.2 and goes beyond its emissions forecasts during the current allocation period, then it is basically left with two choices: either use banked permits or go on the market to buy permits.

Given the underlying assumption of our model that permits trading has already occurred between firms, we investigate the changes in banked permits at the installation level that occured in a context of regulatory uncertainty on the EU ETS during 2005-2007. Banking behaviors greatly vary between the 7 companies that belong to our case-studies. In the sub-sample of firms which record the highest permits surpluses, we remark net banking patterns for the largest installations in terms of allocation for ArcelorMittal (Figures 3.10 to 3.12, Table 3.8, see Appendix C) and Dalkia (Figures 3.13 to 3.15, Tables 3.9 to 3.11), as well as

---

[49] Moreover, due to institutional fungibility between the EU ETS and the Kyoto Protocol as of 2008, the possibility to transfer banked allowances from Phase I to Phase II has been restricted by all MS. For an extensive discussion of the inter-period ban on banking in the EU ETS, see Alberola and Chevallier (2007).

[50] Such as allocation criteria or banking provisions.

[51] See the preceding section for an extensive discussion based on increasing futures prices over 2008-2012. We do not further comment this type of risk in the remainder of this section.

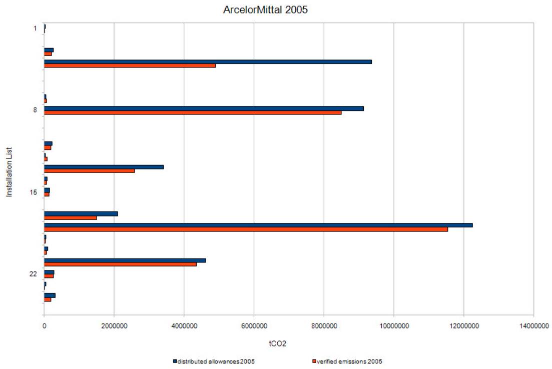

Figure 3.12: Distributed Allowances and Verified Emissions for ArcelorMittal in 2005 from Reuters Carbon Market Data

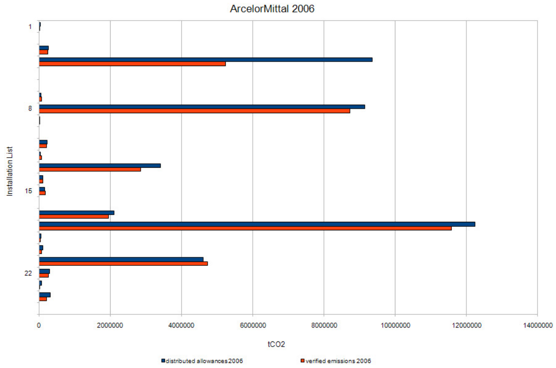

Figure 3.13: Distributed Allowances and Verified Emissions for ArcelorMittal in 2006 from Reuters Carbon Market Data

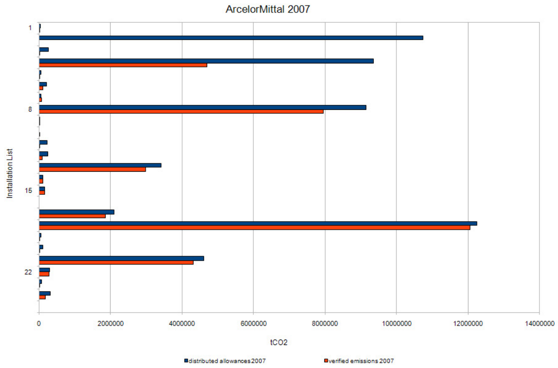

Figure 3.14: Distributed Allowances and Verified Emissions for ArcelorMittal in 2007 from Reuters Carbon Market Data

for Eesti Energia's installation (Figures 3.16 to 3.18, Table 3.12). This comment applies especially for installations in the combustion sector which seem to have benefited from windfall profits during the NAPs I allocation process. In the sub-sample of firms which record the highest permits shortages, we observe asymmetric banking (borrowing) patterns for Enel (Figures 3.19 to 3.21, Table 3.12), E.ON (Figures 3.22 to 3.24, Tables 3.13 and 3.14) and Union Fenosa (Figures 3.28 to 3.30, Table 3.17) depending on whether those installations were characterized by a net long (short) position during 2005-2007. The same comment apply to our last sub-sample of firms for RWE, the highest emitter of CO_2 on the market (Figures 3.25 to 3.27, Tables 3.15 and 3.16).

Based on the visual inspection of the data, we have highlighted in this section a wide variation in the amount of banked permits at the installation level during 2005-2007. Three kinds of arguments may explain these variations between firms. First, differentiated allocation rules were enforced by the regulator between EU ETS sectors that affect firms' permits supply. Second, unforeseen economic activity events may impact firms' production levels and their permits demand. Third, these heterogeneous behaviors in terms of banked permits may come from the political uncertainty described earlier regarding banking provisions and NAPs II. The latter argument is in line with the theoretical framework regarding the effects of political decision changes on firms' banking behavior derived in Sections 3.2.2 and 3.2.3. This first step of the inspection of the data therefore brings us to a more detailed analysis analysis of the potential for permits pooling by the parent company in the next section.

The Pooling Behavior at the Group-Level

Let us detail first the rationale behind risks pooling, and second the actual behavior of the firms contained in our sample.

To our best knowledge, only Alberola et al. (2008) evoke the existence of pooling behavior in the EU ETS. In this article, we have detailed the economic intuitions behind it. Before investigating the pooling behavior empirically, it is

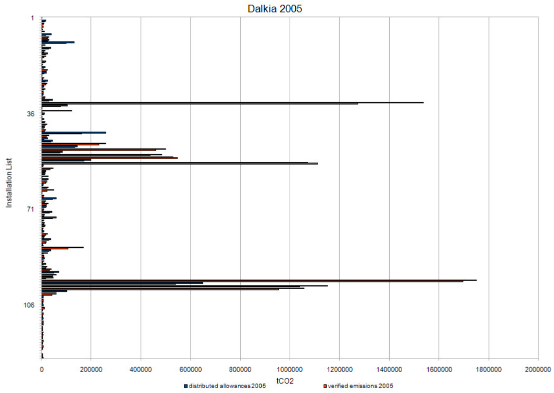

Figure 3.15: Distributed Allowances and Verified Emissions for Dalkia in 2005 from Reuters Carbon Market Data

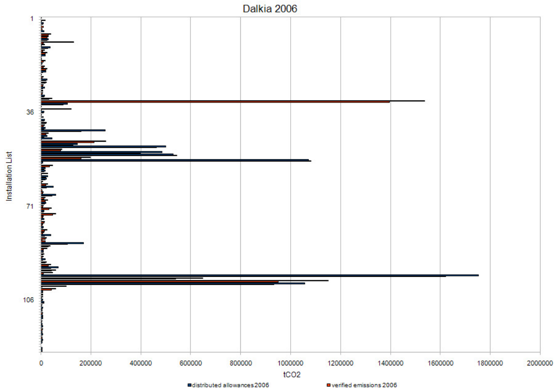

Figure 3.16: Distributed Allowances and Verified Emissions for Dalkia in 2006 from Reuters Carbon Market Data

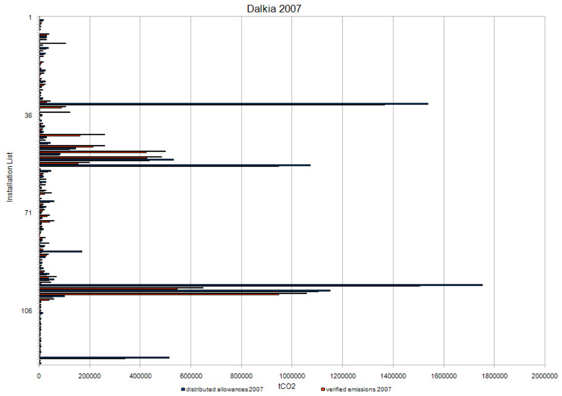

Figure 3.17: Distributed Allowances and Verified Emissions for Dalkia in 2007 from Reuters Carbon Market Data

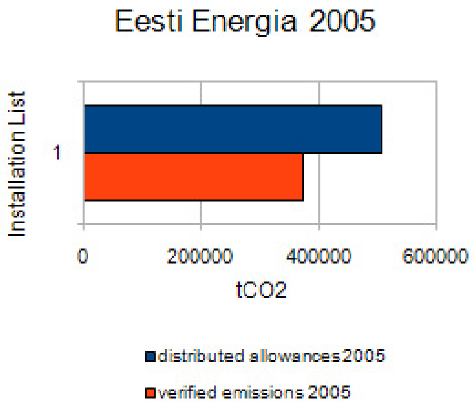

Figure 3.18: Distributed Allowances and Verified Emissions for Eesti Energia in 2005 from Reuters Carbon Market Data

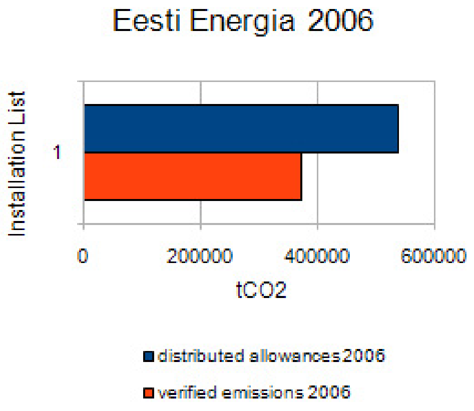

Figure 3.19: Distributed Allowances and Verified Emissions for Eesti Energia in 2006 from Reuters Carbon Market Data

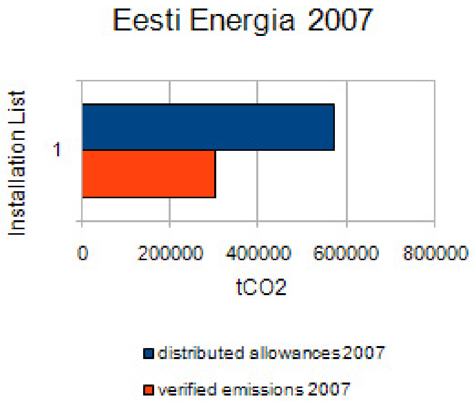

Figure 3.20: Distributed Allowances and Verified Emissions for Eesti Energia in 2007 from Reuters Carbon Market Data

worth emphasizing that the CITL[52], which oversees all national registries, displays extensive information at the installation level concerning allocation and verified emissions. However, not all registries have been connected to date, and the CITL contains raw data that needs to be reorganized between subsidiaries and parent companies[53]. Hence, we do not aim at an exhaustive discussion on this topic, but rather at introducing empirical perspectives that are relevant to our theoretical results.

On the EU ETS, pooling behaviors may emerge at the group level in order to save the cost of purchasing permits. The economic logic of such an argument unfolds as follows: if there exist both types of net short and net long subsidiaries, the parent company may transfer allowances internally between them so that the net position of the parent company is globally in compliance. Thus, the exposure to the risk of permits shortage during compliance periods may be reduced by this intra re-allocation of permits. This type of behavior is close to the theoretical finding detailed in Section 3.2.3 with the role of the agency pooling risks. This logic holds only if there is an alternate of net short and net long installations at the group level, that is why we detail several cases that may apply.

Among the three firms in our sample that are in a net short position, Union Fenosa exhibits in Table 3.17 the largest shortage by 7.3M European Union Allowances (EUAs)[54] in 2007. Out of twelve installations, nine are in a short position which may only be compensated internally by 2M EUAs in surplus. Thus, the pooling of allowances by the parent company allows to reduce the risk of permits shortage by 25% for some, but not all, subsidiaries. The visual inspection of the data in Figures 3.28 to 3.30 reveals that three installations are especially short of permits over 2005-2007. Next, we turn our attention to E.ON which records in

---

[52] Available at *http://ec.europa.eu/environment/ets/*, cited May 2008.

[53] For a detailed analysis on this compilation of emissions data at the group level, see Trotignon and McGuiness (2007) and Trotignon et al. (2008). As another preliminary remark, note it is not yet technically possible to track permits exchanges at the European level, although each permit is marked with an unique identifier, since this information will only be disclosed publicly after five years of permit trading in the EU ETS.

[54] One EUA is equal to one ton of CO_2 emitted in the atmosphere.

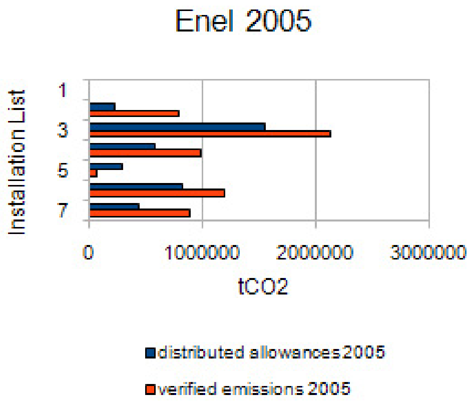

Figure 3.21: Distributed Allowances and Verified Emissions for Enel in 2005 from Reuters Carbon Market Data

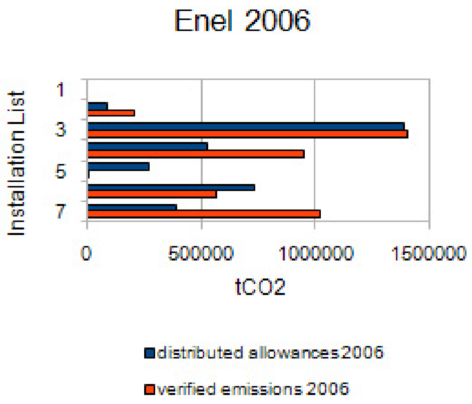

Figure 3.22: Distributed Allowances and Verified Emissions for Enel in 2006 from Reuters Carbon Market Data

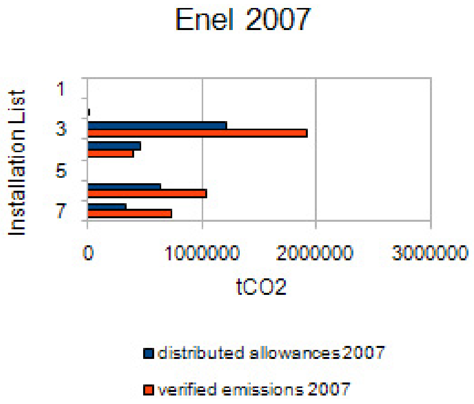

Figure 3.23: Distributed Allowances and Verified Emissions for Enel in 2007 from Reuters Carbon Market Data

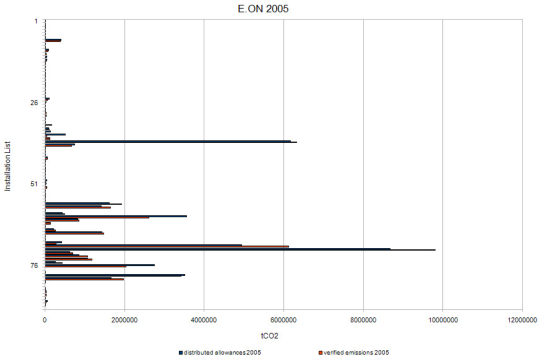

Figure 3.24: Distributed Allowances and Verified Emissions for Eon in 2005 from Reuters Carbon Market Data

