Economic Impact of the European Union Emission Trading Scheme: Evidence from the Refining Sector

by

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Abstract

I study the economic impact of the European Union Emission Trading Scheme (EU ETS) on the refining industry in Europe. I contrast previous *ex-ante* studies with the lessons from a series of interviews I conducted with industrials, and the public data available on the first phase of the scheme, effective from January 1st, 2005 to December 31st, 2007. I conclude that because of organizational inertia, weak incentives linked to the low emission permit price that prevailed during its second part, and important industrial and regulatory constraints, the Phase I of EU ETS has had a limited economic impact on firms. However, this first trading period was instrumental in allowing the refining sector to build the capabilities needed to respond efficiently to the carbon price signal in the long run. I argue that the internal and external constraints that this first phase revealed will shape the future outcome of the scheme. Based on evidence from the refining sector under EU ETS, I take position in the current debate over policy design to suggest ways for regulators to improve the economic impact and environmental effectiveness of carbon markets.

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"Man muss noch Chaos in sich haben, um einen tanzenden Stern gebären zu können."

– Friedrich Nietzsche, Zarathustra

providers of advices, criticism and support, when I needed them most.

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My parents have been an enduring presence during my years of studies. I was very lucky to receive their visits, support and encouragements during this year and a half of studies abroad. Not a day goes by without me thinking about them. They gave me the most beautiful of all gifts by raising me in a world without walls and frontiers. It is in trying to follow their compelling example that I became this jack of all trades, now a master of one.

I dedicate this thesis to my younger brother Pierre-Louis, whose laughter, sparkling eyes and passion for Rocky Balboa I missed most during those eighteen months. Pierre-Louis, when I open back the dusty pages of this thesis in twenty years of time, I hope that we will have climbed the stairs of the Philadelphia Museum of Art together, and that you have become the Tiger Woods of our times. I'm counting on you, do not make me add yet another flawed forecast to this thesis!

Finally, I want to express all my love, gratitude and admiration to a dancing star who emerged out of the Chaos, for having brought so much magic to my world.

Contents

List of Tables

List of Figures

13

Part I

The European refining sector under EU ETS: Background

Chapter 1

Introduction: the European refining sector under EU ETS

This research work studies the economic impact of the European Union Emissions Trading System on the petroleum refining industry. This first chapter introduces the subject as a topic of research in technology policy, by addressing a simple question: why do we care at all?

A short answer to this blunt question: 'It's the economy, stupid!'. Because it imposes significant costs on firms and society, EU ETS comes under severe scrutiny by the diverse stakeholders impacted by this regulatory process. Commentators argue that if the scheme on which Europe has built its environmental leadership and most of its aspirations to geopolitical relevance is to be successful and last as a nucleus for future worldwide carbon policies, it is of the utmost importance to make sure that it makes good economic sense (The Economist 2006; 2007a). The questions at hand include the economic efficiency of the scheme, its effectiveness in inducing firms to abate emissions, and the distributional impact of its allocation system. I study one specific sector under EU ETS, the European petroleum refining industry, in an attempt to shed some light on those various issues.

This chapter frames the question of the economic impact of carbon markets. It presents the issue at stake and the reasons for my focus on the European refining sector. It finally outlines the methodology and the objectives of this research project, and presents the structure of the thesis.

1.1 The economic impact of carbon markets

1.1.1 Market-based instruments for environmental policy

Market-based environmental regulation instruments seek to correct an environmental externality by allocating property rights in socially optimal amounts over the cause of the externality to firms, and creating a market to trade those property titles. Carbon markets function by capping the total allowed greenhouse gas emissions in a given sector, issuing or selling allowances to firms in corresponding amounts, and creating an institutional setting for trading of those permits. Because firms that face a low abatement cost can profit from the sale of their unused allowances, and those that face high abatement costs can buy them rather than engage in costly emission reductions investments, market-based regulations theoretically achieve fixed emission reduction targets at the lowest possible social cost.

Historically, market-based instruments (MBIs) first appeared in the US regulatory system. On the theoretical ground laid by the seminal work of Coase (1960) and Dales (1968), the US Environmental Protection Agency started experimenting with market-based instruments in the 1970s for air pollutant emissions, and in the 1980s for lead gasoline content. It is however only in the 1990s that cap-and-trade mechanisms were recognized as a practically feasible and efficient way of tackling externalities regulation, with the Acid Rain Program SO_2 emissions trading mechanism set by the 1990 Clean Air Act, and the Northeast NO_x Budget trading program. For a historical account of these developments and a summary of the lessons drawn from these early experiments with MBIs, refer specifically to Ellerman et al. (2003), Ellerman (2003b) and Stavins (1998). The emergence of market based instruments in mainstream policymaking culminated with the 1997 Kyoto protocol, which included a trading provision explicitly mentioning the use of trading instruments to minimize compliance costs (Hahn and Stavins (1999)).

1.1.2 EU ETS: context, history