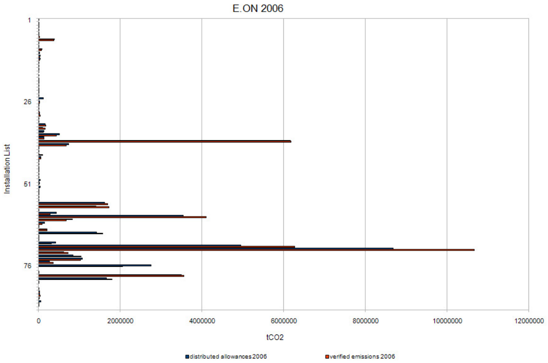

Figure 3.25: Distributed Allowances and Verified Emissions for Eon in 2006 from Reuters Carbon Market Data

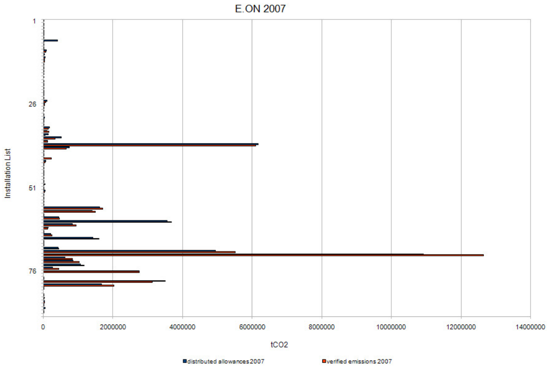

Figure 3.26: Distributed Allowances and Verified Emissions for Eon in 2007 from Reuters Carbon Market Data

Tables 3.13 and 3.14 a net short position of 2.7M EUAs. 31 out of 89 installations encounter a permits shortage, and the potential for permits transfer at the group level amounts to 1.6M EUAs. Hence, the risk pooling strategy by the parent company may save the costs of permits purchase on the market by 60%. The distribution of subsidiaries in Figures 3.22 to 3.24 also reveals a strong dispersion in terms of size, with one installation of 1M allocated allowances being consistently short over 2005-2007. In Table 3.12, Enel records a net deficit of allowances by 1.5M in 2007. Five out of nine installations are net short, which may only be compensated by another subsidiary by 0.05M EUAs. Figures 3.19 to 3.21 confirms this analysis, with most installations being net short in 2007. From this sub-sample of firms with permits shortages, our analysis has confirmed the potential for risk-sharing and thereby the pooling behavior at the group level that constitutes one of the main finding in Section 3.2.3. Let us now examine another sub-sample of firms with permits surpluses.

Among the three firms in our sample that are in a net long position, ArcelorMittal stands out as holding the largest surplus of allowances. Indeed, as shown in Table 3.8, it is net long by 18.9M EUAs during the compliance year 2007. There appears to be little room for permits pooling within subsidiaries. Only two out of twenty five installations are in a slightly short position, which may easily be counterbalanced by permits reallocation from other installations within the group. This situation is confirmed by the visual inspection of the data in Figures 3.10 to 3.12. Overall, the parent company is a net seller on the permits market. In Tables 3.9 to 3.11, Dalkia also exhibits a large surplus of 2.4M EUAs in 2007. Four out of 125 installations are net short, which supposes similarly that their deficit may be compensated internally by the parent company, thereby covering the risk of permits shortage for its subsidiaries. From Figures 3.13 to 3.15, one may remark that the distribution of installations is very heterogeneous with two installations above 1M of allocated allowances holding substantive surpluses. On a smaller scale, Eesti Energia displays in Table 3.12 a net long position of 0.27M EUAs in 2007 for one installation being reported in the Reuters Carbon Market Database. Without commenting further the possibility of pooling risks, Figures

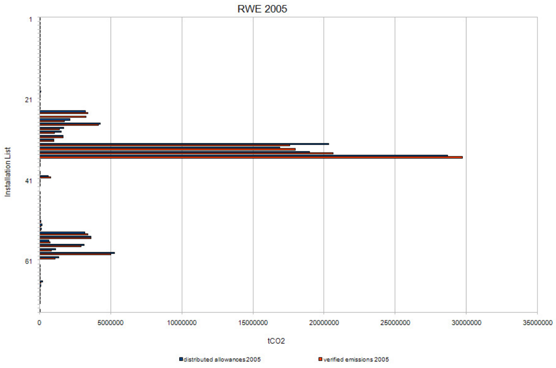

Figure 3.27: Distributed Allowances and Verified Emissions for RWE in 2005 from Reuters Carbon Market Data

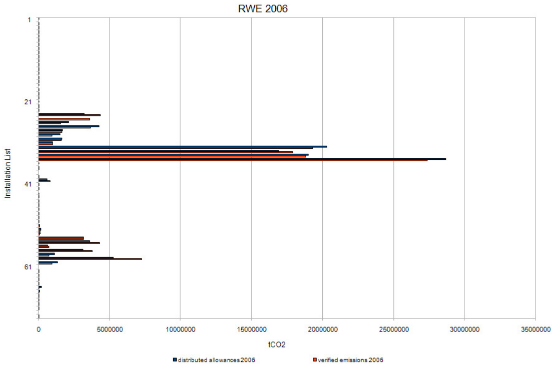

Figure 3.28: Distributed Allowances and Verified Emissions for RWE in 2006 from Reuters Carbon Market Data

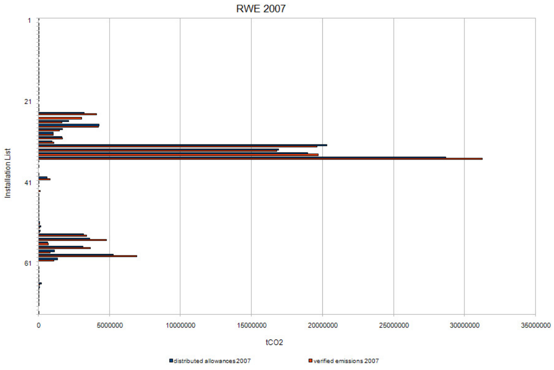

Figure 3.29: Distributed Allowances and Verified Emissions for RWE in 2007 from Reuters Carbon Market Data

3.16 to 3.18 reveals that this permits surplus has been increasing from 2005 to 2007. This second sub-sample of firms has confirmed the liquidity of the permits market in terms of extra-allowances available for trading during each compliance period. Given this high level of heterogeneity between firms, if parent companies are still in a net short position after pooling allowances internally, they may buy allowances on the market to be globally in compliance.

Finally, we comment the case of RWE which is the largest CO_2 emitter in the current European system with 128M EUAs verified emissions in 2007. From Tables 3.15 and 3.16, we observe that RWE is in a net *short* position by 8.6 M EUAs. 21 out of 73 installations encounter an permits shortage, which may be compensated internally by the parent company by 2.8M EUAs, *i.e.* 33% of the total permits shortage. The distribution of installations displayed in Figures 3.25 to 3.27 reveal that RWE gathers very large installations, with 4 installations being allocated above 1.5M EUAs in 2007. One installation above 2M EUAs allocated records a net *shortage* of allowances in 2007[55]. Our analysis has therefore confirmed the potential for permits pooling between subsidiaries by the parent company, which is conform to the theoretical finding on the optimal risk-sharing rule enforced by the agency derived in Section 3.2.3.

In this second section, we have detailed firms' behaviour when there are political uncertainties on the emissions permit market, especially with respect to the variation of political decisions concerning allocation. Our theoretical framework has underlined the importance of the banking behavior at the firm level, and of the allowance pooling management by an agency, in order to share optimally this risk. Our empirical discussion has shown the relevance of these risk-hedging strategies in the EU ETS, through the banking behavior at the installation levelm and the repartition of allowances at the group level by the parent company.

---

[55] This analysis complements the explanation of the central role played by German power producers on the EU ETS, which we have developed in Section 2.3 for the *negative* sign of the *combde* coefficient.

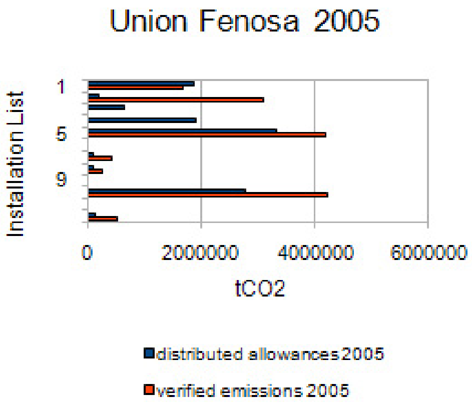

Figure 3.30: Distributed Allowances and Verified Emissions for Union Fenosa in 2005 from Reuters Carbon Market Data

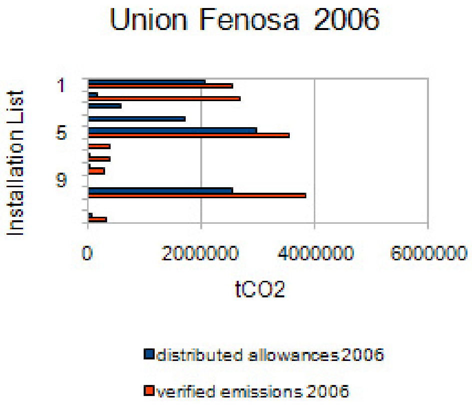

Figure 3.31: Distributed Allowances and Verified Emissions for Union Fenosa in 2006 from Reuters Carbon Market Data

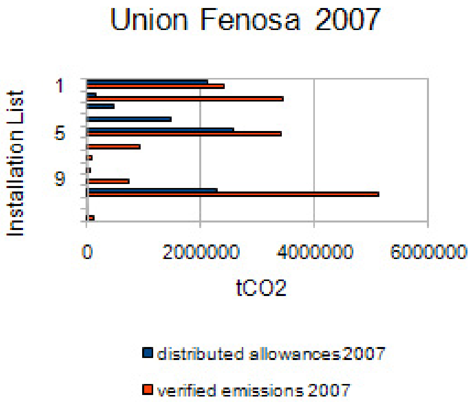

Figure 3.32: Distributed Allowances and Verified Emissions for Union Fenosa in 2007 from Reuters Carbon Market Data

Conclusion

Chapter 3 deals with firms' risk hedging strategies, in presence of political, economic or financial uncertainties, on a tradable permits market such as the EU ETS.

The first section of Chapter 3 constitutes an attempt to characterize investors' risk aversion on the European carbon market based on the newly available plain vanilla European option prices dataset taken from the European Climate Exchange. On the EU ETS, investors update their subjective beliefs about the distribution of allowance returns based on institutional constraints. More specifically, we test the empirical relationship between information disclosure by the European Commission and shifts in investors' risk aversion during the 2006 compliance event. The publication by the European Commission of 2006 verified emissions on April 30, 2007 is central to the analysis. It constitutes indeed the only event around which carbon derivatives products on the European Climate Exchange offer sufficient data to estimate changes in risk aversion *ex-ante* and *ex-post*. Based on the theoretical link that exists between the risk neutral and historical probabilities distribution on the one hand, and the risk aversion function on the other hand, we construct our estimation strategy by adapting to longer term options the existing methodology developed by (89), (1) and (131). Following (1), we estimate the risk neutral distribution non parametrically from option prices while the historical distribution is recovered semi parametrically from futures using an asymmetric GARCH procedure, as presented in (9) and (131). Our study ranges from October 1, 2006 to November 23, 2007. Since the shifts in risk aversion are more likely to occur around yearly compliance events, we split our dataset on April 30, 2007.

Our findings may be summarized as follows. First, we find a lower level of implied volatility after the EC communication of the 2006 compliance results for contracts of maturities December 2008 and 2009. Second, we uncover the exact opposite of the usual leverage effect found on equity markets whereby periods of increasing markets coincide with periods of higher volatility. The former result emphasizes the critical role of information disclosure that was expected. The latter result reveals that the risk is associated with *increasing* allowance prices after the

2006 compliance event in a context of a low environmental constraint on the EU ETS. Third, the pricing kernel reacts counter-cyclically. Fourth, based on a comparison for a comparable range of maturities and moneynesses, we show that risk aversion is higher on the European carbon market than on equity markets during our study period. We believe that this study will be replicable if the future development of the European carbon market allows for more frequent and structured revelation of official information by the European Commission. Similarly, it may be possible to adapt the methodology and conduct further research around quarterly or monthly events studies to identify whether other events than compliance events may also have strong effects on changes in investors' preferences.

The second section of Chapter 3 shows that, once permits trading between firms has occurred, the presence of uncertainty regarding political decision changes in permits allocation rules may provide incentives for firms to bank permits in order to hedge against this risk. The conditions under which risk-neutral firms hedge their risk by banking permits is linked to the third derivative of the production function. Besides, we have characterized an optimal risk-sharing rule when the uncertainty is associated either to the repartition of permits between firms, or to the global permits allocation. This rule depends on firms' technological characteristics, and more precisely on the concavity of the production function with respect to pollution.

As for the empirical evidence, we have selected three types of firms operating on the EU ETS characterized by the highest allowances surpluses, the highest allowances shortages and the highest CO_2 emissions level on the market. Thus, we obtain a sample of seven firms out of 800 included in the Reuters Carbon Market Database. These case studies allow us to provide some qualitative insights of the theoretical results. First, the investigation of the banking behavior has revealed asymmetric banking (borrowing) patterns at the installation level as a consequence of varying net long (short) positions during 2005-2007. Second, the investigation of the pooling behavior has confirmed the potential for internal permits transfers between subsidiaries at the group level. The former result is consistent with what was expected from Section 3.2.2, *i.e.* to observe a variation of the number of permits banked by firms in reaction to political uncertainty concerning Phase II of the EU ETS. The latter result illustrates the economic logic derived in Section 3.2.3, *i.e.* the parent company acts as the agency to introduce an optimal risks-sharing rule between subsidiaries.

From a regulatory viewpoint, the management of the environment through the introduction of permits implies that firms have the ability to bank permits in order to hedge the risks linked to political decision changes. The banking of permits is not motivated here by adaptation concerns to environmental constraints, but by the need to counter-balance political risks attached with the introduction of permits systems. Our analysis has therefore confirmed the key role played by banking provisions in order to cope with the potential political uncertainty related to the creation of permits markets.

Appendix to Chapter 3

Appendix C

3.1 Risk Aversion and Institutional Information Disclosure on the European Carbon Market: a Case-Study of the 2006 Compliance Event

3.1.3 Estimation Methodology

Risk-neutral distribution, objective distribution and the pricing kernel

Let S_t be the price of a financial asset at time t. For any date that is superior to the date of today, the price of this asset is uncertain, and this uncertainty is quantified though probability distribution functions. The subjective distribution represents the expectations of the representative agent for the future price of this asset. It is a distribution that gives a probability to each possible future state for a given asset and maturity, according to the risk perception of the representative agent. This representative agent is supposed to summarize the global view of each of the market participant.

On the contrary, the risk neutral distribution is supposed to be the distribution that makes agents neutral toward risk and is used to give a fair price to assets. In a one period framework, this distribution is such as:

$$S_0 = e^{-r}\mathbb{E}^Q[S_1] \tag{3.40}$$

where r is the risk free rate and $\mathbb{E}^Q[.]$ is the expectation of S_1 under the risk neutral distribution Q. This distribution is assumed to be unique. Under this distribution, there should be no arbitrage opportunity and the risk free rate discounted asset prices should be martingale. In order to find a relation that looks like equation (3.40), we need to find the right probability distribution - that cannot be the subjective one - and that is called risk neutral. Here, we present the link between the risk neutral and the subjective distribution.

There exists several presentations for the link between risk neutral and subjective distribution. Let $U(.)$ be the utility function of the representative agent of the economy that is considered. In a single period framework, this consumer is supposed to maximize the aggregated utility function $F(.)$:

$$F(X) = U(C_0) + \beta\mathbb{E}^H[U(C_1(X))] \tag{3.41}$$

with X the level of savings and W the initial endowment for this agent. The agent's consumption at time 0 is given by:

$$C_0 = W - X \tag{3.42}$$

On the contrary, at time 0, the agent is supposed to invest X in a financial asset whose price at time 0 is S_0 and S_1 at time 1, yielding a risky return $R = \frac{S_1}{S_0} - 1$. Then, at time 1, the agent's consumption under uncertainty is:

$$C_1 = X(1 + R) \tag{3.43}$$

where R is a stationary random variable. With these settings in mind, the aggregated utility function can be set to:

$$F(X) = U(W_0 - X) + \beta \mathbb{E}^H[U(X(1+R))] \tag{3.44}$$

β represents a psychologic discount factor. $\mathbb{E}^H[.]$ underlines the fact that the utility expectation is computed in respect with the subjective distribution of R, *i.e.* the subjective probability distribution that the representative agent associates to R. Finally, the optimization program is:

$$\max_X F(X) \tag{3.45}$$

The first order conditions of the optimization problem yield:

$$\beta \mathbb{E}^H \left[S_1 \frac{U'(C_1(S_1))}{U'(C_0)} \right] = S_0 \tag{3.46}$$

This relation is true for any asset in the economy and thus for a pure discount bond, paying without any risk \$1 in any state of the economy in the second period. This asset's price at time 1 is e^{-r}. For this kind of asset, equation (3.46) is now:

$$\beta \mathbb{E}^H \left[\frac{U'(C_1(S_1))}{U'(C_0)} \right] = e^{-r} \tag{3.47}$$

Combining equations (3.46) and (3.47), we obtain the link between RN and subjective distribution:

$$S_0 = e^{-r} \int S_1 \frac{\frac{U'(C_1(S_1))}{U'(C_0)}}{\mathbb{E}^H \left[\frac{U'(C_1(S_1))}{U'(C_0)} \right]} h(S_1) dS_1 = e^{-r} \int S_1 \xi(S_1) h(S_1) dX = e^{-r} \mathbb{E}^Q[S_1] \tag{3.48}$$

where $h(.)$ is the subjective distribution density function associated to the uncertain future price of the asset S_1.

We can note that:

- $h(S_1)\xi(S_1) \geq 0$ a.s.
- $\int h(S_1)\xi(S_1)dS_1 = 1$

which is consistent with the idea that $h(S_1)\xi(S_1)$ is a probability density function.

In so far as we assumed that there exist a unique distribution that is such that:

$$S_0 = e^{-r}\mathbb{E}[S_1] \tag{3.49}$$

and that this distribution is the risk neutral one, we just found it, with a density function that is equal to $\xi(S_1)h(S_1)$. $\xi(.)$ is often refereed to as the *Stochastic Discount Factor* ((Cochrane (2002), Gourieroux et Montfort (2007))). The risk neutral density function $q(.)$ is given by:

$$q(S_1) = \xi(S_1)h(S_1) \tag{3.50}$$

By slightly changing the notations, we get the following result:

$$\xi(S_1) = \lambda U'(C_1(S_1)) \tag{3.51}$$

with:

$$\frac{1}{\lambda} = \frac{U'(C_0)}{\mathbb{E}^H\left[\frac{U'(C_1(S_1))}{U'(S_0)}\right]} \tag{3.52}$$

which leads to rewriting equation (3.50), and by taking log on both sides we get:

$$\log(q(S_1)) = \log\lambda + \log U'(C_1(X)) + \log h(X) \tag{3.53}$$

By differentiating the latter equation we obtain the relation highlighted by Leland (1980):

$$\frac{q'(S_1)}{q(S_1)} = \frac{U''(C_1(S_1))}{U'(C_1(S_1))} + \frac{h'(S_1)}{h(S_1)} \tag{3.54}$$

where $\frac{U''(C_1(S_1))}{U'(C_1(S_1))}$ is by *definition* the representative agent's risk aversion. Thus, the market risk aversion is then given by:

$$RA(S_1) = -\frac{U''(S_1)}{U'(S_1)} = \frac{h'(S_1)}{h(S_1)} - \frac{q'(S_1)}{q(S_1)} \tag{3.55}$$

From the previous calculations, we get the following two lemma:

Lemma 1 *Let S_t be the price of a financial asset at time t. Let $h(.)$ be the density function associated to S under the subjective distribution. Then we have:*

$$S_t = e^{-r(T-t)}\mathbb{E}^Q[S_T] \tag{3.56}$$

where Q is for the risk neutral measure. The risk neutral density function is then defined by:

$$q(S_T) = h(S_T)\xi(S_T) \tag{3.57}$$

with $\xi(.)$ the stochastic discount factor, that is equal to:

$$\xi(S_T) = \frac{U'(C_T)}{U'(C_t)} \frac{1}{\mathbb{E}^H\left[\frac{U'(C_T)}{U'(C_t)}\right]} \tag{3.58}$$

where $\mathbb{E}^H[.]$ is the expectation under the subjective distribution.

Lemma 2 *Under the settings of the Lemma 1 concerning the representative agent's risk aversion $\frac{U''(C_T)}{U'(C_T)}$, the market risk aversion is equal to:*

$$RA(S_T) = \frac{h'(S_T)}{h(S_T)} - \frac{q'(S_T)}{q(S_T)} \tag{3.59}$$

The projected pricing kernel

The previous developement dwelled on the consumption of the representative agent, which is not a perfectly observale asset. In order to use financial assets' returns as the only measurable state variable, we prefer to use the *projected pricing kernel* as developed in Cochrane (2002) and Rosenberg and Engle (2002). Let

$$\xi(C_T(S_T)) \tag{3.60}$$

be the pricing kernel, using the previous notations. This pricing kernel is only an indirect function of S_T, through the final consumption of the representative agent, in so far as:

$$\xi(C_T(S_T)) = \frac{U'(C_T)}{U'(C_t)} \frac{1}{\mathbb{E}^H\left[\frac{U'(C_T)}{U'(C_t)}\right]} \tag{3.61}$$

The basic pricing relation for a given asset $S_.$ is:

$$\begin{aligned}
S_t &= \mathbb{E}[\xi(C_T)S_T] && (3.62)\\
&= \int_{S_T}\int_{C_T} \xi(C_T)S_T h(S_T, C_T)dS_T dC_T && (3.63)\\
&= \int_{S_T}\int_{C_T} \xi(C_T)S_T h(C_T|S_T)h(S_T)dS_T dC_T && (3.64)\\
&= \int_{S_T} \mathbb{E}[\xi(C_T)|S_T]S_T h(S_T)dS_T && (3.65)\\
&= \int_{S_T} \tilde{\xi}(S_T)S_T h(S_T)dS_T && (3.66)\\
&= \mathbb{E}[\tilde{\xi}(S_T)S_T] && (3.67)
\end{aligned}$$

with $\tilde{\xi}(S_T) = \mathbb{E}[\xi(C_T)|S_T]$ the projected pricing kernel. As shown in Cochrane (2002), working with $\xi(.)$ or $\tilde{\xi}(.)$ is equivalent, but makes the estimation considerably easier. The stochastic discount factor only depends on the asset price, and not on the representative agent consumption. See the references in Rosenberg and

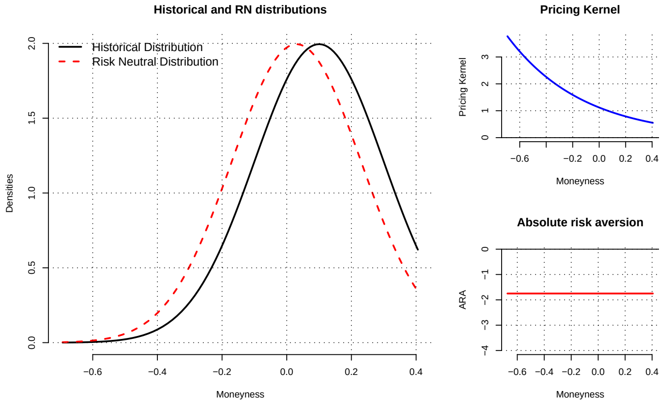

Figure 3.33: The pricing kernel in the Black Scholes economy

Engle (2002) for similar works using proxy for the consumption.

In the Black Scholes (1973) economy, with a Constant Absolute Risk Aversion utility function, the pricing kernel derivative is:

$$\frac{d\mathbb{Q}}{d\mathbb{P}} = e^{A(t,T)+B(t,T)\log\frac{S_T}{S_t}}$$

with $\mathbb{Q}$ the measure of the risk-neutral distribution and $\mathbb{P}$ the measure of the historical distribution.

The pricing kernel is an exponential affine function of the state variable: the logarithm of the price. Thus, the pricing kernel contains an implicit assumption on the slope of the risk aversion and gives us a distance measure between the risk-neutral and historical distributions as displayed in Figure 3.31.

Concerning the projection of the pricing kernel on a single state variable of interest, see the discussion developed in Section 3.1.3.

Statistical Test of the Futures Spread

Let $F(t,T)$ be the futures price at time t for delivery of a commodity at T. Let $S(t)$ be the spot price at t. In the absence of storage costs for CO_2 allowances, it is equivalent to test $S_t = F_T e^{-r(T-t)}$ or $F_{T_1} e^{-r(T_1-t)} = F_{T_2} e^{-r(T_2-t)}$ since the value of both discounted future contracts in the latter equation are equal to S_t.

Sample mean	0.29
Sample Std. Dev.	0.02
Test Statistics	13.19
P-value	0.00

Table 3.1: December 2008 and December 2009 Futures Spread Test Statistics

Let $x_t = F_{Dec.08}e^{-r(T_{Dec.08}-t)} - F_{Dec.09}e^{-r(T_{Dec.09}-t)}$ be a stationary weakly dependent process. Testing that the futures are only compounded values of the spot asset simply means to test that $\mathbb{E}[x_t] = 0$ statistically. The null hypothesis of our test is that:

$$\begin{cases} H_0: & E[x_t] = 0 \\ H_1: & E[x_t] \neq 0 \end{cases} \tag{3.68}$$

Under the hypothesis of the Lindberg-Levy variant of the Central Limit Theorem, it is straightforward to check that the population estimator of the former expectation has the following distribution:

$$n\left(\frac{1}{n}\sum_{t=1}^{n} x_t - \mathbb{E}[x_t]\right) \xrightarrow{\mathcal{L}} N\left(0, \Sigma\right), \tag{3.69}$$

with $\Sigma = n^2 \times \mathbb{V}\left[\frac{1}{n}\sum_{t=1}^{n} x_t\right]$. This latter quantity is estimated through the Newey West estimator for asymptotic variance (See e.g. (78)). Under the null hypothesis, the test statistics is

$$t_n = \frac{\frac{1}{n}\sum_{t=1}^{n} x_t}{\Sigma/n} \tag{3.70}$$

and should belong to the usual confidence interval up to a 95% risk level. For further details, see (73) (Univariate Central Limit Theorem, p.116).

	Strikes in €	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
December 2008	**Call prices**	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	156	156
	Put prices	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	156	156
	Total	570	570	570	570	570	570	570	570	570	570	570	570	570	570	570	570	312	312
	Strikes in €	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
December 2009	**Call prices**	247	247	247	247	247	247	247	247	247	247	247	247	247	247	247	156	156	156
	Put prices	247	247	247	247	247	247	247	247	247	247	247	247	247	247	247	156	156	156
	Total	494	494	494	494	494	494	494	494	494	494	494	494	494	494	494	312	312	312

Table 3.2: Number of available option prices from ECX

	Strikes in €	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
December 2008	**Call prices**	N.A.	N.A.	50	50	142	143	73	159	213	58	185	317	96	500	222	158	N.A.	100
	Put prices	185	80	118	172	103	58	58	200	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
	Total	185	80	168	222	246	200	132	359	213	58	185	317	96	500	222	158	N.A.	100
	Strikes in €	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
December 2009	**Call prices**	N.A.	N.A.	N.A.	N.A.	135	N.A.	50	N.A.	N.A.	366	N.A.	N.A.	N.A.	N.A.	217	N.A.	N.A.	N.A.
	Put prices	N.A.	N.A.	N.A.	15	200	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
	Total	N.A.	N.A.	N.A.	15	335	N.A.	50	N.A.	N.A.	366	N.A.	N.A.	N.A.	N.A.	217	N.A.	N.A.	N.A.

Table 3.3: Average volume contract for each strike from ECX

	Min	**Max**	**Average**	**Std. Dev.**	**Skewness**	**Excess Kurtosis**	**Jarque Berra test**	**Box pierce test**
December 2008 contract								
Returns	-0,092	0,094	0,001	0,026	-0,404	1,667	0	0,202
Residual	-2,644	2,027	-0,002	0,91	-0,345	-0,104	0,056	0,265
Residual sample #1	-2,618	1,963	-0,026	0,872	-0,452	0,355	0,091	0,236
Residual sample #2	-2,644	2,027	0,017	0,939	-0,262	-0,347	0,306	0,865
December 2009 contract								
Returns	-0,088	0,101	0,001	0,025	-0,259	1,685	0	0,332
Residual	-2,619	2,076	-0,005	0,908	-0,306	-0,149	0,097	0,377
Residual sample #1	-2,373	2,086	-0,034	0,871	-0,337	0,172	0,292	0,467
Residual sample #2	-2,619	1,985	0,018	0,936	-0,272	-0,31	0,307	0,837

Table 3.4: Descriptive statistics for the December 2008 and December 2009 contracts

with *StdDev.* the standard deviation.

		ω_0	ω_1	α	β	δ	μ	**Log-likelihood**
December 2008 contract								
ARCH(1)	Estimate	0,079	-0,033	0,088	-	-	0,129	-666,097
	t-Stat.	6,074	-2,261	12,054	-	-	6,036	0,000
GARCH(1,1)	Estimate	0,010	-0,006	0,102	0,812	-	0,150	-659,105
	t-Stat.	3,552	-5,336	54,798	152,358	-	8,159	0,000
GJR-GARCH(1,1)	Estimate	0,009	-0,006	0,128	0,823	-0,061	0,181	-658,519
	t-Stat.	3,799	-5,859	39,471	164,938	-18,046	9,416	0,000
December 2009 contract								
ARCH(1)	Estimate	0,081	-0,037	0,078	-	-	0,136	-659,259
	t-Stat.	5,800	-2,378	12,292	-	-	6,625	0,000
GARCH(1,1)	Estimate	0,009	-0,006	0,105	0,808	-	0,150	-652,274
	t-Stat.	3,832	-5,544	54,869	155,761	-	8,709	0,000
GJR-GARCH(1,1)	Estimate	0,009	-0,006	0,132	0,820	-0,064	0,181	-651,645
	t-Stat.	4,238	-6,250	38,876	170,801	-18,370	10,022	0,000

Table 3.5: Estimation of the time series models for the December 2008 and December 2009 contracts

The estimated model is:

$$
\begin{aligned}
&r_t = \mu + \sigma_t \epsilon_t \\
&\sigma_t^2 = \omega_0 + \omega_1 I_t + \alpha (r_{t-1} - \mu)^2 + \beta \sigma_{t-1}^2 + \delta \max(0, -(r_{t-1} - \mu))^2 \\
&\epsilon_t \sim N(0,1)
\end{aligned}
$$

3.2 Bankable Permits under Uncertainty and Optimal Risk Management Rules: Theory and Empirical Evidence

3.2.4 Empirical Evidence

Installation List	Country	Activity	Permit Identifier	Distributed Allowances 2005	Verified Emissions 2005	Net Short/Long Position 2005	Distributed Allowances 2006	Verified Emissions 2006	Net Short/Long Position 2006	Distributed Allowances 2007	Verified Emissions 2007	Net Short/Long Position 2007
1	France	Combustion	6301117	32067	21607	10460	32067	16732	15335	32067	18734	13333
2	Romania	Roasting	02-14-2007	0		0	0		0	10740796		10740796
3	France	Iron	6201286	264048	208249	55799	264048	236087	27961	264048	2378	261670
4	Belgium	Iron	VL201	9358697	4896453	4462244	9358697	5238916	4119781	9358697	4686947	4671750
5	Romania	Cement	05-24-2007	0		0	0		0	57844	3059	54785
6	Romania	Roasting	05-23-2007	0		0	0		0	210315	96994	113321
7	Spain	Iron	ES152805000837	60495	62372	-1877	60495	72612	-12117	60495	72619	-12124
8	France	Iron	6401052	9140902	8494864	646038	9140902	8725948	414954	9140901	7950830	1190071
9	Spain	Combustion	ES104601001147	0		0	24239	15882	8357	24239	16334	7905
10	Czech Rep	Iron	CZ-0435-07	0	0	0	0	0	0	0	7048	-7048
11	Belgium	Iron	VL202	229692	185972	43720	229692	207584	22108	229692	17634	212058
12	Germany	Combustion	14310-0819	31449	87444	-55995	31449	72779	-41330	249966	82266	167700
13	Germany	Iron	14220-0024	3416399	2582432	833967	3416399	2854331	562068	3416399	2984047	432352
14	Germany	Iron	14220-0033	96771	79619	17152	96771	100849	-4078	96771	97972	-1201
15	Germany	Cement	14240-0073	163007	136510	26497	163007	167828	-4821	163007	155281	7726
16	Germany	Iron	14225-0001		0	0		0	0			0
17	Germany	Iron	14220-0038	2101714	1501581	600133	2101714	1951193	150521	2101714	1852048	249666
18	France	Iron	7000956	12244979	11534467	710512	12244979	11578949	666030	12244978	12059456	185522
19	France	Combustion	7000955	48558	29108	19450	48558	27512	21046	48559	25334	23225
20	France	Combustion	5101363	112163	70993	41170	112163	71407	40756	112162	6783	105379
21	France	Iron	6201364	4615803	4353850	261953	4615803	4737538	-121735	4615802	4321829	293973
22	Germany	Iron	14220-0007	284157	264572	19585	289805	267586	22219	286981	272139	14842
23	Belgium	Iron	WAI133P047	61946	3376	58570	61947	22311	39636	61947	25233	36714
24	Belgium	Iron	WAI141P047	317512	186099	131413	317513	212166	105347	317513	177203	140310
25	Germany	Iron	14225-0004		0	0		0	0			0
Total				42580359	34699568	7880791	42610248	36578210	6032038	53834893	34932168	18902725

Table 3.6: Distributed Allowances, Verified Emissions and Net Short/Long Position for ArcelorMittal (2005-2007) from Reuters Carbon Market Data

Installation List	Country	Activity	Permit Identifier	Distributed Allowances 2005	Verified Emissions 2005	Net Short/Long Position 2005	Distributed Allowances 2006	Verified Emissions 2006	Net Short/Long Position 2006	Distributed Allowances 2007	Verified Emissions 2007	Net Short/Long Position 2007
1	Germany	Combustion	14310-0936	1408	0	1408	1408	0	1408	1408		1408
2	France	Combustion	5401474	16643	12462	4181	16643	1269	15374	16642	13037	3605
3	France	Combustion	5401291	8899	6932	1967	8899	6822	2077	8898	6236	2662
4	Poland	Combustion	PL-0119-05	92	8699	-8607	92	8672	-8580	92	6454	-6362
5	Poland	Combustion	PL-0118-05	52	5305	-5253	52	5563	-5511	52	5139	-5087
6	France	Combustion	6506250	12359	0	12359	12359	0	12359	0		0
7	France	Combustion	10100059	39363	18349	21014	39363	29305	10058	39364	30138	9226
8	France	Combustion	6804213	29774	25736	4038	29774	25544	4230	29775	26541	3234
9	France	Combustion	6506348	29086	24995	4091	29086	24727	4359	29086	2144	26942
10	France	Combustion	6507039	132299	100653	31646	132299	10219	122080	1323	104265	-102942
11	France	Combustion	6301088	13936	2917	11019	13936	2321	11615	13935	2205	11730
12	France	Combustion	10000670	37602	28772	8830	37602	28287	9315	37601	26837	10764
13	France	Combustion	7001019	15176	11016	4160	15176	8393	6783	15176	824	14352
14	France	Combustion	5701271	24004	18023	5981	24004	17909	6095	24003	16718	7285
15	France	Combustion	7001008	16529	10524	6005	16529	99	16430	16529	944	15585
16	France	Combustion	5600126	54	182	-128	54	473	-419	55	167	-112
17	France	Combustion	5600072	18173	12367	5806	18173	9996	8177	18173	8647	9526
18	France	Combustion	7000994	4655	2285	2370	4655	2258	2397	4654	2171	2483
19	France	Combustion	7001007	13821	9724	4097	13821	9209	4612	1382	7785	-6403
20	France	Combustion	7001005	25248	19230	6018	25248	20033	5215	25247	18517	6730
21	France	Combustion	10001610	20674	8928	11746	20674	8598	12076	20674	8383	12291
22	France	Combustion	6103619	3614	2144	1470	3614	2248	1366	3615	2578	1037
23	France	Combustion	7001215	9212	5488	3724	9212	5702	3510	9212	6036	3176
24	France	Combustion	7204930	25699	15622	10077	25699	19392	6307	25700	13831	11869
25	France	Combustion	5101900	23455	17960	5495	23455	17693	5762	23454	16841	6613
26	France	Combustion	6506346	9732	6451	3281	9732	6644	3088	9733	592	9141
27	France	Combustion	5104966	14428	9358	5070	14428	8409	6019	14427	825	13602
28	France	Combustion	6506331	8538	6699	1839	8538	6577	1961	8537	5426	3111
29	France	Combustion	6104721	6556	4630	1926	6556	6031	525	6555	1468	5087
30	France	Combustion	10000710	15690	12298	3392	15690	12164	3526	15690	12378	3312
31	France	Combustion	10004212	44547	29785	14762	44547	32304	12243	44546	28353	16193
32	Czech Rep	Combustion	CZ-0317-05	1536408	1272513	263895	1536408	1395596	140812	1536408	1366581	169827
33	France	Combustion	5902116	105280	77601	27679	105280	89461	15819	105280	86921	18359
34	Czech Rep	Combustion	CZ-0320-05	277	168	109	277	0	277	277	19	258
35	Czech Rep	Combustion	CZ-0236-05	121980	2453	119527	121980	1472	120508	121980	1854	120126
36	Czech Rep	Combustion	CZ-0326-05	12412	10650	1762	12412	10133	2279	12412	9864	2548
37	Czech Rep	Combustion	CZ-0323-05	1187	652	535	1187	612	575	1187	538	649
38	Czech Rep	Combustion	CZ-0324-05	9694	6	9688	9694	0	9694	9694		9694
39	France	Combustion	6506493	14174	11624	2550	14174	13052	1122	14174	8562	5612
40	France	Combustion	6506496	22855	14020	8835	22855	19605	3250	22856	17724	5132
41	France	Combustion	6506494	13637	11096	2541	13637	10781	2856	13636	9535	4101
42	France	Combustion	6506495	17019	13293	3726	17019	12866	4153	17020	11455	5565

Table 3.7: Distributed Allowances, Verified Emissions and Net Short/Long Position for Dalkia, Installations #1-42 (2005-2007) from Reuters Carbon Market Data

Installation List	Country	Activity	Permit Identifier	Distributed Allowances 2005	Verified Emissions 2005	Net Short/Long Position 2005	Distributed Allowances 2006	Verified Emissions 2006	Net Short/Long Position 2006	Distributed Allowances 2007	Verified Emissions 2007	Net Short/Long Position 2007
43	France	Combustion	12100006	258367	161935	96432	258367	160822	97545	258366	161574	96792
44	France	Combustion	6205585	30298	19733	10565	30298	18655	11643	30297	16661	13636
45	Czech Rep	Combustion	CZ-0322-05	25331	10436	14895	25331	12526	12805	25331	3148	22183
46	France	Combustion	6702704	45079	36378	8701	45079	3518	41561	45079	33679	11400
47	Czech Rep	Combustion	CZ-0329-05	259849	231008	28841	259849	212172	47677	259849	212777	47072
48	Czech Rep	Combustion	CZ-0330-05	145109	134628	10481	145109	128543	16566	145109	120889	24220
49	Czech Rep	Combustion	CZ-0328-05	500434	459501	40933	500434	463885	36549	500434	422977	77457
50	Czech Rep	Combustion	CZ-0327-05	83906	74250	9656	83906	78063	5843	83906	79149	4757
51	Czech Rep	Combustion	CZ-0321-05	485373	438908	46465	485373	398661	86712	485373	425107	60266
52	Czech Rep	Combustion	CZ-0325-05	530000	547298	-17298	530000	544509	-14509	530000	436681	93319
53	Czech Rep	Combustion	CZ-0318-05	198090	172429	25661	198090	160004	38086	198090	155261	42829
54	Czech Rep	Combustion	CZ-0237-05	1071343	1112121	-40778	1071343	1080780	-9437	1071343	946572	124771
55	Czech Rep	Combustion	CZ-0362-05	6872	5169	1703	6872	486	6386	0	4312	-4312
56	Czech Rep	Combustion	CZ-0319-05	47017	33895	13122	47017	34253	12764	47017	35112	11905
57	France	Combustion	5100692	18226	14319	3907	18226	13604	4622	18226	11914	6312
58	France	Combustion	5302859	16138	12453	3685	16138	12528	3610	16138	11062	5076
59	France	Combustion	6301089	27413	2851	24562	27413	933	26480	27414	764	26650
60	France	Combustion	6400007	26594	22012	4582	26594	19942	6652	26594	9308	17286
61	France	Combustion	5101812	23347	18309	5038	23347	17749	5598	23348	1708	21640
62	France	Combustion	5900460	8597	5653	2944	8597	749	7848	8597	6466	2131
63	France	Combustion	6506455	28045	21164	6881	28045	20907	7138	28046	19979	8067
64	France	Combustion	10000729	49206	21583	27623	49206	21487	27719	49206	22161	27045
65	France	Combustion	6000326	1608	1947	-339	1608	3886	-2278	1608	322	1286
66	France	Combustion	6103448	9752	8252	1500	9752	7132	2620	9752	739	9013
67	France	Combustion	5800444	58868	45017	13851	58868	45461	13407	58869	41996	16873
68	France	Combustion	5800446	16564	12478	4086	16564	12446	4118	16563	11243	5320
69	France	Combustion	5101102	28111	19981	8130	28111	17844	10267	28112	16994	11118
70	France	Combustion	5702209	20950	17017	3933	20950	15687	5263	20949	15035	5914
71	France	Combustion	6202458	10201	7994	2207	10201	7667	2534	10201	7051	3150
72	France	Combustion	7001170	41867	33151	8716	41867	32761	9106	41866	32409	9457
73	France	Combustion	5802051	11296	10635	661	11296	8914	2382	11297	4234	7063
74	France	Combustion	5800448	59079	43790	15289	59079	47574	11505	59080	41412	17668
75	France	Combustion	6505672	10670	7607	3063	10670	7533	3137	10669	6999	3670
76	France	Combustion	6505673	12676	9341	3335	12676	977	11699	12677	9116	3561
77	France	Combustion	6507535	16055	11627	4428	16055	11721	4334	16055	10796	5259
78	France	Combustion	6505669	6491	4951	1540	6491	5103	1388	6491	4455	2036
79	France	Combustion	6400260	9141	7845	1296	9141	6535	2606	914	581	333
80	France	Combustion	6501948	23865	16709	7156	23865	16052	7813	23865	12233	11632
81	France	Combustion	5701841	11568	8830	2738	11568	8409	3159	11568	8182	3386
82	France	Combustion	10004438	38511	29523	8988	38511	14414	24097	38512	3456	35056
83	France	Combustion	10004382	21041	16679	4362	21041	16443	4598	21040	16543	4497
84	France	Combustion	7001213	4091	6657	-2566	4091	16214	-12123	4090	15879	-11789

Table 3.8: Distributed Allowances, Verified Emissions and Net Short/Long Position for Dalkia, Installations #43-84 (2005-2007) from Reuters Carbon Market Data

Installation List	Country	Activity	Permit Identifier	Distributed Allowances 2005	Verified Emissions 2005	Net Short/Long Position 2005	Distributed Allowances 2006	Verified Emissions 2006	Net Short/Long Position 2006	Distributed Allowances 2007	Verified Emissions 2007	Net Short/Long Position 2007
85	France	Combustion	7001214	169972	107279	62693	169972	106738	63234	169972	10343	159629
86	France	Combustion	5801277	36927	29429	7498	36927	30474	6453	36927	28154	8773
87	France	Combustion	7001023	23864	6312	17552	23864	8938	14926	23863	5267	18596
88	France	Combustion	7001022	11120	8897	2223	11120	9131	1989	11121	899	10222
89	France	Combustion	7001564	12166	7187	4979	12166	8624	3542	12167	8532	3635
90	France	Combustion	7000998	8976	5693	3283	8976	5988	2988	8977	5953	3024
91	France	Combustion	5800447	17184	8190	8994	17184	8292	8892	17185	7436	9749
92	France	Combustion	6702335	22246	17541	4705	22246	16967	5279	22247	17494	4753
93	France	Combustion	10800048	40238	32892	7346	40238	28803	11435	40238	28444	11794
94	France	Combustion	6600637	69569	48950	20619	69569	38505	31064	69570	36534	33036
95	France	Combustion	10000045	59542	44876	14666	59542	41564	17978	59541	38008	21533
96	Poland	Combustion	PL-0097-05	47400	16252	31148	47400	10957	36443	47400	7430	39970
97	Poland	Combustion	PL-0098-05	1752300	1697392	54908	1752300	1622121	130179	1752300	1505584	246716
98	Poland	Combustion	PL-0104-05	649700	540263	109437	649700	538958	110742	649700	545138	104562
99	Poland	Combustion	PL-0103-05	1151200	1039988	111212	1151200	949324	201876	1151200	1105197	46003
100	Poland	Combustion	PL-0102-05	1057400	956264	101136	1057400	932665	124735	1057400	947299	110101
101	France	Combustion	6504212	100808	59494	41314	100808	5781	95027	100808	54519	46289
102	France	Combustion	6803995	59296	41493	17803	59296	40881	18415	59296	38993	20303
103	Slovak Rep	Combustion	105-027-2005	7865	7049	816	7865	6787	1078	7864	5735	2129
104	Slovak Rep	Combustion	105-024-2005	7881	7317	564	7880	6376	1504	7880	5726	2154
105	Slovak Rep	Combustion	105-019-2005	6743	4585	2158	6743	436	6307	6742	3283	3459
106	Slovak Rep	Combustion	105-020-2005	7251	6358	893	7251	5854	1397	7251	5094	2157
107	Slovak Rep	Combustion	105-033-2005	13556	12696	860	13556	12053	1503	13556	10797	2759
108	Slovak Rep	Combustion	105-034-2005	5124	890	4234	5124	380	4744	5124	193	4931
109	Slovak Rep	Combustion	105-029-2005	7165	6288	877	7165	5669	1496	7165	4927	2238
110	Slovak Rep	Combustion	105-017-2005	5744	5293	451	5744	4851	893	5744	4266	1478
111	Slovak Rep	Combustion	105-008-2005	6397	5974	423	6397	5386	1011	6396	4759	1637
112	Slovak Rep	Combustion	105-032-2005	7912	7452	460	7912	6862	1050	7911	6015	1896
113	Slovak Rep	Combustion	105-026-2005	6479	6415	64	6478	581	5897	6478	5037	1441
114	Slovak Rep	Combustion	105-025-2005	4964	4551	413	4964	426	4538	4963	3857	1106
115	Slovak Rep	Combustion	105-021-2005	4715	5219	-504	4715	4293	422	4715	3631	1084
116	Slovak Rep	Combustion	105-028-2005	7396	5968	1428	7395	5810	1585	7395	5080	2315
117	Slovak Rep	Combustion	105-016-2005	6425	5889	536	6425	5438	987	6424	4694	1730
118	Slovak Rep	Combustion	105-023-2005	5520	5372	148	5520	5001	519	5520	4457	1063
119	Slovak Rep	Combustion	105-031-2005	6781	6477	304	6780	5853	927	6780	5218	1562
120	Slovak Rep	Combustion	105-030-2005	5044	4451	593	5044	4152	892	5044	3748	1296
121	Slovak Rep	Combustion	105-022-2005	6788	6646	142	6788	6159	629	6788	5436	1352
122	Slovak Rep	Combustion	105-018-2005	4117	3499	618	4116	3132	984	4116	2854	1262
123	Romania	Combustion	03-30-2007	0		0	0		0	514797	340204	174593
124	France	Combustion	5401262	4768	3958	810	4768	3946	822	4768	3354	1414
125	Belgium	Combustion	WAI124P065	6172	6618	-446	6173	4477	1696	6173	3242	2931
Total				12207995	10525031	1682964	12207991	10106621	2101370	12551909	10118300	2433609

Table 3.9: Distributed Allowances, Verified Emissions and Net Short/Long Position for Dalkia, Installations #85-125 (2005-2007) from Reuters Carbon Market Data

Installation List	Country	Activity	Permit Identifier	Distributed Allowances 2005	Verified Emissions 2005	Net Short/Long Position 2005	Distributed Allowances 2006	Verified Emissions 2006	Net Short/Long Position 2006	Distributed Allowances 2007	Verified Emissions 2007	Net Short/Long Position 2007
Eesti Energia												
1	Estonia	Combustion	KL-0022	505968	373270	132698	537952	371992	165960	572064	302229	269835
Enel												
3	Spain	Combustion	ES025001000989									
4	Spain	Combustion	ES011101000060	226476	784539	-558063	88931	211016	-122085	0	6225	-6225
5	Spain	Combustion	ES011401000047	1543744	2126527	-582783	1386012	1407854	-21842	1208371	1919952	-711581
6	Spain	Combustion	ES024401000188	583889	982336	-398447	524230	947485	-423255	457041	404548	52493
7	Spain	Combustion	ES025001000187	289262	67133	222129	270088	5556	264532	0		0
8	Spain	Combustion	ES071301000402	820404	1193541	-373137	736580	562635	173945	642175	1039547	-397372
9	Spain	Combustion	ES080801000514	434947	891905	-456958	390506	1022993	-632487	340456	732426	-391970
Total				3898722	6045981	-2147259	3396347	4157539	-761192	2648043	4102698	-1454655

Table 3.10: Distributed Allowances, Verified Emissions and Net Short/Long Position for Eesti Energia and Enel (2005-2007) from Reuters Carbon Market Data

Installation List	Country	Activity	Permit Identifier	Distributed Allowances 2005	Verified Emissions 2005	Net Short/Long Position 2005	Distributed Allowances 2006	Verified Emissions 2006	Net Short/Long Position 2006	Distributed Allowances 2007	Verified Emissions 2007	Net Short/Long Position 2007
1	Germany	Combustion	14310-0066	5624	3341	2283	5624	0	5624	5624		5624
2	Germany	Combustion	14310-0110	3470	3323	147	3470	4948	-1478	3470	1274	2196
3	Germany	Combustion	14310-0247	16898	17098	-200	16898	15887	1011	16898	14736	2162
4	Germany	Combustion	14310-0346	12204	11243	961	12204	9607	2597	12204	6578	5626
5	Germany	Combustion	14310-0350	17154	16515	639	17154	15976	1178	17154	17607	-453
6	Germany	Combustion	14310-0384	4503	301	4202	4503	24344	-19841	4503	24848	-20345
7	Germany	Combustion	14310-0394	400918	393426	7492	400918	380311	20607	400918	3434	397484
8	Germany	Combustion	14310-0399	22125	21219	906	22125	19696	2429	22125	19648	2477
9	Germany	Combustion	14310-0693	17128	11438	5690	17128	11484	5644	17128	10419	6709
10	Germany	Combustion	14310-0788	93351	76198	17153	93351	68302	25049	93351	70276	23075
11	Germany	Combustion	14310-0855	31934	23879	8055	31934	24512	7422	31934	21746	10188
12	Germany	Combustion	14310-0862	45304	30749	14555	45304	27867	17437	45304	26899	18405
13	Germany	Combustion	14310-0903	42359	30234	12125	42359	29596	12763	42359	27947	14412
14	Germany	Combustion	14310-0955	9036	7446	1590	9036	6587	2449	9036	6289	2747
15	Germany	Combustion	14310-0957	17704	16652	1052	17704	15669	2035	17704	15172	2532
16	Germany	Combustion	14310-1036	9892	8919	973	9892	10447	-555	9892	7701	2191
17	Germany	Combustion	14310-1048	4662	5224	-562	4662	0	4662	4662		4662
18	Germany	Combustion	14310-1052	6709	790	5919	6709	0	6709	6709		6709
19	Germany	Combustion	14310-1054	642	494	148	642	438	204	642	160	482
20	Germany	Combustion	14310-1055	13929	15082	-1153	13929	14498	-569	13929	11315	2614
21	Germany	Combustion	14310-1057	17751	15129	2622	17751	15071	2680	17751	13292	4459
22	Germany	Combustion	14310-1059	6395	10233	-3838	6395	7861	-1466	6395	9746	-3351
23	Germany	Combustion	14310-1150	10061	12342	-2281	10061	11127	-1066	10061	9651	410
24	Germany	Combustion	14310-1300	7355	6799	556	7355	725	6630	7355	5841	1514
25	Germany	Combustion	14320-0006	114150	69031	45119	114150	7815	106335	114150	64876	49274
26	Germany	Combustion	14330-0024	33708	2158	31550	33708	22831	10877	33708	30888	2820
27	Germany	Combustion	14330-0025	1645	1486	159	1645	171	1474	1645	259	1386
28	Germany	Combustion	14330-0026	5277	1662	3615	5277	6681	-1404	5277		5277
29	Germany	Combustion	14330-0027	20711	38215	-17504	20711	32002	-11291	20711	25937	-5226
30	Germany	Combustion	14330-0028	31010	26805	4205	31010	50338	-19328	31010	15955	15055
31	Germany	Combustion	14330-0029	11612	14057	-2445	11612	13889	-2277	11612	651	10961
32	Germany	Combustion	14330-0031	3275	981	2294	3275	2371	904	3275	1869	1406
33	Germany	Combustion	14330-0032	169298	14698	154600	169298	178301	-9003	169298	149693	19605
34	Germany	Combustion	14310-0435	98988	101312	-2324	98988	161801	-62813	98988	162347	-63359
35	Netherlands	Combustion	200400156	135511	119	135392	135511	126196	9315	135511	54039	81472
36	Netherlands	Combustion	200400157	520204	50612	469592	520204	443254	76950	520203	339349	180854
37	Netherlands	Combustion	200400154	131404	116678	14726	131404	130933	471	131404	123972	7432
38	Netherlands	Combustion	200400153	6166456	6324962	-158506	6166456	6189119	-22663	6166456	6108992	57464
39	Netherlands	Combustion	200400155	744953	675927	69026	744953	679407	65546	744953	660029	84924
40	Germany	Combustion	14310-0506	1834	1722	112	1834	2203	-369	1834	1884	-50
41	Germany	Combustion	14310-0386	130	154	-24	130	553	-423	130	113	17
42	Germany	Combustion	14310-0425	15319	1782	13537	15319	103822	-88503	15319	236057	-220738
43	Germany	Combustion	14310-0349	63171	55822	7349	63171	53964	9207	63171	53305	9866
44	Germany	Combustion	14310-0061	922	731	191	922	105	817	922	987	-65
45	Germany	Combustion	14310-0059	1051	783	268	1051	819	232	1051	944	107

Table 3.11: Distributed Allowances, Verified Emissions and Net Short/Long Position for E.ON, Installations #1-45 (2005-2007) from Reuters Carbon Market Data

Installation List	Country	Activity	Permit Identifier	Distributed Allowances 2005	Verified Emissions 2005	Net Short/Long Position 2005	Distributed Allowances 2006	Verified Emissions 2006	Net Short/Long Position 2006	Distributed Allowances 2007	Verified Emissions 2007	Net Short/Long Position 2007
46	Germany	Combustion	14310-0429	522	1523	-1001	522	2656	-2134	522	906	-384
47	Germany	Combustion	14310-0656	1162	1945	-783	1162	3139	-1977	1162	3322	-2160
48	Germany	Combustion	14310-0428	24	20	4	24	127	-103	24	19	5
49	Germany	Combustion	14310-0388	2915	703	2212	2915	556	2359	2915	333	2582
50	Germany	Combustion	14310-0833	44700	2286	42414	44700	2411	42289	44700	5084	39616
51	Germany	Combustion	14310-0328	23642	18782	4860	23642	19086	4556	23642	16338	7304
52	Germany	Combustion	14310-0333	44734	38933	5801	44734	33482	11252	44734	30213	14521
53	Germany	Combustion	14310-1053	15436	12784	2652	15436	10723	4713	15436	7937	7499
54	Germany	Combustion	14310-0065	1766	1739	27	1766	3353	-1587	1766	1380	386
55	Germany	Combustion	14310-0062	921	547	374	921	1182	-261	921	992	-71
56	Germany	Combustion	14310-0060	2296	2584	-288	2296	768	1528	2296	1846	450
57	Germany	Combustion	14310-0832	1618182	1926043	-307861	1618182	1692312	-74130	1618182	1703588	-85406
58	Germany	Combustion	14310-0424	1413422	1650808	-237386	1413422	1725278	-311856	1413422	1491266	-77844
59	Germany	Combustion	14310-0420	2379	5074	-2695	2379	282	2097	2379	1184	1195
60	Germany	Combustion	14310-0906	440237	499563	-59326	440237	282381	157856	440237	461949	-21712
61	Germany	Combustion	14310-0742	3552957	2610998	941959	3552957	4100667	-547710	3552957	3678763	-125806
62	Germany	Combustion	14310-0907	827962	858731	-30769	827962	683068	144894	827962	944942	-116980
63	Germany	Combustion	14310-0651	144603	143919	684	144603	90875	53728	144603	133392	11211
64	Germany	Combustion	14310-0550	12181	8258	3923	12181	1347	10834	12181	17522	-5341
65	Germany	Combustion	14310-0438	215714	260204	-44490	215714	209632	6082	215714	242358	-26644
66	Germany	Combustion	14310-0741	1430124	1477324	-47200	1430124	1569001	-138877	1430124	1607553	-177429
67	Germany	Combustion	14310-0647	1364	962	402	1364	804	560	1364	660	704
68	Germany	Combustion	14310-1345	2315	2858	-543	2315	2898	-583	2315	264	2051
69	Germany	Combustion	14310-0909	419121	286684	132437	419121	323555	95566	419121	442209	-23088
70	Germany	Combustion	14310-0831	4949048	6125032	-1175984	4949048	6274756	-1325708	4949048	5513703	-564655
71	Germany	Combustion	14310-0649	8679778	9815880	-1136102	8679778	10671936	-1992158	10929778	12646858	-1717080
72	Germany	Combustion	14310-0836	626969	694416	-67447	626969	722379	-95410	626969	839379	-212410
73	Germany	Combustion	14310-0888	854487	1071534	-217047	854487	1043304	-188817	854487	1033278	-178791
74	Germany	Combustion	14310-1346	1076222	1174175	-97953	1076222	1025640	50582	1076222	1172046	-95824
75	Germany	Combustion	14310-0834	270688	427882	-157194	270688	357688	-87000	270688	439941	-169253
76	Germany	Combustion	14310-1347	2758879	2032467	726412	2758879	2053648	705231	2758879	2758584	295
77	Germany	Combustion	14310-1392		0	0		0	0			0
78	Germany	Combustion	14310-1348	1546	3628	-2082	1546	3665	-2119	1546	2296	-750
79	Germany	Combustion	14310-0390	3505642	3424354	81288	3505642	3553304	-47662	3505642	3139510	366132
80	Germany	Combustion	14310-0383	1669361	1972741	-303380	1669361	1798761	-129400	1669361	2019747	-350386
81	Germany	Combustion	14310-0708	163	825	-662	163	1154	-991	163	1786	-1623
82	Germany	Combustion	14330-0073			0			0			0
83	Germany	Combustion	14310-0745	164	776	-612	164	770	-606	164	939	-775
84	Germany	Combustion	14320-0002	33243	23896	9347	33243	30271	2972	33243	24361	8882
85	Germany	Combustion	14330-0030	32250	34936	-2686	32250	43857	-11607	32250	33547	-1297
86	Germany	Combustion	14310-0526	15903	3849	12054	22921	3066	19855	19412	4786	14626
87	Germany	Combustion	14330-0038	62217	27623	34594	62217	2696	59521	62217	315	61902
88	Germany	Combustion	14330-0039	2616	2269	347	2616	188	2428	2616	1844	772
89	Germany	Combustion	14330-0072			0			0			0
Total				43845592	44887326	-1041734	43852610	47268194	-3415584	46099100	48783665	-2684565

Table 3.12: Distributed Allowances, Verified Emissions and Net Short/Long Position for E.ON, Installations #46-89 (2005-2007) from Reuters Carbon Market Data

Installation List	Country	Activity	Permit Identifier	Distributed Allowances 2005	Verified Emissions 2005	Net Short/Long Position 2005	Distributed Allowances 2006	Verified Emissions 2006	Net Short/Long Position 2006	Distributed Allowances 2007	Verified Emissions 2007	Net Short/Long Position 2007
1	Germany	Ceramics	14260-0013	3482	2396	1086	3482	0	3482	3482		3482
2	Germany	Ceramics	14260-0057	3118	2953	165	3118	2881	237	3118	2826	292
3	Germany	Ceramics	14260-0096	5020	3314	1706	5020	3412	1608	5020	3856	1164
4	Germany	Ceramics	14260-0111	1581	1319	262	1581	1632	-51	1581	1231	350
5	Germany	Ceramics	14260-0112	1941	1933	8	1941	1742	199	1941	1819	122
6	Germany	Ceramics	14260-0115	54196	40715	13481	54196	45701	8495	28060	57008	-28948
7	Germany	Ceramics	14260-0116	539	493	46	539	431	108	539	429	110
8	Germany	Ceramics	14260-0118	1346	1175	171	1346	1153	193	1346	1194	152
9	Germany	Ceramics	14260-0121	13029	9814	3215	13029	7524	5505	13029	6954	6075
10	Germany	Ceramics	14260-0129	3195	2158	1037	3195	2006	1189	3195		3195
11	Germany	Ceramics	14260-0153	336	322	14	336	395	-59	336	306	30
12	Germany	Ceramics	14260-0155	3863	4071	-208	3863	4611	-748	3863	4329	-466
13	Germany	Ceramics	14260-0169	12280	12188	92	12280	11562	718	12280	9255	3025
14	Germany	Ceramics	14260-0181	5281	3987	1294	5281	3925	1356	5281	3415	1866
15	Germany	Ceramics	14260-0221	14301	14789	-488	14301	9953	4348	14301	1235	13066
16	Germany	Ceramics	14260-0222	9682	10138	-456	9682	1253	8429	9682	7295	2387
17	Germany	Ceramics	14260-0223	7103	0	7103	7103	0	7103	7103		7103
18	Germany	Ceramics	14260-0224	6420	6672	-252	6420	5609	811	6420	6818	-398
19	Germany	Paper	14280-0098	65369	55797	9572	65369	56556	8813	65369	51289	14080
20	Germany	Paper	14280-0106	7901	4611	3290	7901	4799	3102	7901	4645	3256
21	Germany	Combustion	14310-0055	7	0	7	7	0	7	7		7
22	Germany	Combustion	14310-0637	33196	13747	19449	33196	14776	18420	33196	7071	26125
23	Germany	Combustion	14310-0680	21505	2125	19380	21505	2034	19471	21505	22291	-786
24	Germany	Combustion	14310-0856	3240622	3388560	-147938	3240622	4351049	-1110427	3240622	4112952	-872330
25	Germany	Combustion	14310-0931		3274376	-3274376		3601708	-3601708		3061616	-3061616
26	Germany	Combustion	14310-0950	2118174	1738304	379870	2118174	1569243	548931	2118174	1652194	465980
27	Germany	Combustion	14310-0952	4276832	4127851	148981	4276832	3668069	608763	4276832	4239735	37097
28	Germany	Combustion	14310-1088	1690717	1394768	295949	1690717	1664380	26337	1690717	1492609	198108
29	Germany	Combustion	14310-1089	1529980	1060298	469682	1529980	977009	552971	1047862	1033304	14558
30	Germany	Combustion	14310-1090	1669388	1634028	35360	1669388	1613914	55474	1648071	1719506	-71435
31	Germany	Combustion	14310-1091	987205	1016733	-29528	987205	1020873	-33668	978093	1105032	-126939
32	Germany	Combustion	14310-1092	20318296	17573788	2744508	20318296	19317451	1000845	20318296	19599684	718612
33	Germany	Combustion	14310-1093	16903648	17980947	-1077299	16903648	17917668	-1014020	16903648	16795941	107707
34	Germany	Combustion	14310-1094	18989348	20612731	-1623383	18989348	18823349	165999	18979965	19683995	-704030
35	Germany	Combustion	14310-1153	28667044	29734760	-1067716	28667044	27386683	1280361	28667044	31252670	-2585626
36	Germany	Combustion	14310-1212	11630	11731	-101	11630	0	11630	11630		11630
37	Germany	Combustion	14310-1228	17108	19168	-2060	17108	19139	-2031	17108	19189	-2081

Table 3.13: Distributed Allowances, Verified Emissions and Net Short/Long Position for RWE, Installations #1-37 (2005-2007) from Reuters Carbon Market Data

Installation List	Country	Activity	Permit Identifier	Distributed Allowances 2005	Verified Emissions 2005	Net Short/Long Position 2005	Distributed Allowances 2006	Verified Emissions 2006	Net Short/Long Position 2006	Distributed Allowances 2007	Verified Emissions 2007	Net Short/Long Position 2007
38	Germany	Combustion	14310-1385		0	0		0	0			0
39	Germany	Combustion	14330-0001	1063	82	981	1063	569	494	1063	308	755
40	UK	Combustion	EA-ETCO2-0160	605912	795147	-189235	605912	828739	-222827	605912	824638	-218726
41	Germany	Combustion	14310-0054	1270	1991	-721	1270	1843	-573	1270	2761	-1491
42	Germany	Combustion	14310-0817	13790	8857	4933	13790	3614	10176	13790		13790
43	Germany	Glass	14250-0093		0	0		48735	-48735		126621	-126621
44	Germany	Combustion	14310-0328	23642	18782	4860	23642	19086	4556	23642	16338	7304
45	Germany	Combustion	14310-0333	44734	38933	5801	44734	33482	11252	44734	30213	14521
46	Germany	Combustion	14310-0655	36540	44518	-7978	36540	27954	8586	36540	6771	29769
47	Germany	Combustion	14310-0446	37613	33104	4509	37613	26702	10911	37613	16015	21598
48	Germany	Combustion	14310-0060	2296	2584	-288	2296	768	1528	2296	1846	450
49	Germany	Ceramics	14260-0124	7869	5222	2647	7869	5159	2710	7869	4967	2902
50	Germany	Ceramics	14260-0125	3812	4877	-1065	3812	5204	-1392	3812	5704	-1892
51	Germany	Combustion	14310-0748	93963	72251	21712	93963	72554	21409	93963	69354	24609
52	Germany	Combustion	14310-0947	154208	107036	47172	154208	110841	43367	154208	105236	48972
53	Germany	Combustion	14310-0946	122999	85932	37067	122999	84859	38140	122999	79983	43016
54	Germany	Combustion	14310-0938	3172057	3406579	-234522	3172057	3174824	-2767	3172057	3378852	-206795
55	Germany	Combustion	14310-0944	3607248	3596816	10432	3607248	4324981	-717733	3607248	4775857	-1168609
56	Germany	Combustion	14310-0943	664401	728470	-64069	664401	726747	-62346	664401	679374	-14973
57	Germany	Combustion	14310-0941	3151994	2921763	230231	3151994	3779996	-628002	3151994	3671289	-519295
58	Germany	Combustion	14310-0945	1141834	847467	294367	1141834	725634	416200	1141834	830154	311680
59	Germany	Combustion	14310-0770	5264108	5017098	247010	5264108	7289168	-2025060	5264108	6925790	-1661682
60	Netherlands	Combustion	200400091	1349869	1106063	243806	1349869	960725	389144	1349869	1076294	273575
61	Austria	Combustion	EMV233	0	0	0	0	0	0	0		0
62	Austria	Combustion	ILE164	13942	721	13221	13942	681	13261	13942	665	13277
63	Czech Rep	Combustion	CZ-0055-05	2540	2198	342	2540	2772	-232	2540	1524	1016
64	Germany	Combustion	14330-0013	6765	25116	-18351	6765	20014	-13249	6765	11221	-4456
65	Germany	Combustion	14310-0165	702	212	490	702	436	266	702	218	484
66	Czech Rep	Combustion	CZ-0059-05	200000	85476	114524	200000	7378	192622	200000	76788	123212
67	Czech Rep	Combustion	CZ-0060-05	106270	46196	60074	106270	35047	71223	106270	18405	87865
68	Czech Rep	Combustion	CZ-0057-05	27013	1590	25423	27013	10496	16517	27013	2826	24187
69	Czech Rep	Combustion	CZ-0056-05	22277	1570	20707	22277	9374	12903	22277	1750	20527
70	Czech Rep	Combustion	CZ-0058-05	35410	23141	12269	35410	22456	12954	35410	6851	28559
71	Czech Rep	Combustion	CZ-0061-05	65150	17636	47514	65150	274	64876	65150	8168	56982
72	Austria	Combustion	IVA235	0	0	0	0	0	0	0		0
73	Germany	Ceramics	14260-0172	7856	6937	919	7856	74	7782	7856	6728	1128
Total				120683830	122817125	-2133295	120683830	124473676	-3789846	120135764	128725202	-8589438

Table 3.14: Distributed Allowances, Verified Emissions and Net Short/Long Position for RWE, Installations #38-73 (2005-2007) from Reuters Carbon Market Data

Installation List	Country	Activity	Permit Identifier	Distributed Allowances 2005	Verified Emissions 2005	Net Short/Long Position 2005	Distributed Allowances 2006	Verified Emissions 2006	Net Short/Long Position 2006	Distributed Allowances 2007	Verified Emissions 2007	Net Short/Long Position 2007
1	Spain	Combustion	ES012101000055	1871029	1692327	178702	2077491	2536246	-458755	2128158	2423841	-295683
2	Spain	Combustion	ES033301000222	190493	3103188	-2912695	171950	2677815	-2505865	150230	3440880	-3290650
3	Spain	Combustion	ES033301000223	637005	0	637005	571919	0	571919	498618		498618
4	Spain	Combustion	ES033301000224	1915851	0	1915851	1720099	0	1720099	1499640		1499640
5	Spain	Combustion	ES062401000351	3312940	4196260	-883320	2974440	3554304	-579864	2593217	3428296	-835079
6	Spain	Combustion	ES074501000404	0	0	0	0	401075	-401075	0	936432	-936432
7	Spain	Combustion	ES074501000405	106446	412660	-306214	41798	387122	-345324	0	110778	-110778
8	Spain	Combustion	ES074501000406	85290	266228	-180938	33492	296481	-262989	0	66894	-66894
9	Spain	Combustion	ES104601000666	0	0	0	0	0	0	0	741233	-741233
10	Spain	Combustion	ES121501000747	2786379	4221684	-1435305	2553409	3847539	-1294130	2280522	5132091	-2851569
11	Spain	Combustion	ES121501000748	0	0	0	0	0	0	0		0
12	Spain	Combustion	ES121501000749	140221	530469	-390248	55061	310591	-255530	0	139806	-139806
Total				11045654	14422816	-3377162	10199659	14011173	-3811514	9150385	16420251	-7269866

Table 3.15: Distributed Allowances, Verified Emissions and Net Short/Long Position for Union Fenosa (2005-2007) from Reuters Carbon Market Data

Conclusion

At the stage of international post-Kyoto negotiations, the adoption of ambitious public policies raises an increasing interest, as society has a whole is more concerned by the scale of damages and the potential irreversibilities linked to climate change. The introduction of a tradable permits market in Europe on January 1, 2005, in order to provide incentives to Member-States to take early abatement measures, may be seen as a decisive first step towards that direction. The creation of the EU ETS has indeed revealed the key role played by the European Union in the preservation of the global public good that constitutes the climate.

This thesis has investigated the market rules of the European carbon market during 2005-2007. The theoretical and empirical approaches used have been fruitful for the analysis of banking, pricing and risk-hedging strategies. These results teach us that institutional learning has indeed occurred within Phase I, both from the viewpoint of market agents and the regulator.

Chapter 1 provides the relevant theoretical framework to analyze the banking and borrowing provisions, by reviewing the environmental and economic effects developed in previous literature. The authorization of these provisions appears desirable on a permit market, since they allow firms to achive their depolluting objective at least cost by smoothing their emissions overtime. However, we have underlined that these provisions change the temporal profile as well as the magnitude of environmental damages. From the regulator's viewpoint, the best configuration of the intertemporal flexibility mechanism therefore consists in authorizing banking without restrictions, and in penalizing borrowing by using a non-unitary intertemporal exchange ratio. Then, we focus on the specific provisions adopted in the EU ETS, *i.e.* a full intertemporal flexibility within 2005-2007 and 2008-2012, but a restriction on the transfer of banked and borrowed allowances between Phases I and II. Over the period going from July 1, 2005 to December 17, 2007, our study based on the Hotelling rule shows that allocation during 2005-2007 has not been optimal intertemporally, in order to create the necessary scarcity of allowances among industrials leading to effective emissions reductions. Moreover, we identify statistically the disconnection between first and second prices, starting when agents correctly integrate the information concerning the restriction on allowance transfer between December 31, 2007 and January 1, 2008. Two distinct price dynamics seem to co-exist from that point in time onwards: EUA prices decreasing asymptotically towards zero until the end of Phase I, and EUA prices strictly increasing as can be observed through the futures term structures for Phase II. Besides the main explanations gathered by market observers, the inefficiency of the EUA price signal to reflect correctly the social value of carbon until the end of Phase I may be explained by the restrictions enforced by Member-States concerning the transfer of quotas, banked or borrowed, from Phase I to Phase II. This sacrifice of the intertemporal flexibility mechanism may be interpreted by the will of the European Commission to limit the transfer of inefficiencies from the creation of the allowance market to Phase II, which simultaneously corresponds the Kyoto Protocol commitment period. Between Phases II and III of the EU ETS, the transfer of allowances has been authorized, which suggests that institutional has indeed occurred.

Chapter 2 is dedicated to the carbon price drivers. Our study shows that EUA price changes may be mainly explained by the variation of energy prices, and by unanticipated temperatures events. We show that their influence vary depending on institutional decisions, such as the 2005 compliance event and the annoucements by the European Commission. Over the period going from July 1, 2005 to April 30, 2007, we identify a first structural break in the CO_2 time series on April 2006, which corresponds to the first revelations by Member-States concerning their net short/long position in terms of allocated allowances with respect to verified emissions. This major institutional event, which led to a price collapse of more than 50% within a few days, has been used as a reliable information by market agents in order to correct their anticipations, thereby eliminating all prior speculative information. The second structural break occurs on October 2006, following the announcement by the European Commission of stricter NAPs II validation criteria. Our estimation results show during the full period the influence of energy prices and extreme weather events on EUA price changes. This influence varies between the sub-periods under consideration, particularly after the 2005 compliance event when market agents adopted a wait-and-see behaviour. Following this event, we are able to identify again the main carbon price drivers. We build on previous literature concerning the non-linearity of the relationship between temperatures and EUA price changes. Our method brings new insights by showing that deviations from seasonal average matter more than temperatures themselves in explaining EUA price changes during extreme weather events. The remaining of Chapter 2 evaluates the effects of the variation of industrial production in EU ETS sectors on EUA price changes. Our disentangling analysis shows that that industrials' net short/long position on the one hand, and the evolution of their activity as measured by production peaks on the other hand, also explain EUA price changes beased the installation's net position as a buyer/seller of quotas on the market. These results statistically validate that the evolution of economic activity may be considered as a price fundamental of CO_2 allowances, while this effect had only been suggested in the professional literature so far. Among EU ETS sectors, these results are obtained in the combustion, iron and steel, and pulp and paper sectors, which total 80% of allocation in the EU ETS. Besides the combined effect of production peaks and compliance positions, we show the superiority of the compliance effect to explain EUA price changes. The combustion sector is indeed the only sector which is characterized by a net short position, while the other two sectors have recorded the longest positions in the EU ETS during 2005-2006. Finally, we extend this analysis at the country level. This study validates the impact of the variation of industrial production on EUA price changes in four countries (Germany, Spain, Poland and the UK), and underlined the central role played by German power producers.

Chapter 3 details the risk-hedging strategies in the EU ETS. Following the methodology existing for stock markets, we recover investors' risk aversion around the 2006 compliance event by using the existing relationship with the risk-neutral and historic probabilities. This methodology has proved to be robust for the stock market. To estimate the risk-neutral probability, we use a new database of option prices, launched on October 2006 on ECX, with CO_2 allowances valid during Phases I and II as the underlying asset. We estimate the average risk-neutral distribution non-parametrically from the series of implied volatilities. Then, we use the futures prices series of maturity December 2008 and December 2009 to model the historical distribution with a semi-parametric asymetric GARCH model. Over the period going from October 1, 2006 to November 23, 2007, we choose to split our database in two subsamples before and after the 2006 compliance event, which constitutes the only compliance event observable empirically. Our results illustrate the dramatic changes in investor's risk aversion around this compliance event. We obtain indeed a lower level of volatility after the announcement by the European Commission, which is conform to the role of information revelation on financial markets. More interestingly, we show that the risk attached to option contracts is linked to increasing CO_2 allowance prices after the 2006 compliance event, which is the exact opposite of the standard leverage effect observed on a standard commodity market. This results reflects the idea that investors are expecting an increasing scarcity of allowances on the medium term, and is also reflected in the futures term structure. We therefore have used an efficient tool to quantify the effects of risk aversion on the European carbon market which, during the period under consideration, has been higher than on the stock market. This study has thus overall underlined the necessity for investors to manage adequately the risk attached to holding CO_2 allowances. With reference to Chapter 1, we examine in the second part of Chapter 3 the consequences of uncertainty linked to the variations of political decisions on firm's behaviour in a two periods setting, when banking is authorized, and when permit trading between firms has already occurred. In presence of a mean preserving augmentation of risk, we show that the firm's banking behaviour is linked to the sign of the third derivative of the production function with respect to emissions. Concerning the optimal risk-sharing rule, we show that the agency may smooth allowances instead of firms when the sum of allocation is known, whatever the changes in allocation rules enforced by the regulator. When the number of allowances distributed during the second period is random, this pooling behaviour of allowances is function of the sensibility of firm's marginal productivity with respect to the number of allowances. We illustrate finally these results by the banking behavior at the installation level, and the pooling behaviour between installations and parent companies in the EU ETS, which underlines the efficiency of the banking instrument as a tool of risk-management.

Overall, this thesis highlights the inefficiencies following the creation of the European carbon market that prevented the emergence of a price signal leading to effective emissions reductions by industrials. The early design inefficiencies of the European carbon market, linked to initial allocation or the inter-period transfer of allowances, seem to have been corrected for the period 2008-2012, thereby limiting the transfer of inefficiencies towards Phase II.

The limits inherent to this piece of work obviously suggest some areas left for further research. In a changing institutional environment, the exhaustive evaluation of the Phase I of the EU ETS needs to be backed by verified emissions data at the installation level, which would constitute an interesting extension of Chapter 2 at the micro-econometric level. Moreover, it will be interesting to replicate the study in Chapter 3 around other events that are likely to affect investors' risk aversion, such as shocks on the energy markets, or if the European Commission communicates on a quarterly basis for instance. Another important dimension in extension of this work consists in the study of risk premia on the European carbon market. Finally, we have only described the pooling behavior at the end of Chapter 3. An interesting area for further research therefore needs to be able to use data on the exhaustive compilation of CITL data between installations and parent companies.

Bibliography

[1] Aït-Sahalia, Y., Lo, A.W. 2000. Nonparametric Risk Management and Implied Risk Aversion. Journal of Econometrics; 94, 9–51.

[2] Alberola, E., Chevallier, J., Cheze, B., 2008. Price Drivers and Structural Breaks in European Carbon Prices 2005-2007. Energy Policy 36(2), 787–797.

[3] Alberola, E., Chevallier, J., Cheze, B., 2008. The EU Emissions Trading Scheme: Disentangling the Effects of Industrial Production and CO_2 Emissions on Carbon Prices. International Economics, forthcoming.

[4] Alberola, E., Chevallier, 2007. European Carbon Prices and Banking Restrictions: Evidence from Phase I (2005-2007). *EconomiX Working Paper Series*, # 2007-32.

[5] Andersen, A. B., Wagener, T. 2002. Extracting Risk Neutral Probability Densities by Fitting Implied Volatility Smiles: Some Methodological Points and an Application to the 3M Euribor Futures Options Prices. ECB Working Paper Series.

[6] Arrow, K.J. 1964. The Role of Securities in the Optimal Allocation of Risk-Bearing. Review of Economic Studies, 31, 91–96.

[7] Babiker, M., Reilly, J., Viguier,L. 2004. Is International Emissions Trading Always Beneficial? The Energy Journal, 25 (2), 33–56.

[8] Baron,, R. 1999. Market Power and Market Access in International GHG Emis-

sion Trading. *IEA Information Paper.* International Energy Agency, Energy and Environment Division.

[9] Barone-Adesi, G.,Engle, R.F., Mancini, L. 2008. A GARCH Option Pricing Model with Filtered Historical Simulation. The Review of Financial Studies, 21, 1223–1258.

[10] Baumol W. and Oates W. E. 1998. *The Theory of Environmental Policy*, Cambridge, Cambridge University Press.

[11] Ben-David, S., Brookshire, D.S., Burness, S., McHee, M., Smidt C. 1999. Heterogeneity, Irreversible Production Choice, and Efficiency in Emission Permits Markets, Journal of Environmental Economics and Management, 38, 176–194.

[12] Benz, E., Truck, S. 2006. Modeling the Price Dynamics of CO_2 Emission Allowances. Energy Economics, forthcoming.

[13] Bernard, A., Paltsev, S., Reilly, J.M., Vielle, M., Viguier, L. 2003. Russia's Role in the Kyoto Protocol. *MIT Joint Program on the Science of Policy and Global Change*, 98.

[14] Berndt, E.K., Robert, E.,Hall, B.H., Hausman, J.A. 1974. Estimation and Inference in Nonlinear Structural Models. Annals of Economic and Social Measurement; 3; 653–665.

[15] Bertholon, H., Monfort, A., Pegoraro, F. 2007. Econometric Asset Pricing Modelling. CREST Working Paper, Paris.

[16] Bessec, M., Fouquau, J. 2008. The Non-Linear Link between Electricity Consumption and Temperature in Europe: A Threshold Panel Approach. Energy Economics, 30(5), 2705–2721.

[17] Bessembinder, H., Coughenour, J.F., Seguin, J.P., Monroe-Smoller, M. Mean Reversion in Equilibrium Asset Prices: Evidence from the Futures Term Structure. The Journal of Finance, 5(1), 361–375.

[18] Biglaiser G., Horowitz J., and Quiggin J. 1995. Dynamic Pollution Regulation. Journal of Regulatory Economics 8, 33–44.

[19] Bohm, P., Russel, C. S. 1985. *Comparative Analysis of Alternative Policy Instruments*, in emphHandbook of Natural Resources and Energy Economics, Kneese, A.V., Sweeny, J.L. (eds), New-York, North-Holland, 395–455.

[20] Bohringer, C., Loshel, A. 2003. Market Power and Hot Air in International Emissions Trading: the Impact of the US Withdrawal from the Kyoto Protocol. Applied Economics, 35(6), 651-663.

[21] Bollerslev, T., 1986. Generalized Autoregressive Conditional Heteroskedasticity. Journal of Econometrics 31, 307–327.

[22] Boltanski, L., Thevenot, L. 1991. *De la justification: les conomies de la grandeur*, editions Gallimard.

[23] Borak, S., Hardle, W.,Truck, S., Weron, R. 2006. Convenience Yields for CO_2 Emission Allowance Futures Contracts. SFB 649 Discussion Paper, 076, Humboldt Universitat, Berlin.

[24] Borch K. 1962. Equilibrium in a Reinsurance Market, Econometrica, 30, 424–444.

[25] Bosetti V., Carraro C., Galeotti M., Massetti E. and Tavoni M. 2006. WITCH: A World Induced Technical Change Hybrid Model. The Energy Journal, Special Issue on Hybrid Modeling of Energy-Environment Policies: Reconciling Bottom-up and Top-down, 13-38.

[26] Bosetti V., Carraro C. and Massetti E. 2008. Banking Permits: Economic Efficiency and Distributional Effects, *Working Papers Fondazione Enrico Mattei* # 2008.1.

[27] Brennan, M. 1958. The Supply of Storage. American Economic Review, 48, 50–72.

[28] Brennan, M. 1991. The Price of Convenience and the Pricing of Commodity Contingent Claims. in Lund, D., Oksendal, B. Stochastic Models and Option Values; Elsevier; New York.

[29] Briere, M. 2006. Market Reactions to Central Bank Communication Policies: Reading Interest Rate Options Smiles. Working Papers CEB; 06-009.

[30] Brockmann, M., Gasser, T., Herrman, E. 1993. Locally Adaptive Bandwith Choice for Kernel Regression Estimators. Journal of the American Statistical Association; 88, 1302–1309.

[31] Brown, S.P.A., Yucel, M.K., 2008. What Drives Natural Gas Prices?. The Energy Journal 29(2), 45–60.

[32] Bunn, D., Fezzi, C., 2007. Interaction of European Carbon Trading and Energy Prices. Fondazione Eni Enrico Mattei working paper 123.

[33] Burniaux, J.M., 1999. How important is market power in achieving Kyoto?: An assessment based on the GREEN model. OECD Workshop on the Economic Modelling of Climate Change.

[34] Breeden, D.T., Litzenberger, R.H. 1978. Prices of State-Contingent Claims Implicit in Option Prices. The Journal of Business, 51(4), 621–651.

[35] Carbon Trust, 2004. *The European Emissions Trading Scheme: Implications for Industrial Competitiveness*, Report.

[36] Carbon Trust, 2005. *The UK Climate Change Programme: Potential Evolution for the Business and Public Sector*, Report.

[37] Cason, T.N., Gangadharan, L. 2006. Emissions Variability in Tradable Permit Markets with Imperfect Enforcement and Banking. Journal of Economic Behavior and Organization 61(2), 199–216.

[38] Chesney, M., Taschini, L. 2008. The Endogenous Price Dynamics of the Emission Allowances: an Application to CO_2 Option Pricing. Swiss Finance Institute Research Paper Series, 08-02.

[39] Chevalier, J.M., Percebois, J., 2008. Gas and Electricity: A Challenge for Europe and for France. French Economic Analysis Council, Report VII-2, Paris.

[86] Chevallier J., Ielpo F., and Mercier L. 2008. Risk Aversion and Institutional Information Disclosure on the European Carbon Market: a Case-Study of the 2006 Compliance Event, Energy Policy, doi:10.1016/j.enpol.2008.07.030.

[41] Christiansen, A., Arvanitakis, A., Tangen, K., Hasselknippe, H., 2005. Price determinants in the EU emissions trading scheme. Climate Policy 5, 15–30.

[42] Cochrane, J., 2002. Asset Pricing. Princeton University Press.

[43] Cont, R., da Fonseca, J. 2002. Dynamics of Implied Volatility Surfaces. Quantitative Finance, 2, 45–60.

[44] Convery, F.J., Redmond, L., 2007. Market and Price Developments in the European Union Emissions Trading Scheme. Review of Environmental Economics and Policy 1, 88–111.

[45] Cronshaw, M.B., Kruse, J.B. 1996. Regulated Firms in Pollution Permit Markets with Banking, Journal of Regulatory Economics, 9(2), 179–189

[46] Cropper M. L. and Oates W. E.,(1992), Environmental Economics: a Survey, Journal of Economics Literature, 30, 675–740.

[47] Decaux, A., Ellerman, A.D., 1998. Analysis of Post-Kyoto CO2 Emissions Trading Using Marginal Abatement Curves. MIT EPPR Report #40.

[48] Demailly, D., Quirion, P., 2008. European Emission Trading Scheme and Competitiveness : a Case Study on the Iron and Steel Industry. Energy Economics 30(4), 2009–2027.

[49] Demailly, D., Quirion, P., 2008. Leakage from Climate Policies and Border Tax Adjustment: Lessons from a Geographic Model of the Cement Industry, forthcoming in Roger Guesnerie and Henry Tulkens, editors, *The Design of Climate Policy*, papers from a Summer Institute held in Venice, CESifo Seminar Series, Boston: The MIT Press.

[50] Diakoulaki, D., Mandaraka, M., 2007. Decomposition Analysis for Assessing the Progress in Decoupling Industrial Growth from CO_2 Emissions in the EU Manufacturing Sector. Energy Economics 29(4), 636–664.

[51] Dinan, T., Rogers, D.L., 2002. Distributional Effects of Carbon Allowance Trading: How Government Decisions Determine Winners and Losers. National Tax Journal 5(2), 199–221.

[52] Dockner, E.,Jorgensen, S.,Long, N. Van.,Sorger, G., 2000. Differential Games in Economics and Management Science. Cambridge Universiy Press.

[53] Ehrhart, K.M., Hoppe, C., Schleich, J., Seifert, S. 2005. The Role of Auctions and Forward Markets in the EU ETS: Counterbalancing the Cost-Inefficiencies of Combining Generous Allocation with a Ban on Banking. Climate Policy, 5, 31–46.

[54] Ehrhart K.M., Hoppe C. and Loschel R. 2008. Abuse of EU Emissions Trading for Tacit Collusion, Environmental and Resource Economics, 41, 347–361.

[55] Ekins, P., Barker, T. 2001. Carbon Taxes and Carbon Emissions Trading. Journal of Economic Surveys, 15(3), 325–376.

[56] Ellerman, A.D., Joskow, P.L., Schmalensee, R., Montero, J.P., Bailey, E., 200O. *Markets for Clean Air: The US Acid Rain Program*, Cambridge University Press.

[57] Ellerman, A.D.,Wing, I.Sue., 2003. Absolute versus Intensity-Based Emission Caps. Climate Policy 3, S7–S20.

[58] Ellerman, A.D., Buchner, B.K., 2007. The European Union Emissions Trading Scheme: Origins, Allocation, and Early Results. Review of Environmental Economics and Policy 1, 66–87.

[59] Ellerman, A.D., Buchner, B.K. 2008. Over-Allocation or Abatement? A Preliminary Analysis of the EU ETS Based on the 2005-06 Emissions Data. Environmental and Resource Economics, doi:10.1007/s10640-008-9191-2.

[60] Ellerman, A.D., Montero, J.P., 2007. The Efficiency and Robustness of Allowance Banking in the U.S. Acid Rain Program. The Energy Journal 28(4).

[61] Ellerman, A.D. 2008. New Entrant and Closure Provisions: How do they Distort? The Energy Journal 29, Special Issue.

[62] Ellerman, A.D., Buchner, B.K., Carraro, C., 2008. *Allocation in the European Emissions Trading Scheme: Rights, Rents and Fairness*, Cambridge University Press.

[63] Etner J. and Jouvet P.A. 2000. Investment Choice with Polluted Capital, Australian Economic Papers 39(4), 465–482.

[64] Eurostat, 2007. Statistical Data on Monthly Production Index. Statistical Office of the European Communities, Brussels. Available at *http : //ec.europa.eu/eurostat*. Cited January 2008.

[65] Fama, E., French, K.R. 1987. Commodity Futures Prices: Some Evidence on Forecast Power, Premiums, and the Theory of Storage. Journal of Business; 60(1); 55–73.

[66] Fama, E., French, K.R. 1988. Business Cycles and the Behavior of Metal Prices. Journal of Finance, 43(5), 1075–1093.

[67] Glosten, L.R., Jagannathan, R., Runkle, D.E. 1993. On the Relation between the Expected Value and the Volatility of the Nominal Excess Return on Stocks. Journal of Finance, 48, 1779–1801.

[68] Godby, R.W., 2000. Market Power and Emissions Trading: Theory and Laboratory Results. Pacific Economic Review 5(3), 349–363.

[69] Godby, R.W., Mestelman, S., Muller, R.A., Welland, J.D. 2000. Emissions Trading with Shares and Coupons when Control of Discharges is Uncertain. Journal of Environmental Economics and Management, 32, 359–381.

[70] Gollier, C. 2001. *The Economics of Risk and Time*, The MIT Press, Massachusetts Institute of Technology.

[71] Gourieroux, C., Monfort, A., Trognon, A. 1984. Pseudo Maximum Likelihood Methods : Theory. Econometrica, 52, 680–700.

[72] Gourieroux, C., Monfort, A. 2007. Econometric Specification of Stochastic Discount Factor Models. Journal of Econometrics, 127(2), 509–530.

[73] Green, W.H. 2000. Econometric Analysis. Fourth Edition; Prentice Hall International.

[74] Greening, L.A., Davis, W.B., Schipper, L., 1998. Decomposition of Aggregate Carbon Intensity for the Manufacturing Sector : Comparison of Declining Trends from 10 OECD Countries for the Period 1971-1991. Energy Economics 20(1), 43–65.

[75] Hahn, R.W., 1984. Market Power and Transferable Property Rights. Quarterly Journal of Economics 99, 753–765.

[76] Hahn R.,(1989), Economics Prescription for Economic Problems: How the Patient Followed the Doctor's Orders, Jounal of Economic Perspectives, 3, 252–262.

[77] Haites, E. 2006. *Allowance Banking in Emissions Trading Schemes: Theory and Practice*. Margaree Consultants Inc., Toronto.

[78] Hall, A. 2005. *The Generalized Method of Moments*. Oxford University Press.

[79] Harrison, D. 2003. Ex Post Evaluation of the RECLAIM Emissions Trading Program for the Los Angeles Air Basin. *OECD Workshop on Ex Post Evaluation of Tradable Permits: Methodological and Policy Issues.*

[80] Heal, G. 2007. A Celebration of Environmental and Resource Economics. Review of Environmental Economics and Policy, 1, 7–24.

[81] Helfand, G.E., Moore, M.R., Liu, Y., 2006. Testing for Dynamic Efficiency of the Sulfur Dioxide Allowance Market. University of Michigan Working Paper.

[82] Helm D., Hepburn C., and Mash R. 2003. Credible Carbon Policy. Oxford Review of Economic Policy 19(3), 438–450.

[83] Hotelling, H. 1931. The Economics of Exhaustible Resources. Journal of Political Economy, 39, 137–175.

[84] Holtsmark, B. 2003. Russian Behaviour in the Market for Permits under the Kyoto Protocol. Climate Policy, 3, 399-415.

[85] IEEE, 1979. Programs for Digital Signal Processing. John Wiley and Sons.

[86] Ielpo F., Chevallier J., Mercier L. 2008. Risk Aversion and Institutional Information Disclosure on the European Carbon Market: a Case-Study of the 2006 Compliance Event, Energy Policy, forthcoming.

[87] Ielpo, F., Guégan, D. 2008. Flexible Time Series Models for Subjective Distribution Estimation with Monetary Policy in View. Brussel Economic Review, forthcoming.

[88] Jacoby, H.D., Ellerman, A.D. 2004. The Safety Valve and Climate Policy. Energy Policy 32, 481–491.

[89] Jackwerth, J.C. 2000. Recovering Risk Aversion from Option Prices and Realized Returns. The Review of Financial Studies, 13(2), 433–451.

[90] Jouvet, P.A., Michel, P., Rotillon, G. 2005. Optimal Growth with Pollution: How to Use Pollution Permits? Journal of Economic Dynamics and Control, 29, 1597–1609.

[91] Jouvet, P.A., Michel, P., Rotillon, G. 2005. Equilibrium with a Market of Permits. Research in Economics, 59, 148–163.

[92] Joskow P.L., 1990. The Performance of Long-Term Contracts: Further Evidence from Coal Markets. The RAND Journal of Economics 21 (2), 251–274.

[93] Jurczenko, E., Maillet, B., Negrea, B. 2001. A Note on Skewness and Kurtosis Adjusted Option Pricing Models under the Martingale Restriction. Quantitative Finance, 21, 479–499.

[94] Kanen J.L.M., 2006. Carbon Trading and Pricing. Environmental Finance Publications.

[95] Karp, L., Newbery, D.M., 1993. Intertemporal Consistency Issues in Depletable Resources in Handbook of Natural Resource and Energy Economics, vol. III, edited by Kneese, A.V., Sweeney, J.L.,Chapter 19, 881–931.

[96] Kling, C., Rubin, J., 1997. Bankable Permits for the Control of Environmental Pollution. Journal of Public Economics 64, 101–115.

[97] Korppoo, A., Karas, J., Grubb, M. 2006. *Russia and the Kyoto Protocol: Opportunities and Challenges.* Royal institute of international affairs edn. Chatham House.

[98] Koutstaal, P. 1997. *Economic Policy and Climate Change : Tradable Permits for Reducing Carbon Emissions*, Edward Elgar.

[99] Kronenberg, T., 2006. Should we worry about the failure of the Hotelling rule? Working Paper, Maastricht University.

[100] Lee, J., Strazicich, M.C., 2001. Testing the Null of Stationarity in the Presence of a Structural Break. Applied Economics Letters 8, 377–382.

[101] Lee, J., Strazicich, M.C., 2003. Minimum LM Unit Root Test with Two Structural Breaks. Review of Economics and Statistics 85 (4), 1082–1089.

[102] Leseur, A., Trotignon, R., Redmond, L., 2007. A Review of the 2005 and 2006 Compliance of Installations from the CITL Data. Caisse des Dépôts–Climate Task Force Research Report.

[103] Leiby, P., Rubin, J., 2001. Intertemporal Permit Trading for the Control of Greenhouse Gas Emissions. Environmental and Resource Economics 19, 229–256.

[104] Leland, H.E. 1980. Who Should Buy Portfolio Insurance? The Journal of Finance, 35(2), 581–594.

[105] Leston, D. 1992. Investment Decisions and Transferable Discharge Permits: an Empirical Study of Water Quality Management under Policy Uncertainty, Environmental and Resource Economics, 2, 441–458.

[106] Liaskas, K., Mavrotas, G., Mandaraka, M., Diakoulaki, D., 2000. Decomposition of industrial $\mathrm{CO_2}$ emissions: The case of European Union. Energy Economics 22(4), 383–394.

[107] Li, X., Sailor, D.J. 1995. Electricity Use Sensitivity to Climate and Climate Change. World Resource Review 7 (3), 334–346.

[108] Liski, M., Montero, J.P., 2005. A Note on Market Power in an Emissions Permit Market with Banking. Environmental and Resource Economics 31(2), Special Issue, 159–173.

[109] Liski, M., Montero, J.P. 2006. On Pollution Permit Banking and Market Power. Journal of Regulatory Economics 29 (3), 283–302.

[110] Loschel, A., Zhang, Z.X., 2002. The Economic and Environmental Implications of the US Repudiation of the Kyoto Protocol and the Subsequent Deals in Bonn and Marrakech. FEEM Nota Di Lavoro #23.2002.

[111] Lucas, R. 1978. Asset Prices in an Exchange Economy; Econometrica, 46, 1429–1445.

[113] Maeda, A., 2003. The Emergence of Market Power in Emision Rights Markets: the Role of Initial Permit Distribution. Journal of Regulatory Economics 24(3), 293–314.

[113] Maeda, A. 2004. Impact of Banking and Forward Contracts on Tradable Permit Markets. Environmental Economics and Policy Studies 6(2), 81–102.

[114] Mansanet-Bataller, M., Pardo, A., Valor, E., 2007. CO_2 Prices, Energy and Weather. The Energy Journal 28 (3), 67–86.

[115] McKinsey, Ecofys 2006. *EU ETS Review: Report on International Competitiveness.* Conducted for European Commission DG Environment.

[116] MEDAD, 2007. Gaz Naturel en France: Les Principaux Résultats en 2006. Energy Observatory, French Ministry of Ecology and Sustainable Development, DGEMP, Paris, France.

[117] Misiolek, W.S., Elder, H.W., 1989. Exclusionary Manipulation of Markets for Pollution Rights. Journal of Environmental Economics and Management 16, 156–166.

[118] Montgomery, W.D., 1972. Markets in Licenses and Efficient Pollution Control Programs. Journal of Economic Theory 5, 395–418.

[119] Newbery, D.M. 2008. Climate Change Policy and Its Effect on Market Power in the Gas Market, Journal of the European Economic Association, 6(4), 727–751.

[120] Newell, R., Pizer, W., Zhang, J., 2000. Managing Permit Markets to Stabilize Prices. Environmental and Resource Economics 31, 133–157.

[121] Noll, R.G., 1982. Implementing Marketable Emissions Permits. The American Economic Review 72, 120–124.

[122] Paolella, M.S., Taschini, L. 2008. An Econometric Analysis of Emission Trading Allowances. Journal of Banking and Finance 32(10), 2022-2032.

[123] Pearce, D.W., Turner, R.K. 1990. *Economic of Natural Resources and the Environment*, Harvester Wheatsheaf.

[124] Perron, P. 1989. The Great Crash, the Oil Price Shock, and the Unit Root Hypothesis. Econometrica, 57 (6), 1361–1401.

[125] Petrakis, E., Sartzetakis, E.S., Xepapadeas, A., 1999. Environmental Regulation and Market Power: Competition, Time Consistency and International Trade. Edward Elgar.

[126] Pindyck, R.S. 1993. The Present Value Model of Rational Commodity Pricing. The Economic Journal, 103, 511–530.

[127] Pindyck, R.S. 1994. Inventories and the Short-Run Dynamics of Commodity Prices. Rand Journal of Economics, 25(1), 141–159.

[128] Pratt, J.W. 1964. Risk Aversion in the Small and in the Large. Econometrica, 32, 122–136.

[129] Raymond, L., 1996. Private Rights in Public Resources: Equity and Property Allocation in Market-Based Environmental Policy. Resources For The Future.

[130] Reinaud, J., 2007. CO_2 Allowance and Electricity Price Interaction: Impact on Industry's Electricity Purchasing Strategies in Europe. IEA Information Paper.

[131] Rosenberg, J.V., Engle, R.F. 2002. Empirical Pricing Kernels. Journal of Financial Economics; 64; 341–372.

[132] Rothschild, M., Stiglitz, J.E. 1971. Increasing Risk: I. A Definition, Journal of Economic Theory, 2(3), 225–243.

[133] Rubin, J. 1996. A model of Intertemporal Emission Trading, Banking, and Borrowing. Journal of Environmental Economics and Management, 31, 269–286.

[134] Sandel, M.J. 1997. It's Immoral to Buy the Right to Pollute (with replies). New York Times, Dec. 15, A29.

[135] Schennach S.M., 2000. The Economics of Pollution Permit Banking in the Context of Title IV of the 1990 Clean Air Act Amendments. Journal of Environmental Economics and Management, 40, 189–210.

[136] Seifert, J., Uhrig-Homburg, M.,Wagner, M. 2008. Dynamic Behavior of CO_2 Spot Prices. Journal of Environmental Economics and Management, forthcoming.

[137] Schleich, J., Ehrhart, K.M., Hoppe, C., Hoppe, C., Seifert, S. 2006. Banning Banking in EU Emissions Trading?. Energy Policy, 34, 112–120.

[138] Sijm, J.P.M., Neuhoff, K., Chen, Y. 2006. CO_2 Cost Pass-Through and Windfall Profits in the Power Sector, Climate Policy 6(1), 49-72.

[139] Slade, M.E., Thille, E. 1997. Hotelling Confronts CAPM: A Test of the Theory of Exhaustible Resources. The Canadian Journal of Economics, 30 (3), 685–708.

[140] Smale, R., Hartley, M., Hepburn, C., Ward J., Grubb M. 2006. The Impact of CO_2 Emissions Trading on Firm Profits and Market Prices, Climate Policy 6(1), 31-48.

[141] Springer, U., 2003. The market for tradable GHG permits under the Kyoto Protocol: a survey of model studies. Energy Economics 25 (5), 527–551.

[142] Stavins R.N., (1995), Transaction Costs and Tradable Permits, Journal of Environmental Economics and Management, 29, 133–148.

[143] Stavins R.N., (1998), What Can We Learn from the Grand Policy Experiment? Lessons from SO2 Allowance Trading. The Journal of Economic Perspectives, 12 (3), 69–88

[144] Trotignon, R.,McGuiness, M., 2007. Technical Memorandum on Analysis of the EU ETS Using the Community Independent Transaction Log. MIT-CEEPR Working Paper 2007-012.

[145] Trotignon, R.,McGuiness, M.,Delbosc, A., 2008. European CO_2 Market and the CITL : The Trial Period Under Scrutiny. Research Report, Mission Climat, Caisse des Dépôts, Paris, forthcoming.

[146] Uhrig-Homburg, M., Wagner, M. 2007. Derivative Instruments in the EU Emissions Trading Scheme - An Early Market Perspective. Working Paper; Chair of Financial Engineering and Derivatives, Universitat Karlsruhe.

[147] UNFCCC. 2000. *Procedures and Mechanisms Relating to Compliance under the Kyoto Protocol: Note by the co-Chairmen of the Joint Working Group on Compliance*, Bonn. Report.

[148] Von der Fehr N.H. 1993. Tradeable Emissions Rights and Strategic Interaction. Environmental and Resource Economics 3, 129–151.

[149] Walker, N. 2006. Concrete Evidence? An Empirical Approach to Quantify the Impact of EU Emissions Trading on Cement Industry Competitiveness. School of Geography, Planning and Environmental Policy, University College Dublin. Working Paper.

[150] Weitzman, M.L. 1974. Prices vs. Quantities. Review of Economic Studies, 41, 477–491.

[151] Working, H. 1949. The Theory of the Price of Storage. American Economic Review, 12, 1254–1262.

[152] Wossink, A., Gardebroek, C. 2006. Environmental Policy Uncertainty and Marketable Permit Systems: the Dutch Phosphate Quota Program, American Journal of Agricultural Economics, 88, 16–27.

[153] Zakoian, J.M., 1994. Threshold Heteroskedastic Models. Journal of Economic Dynamics and Control, 18 (5), 931–944.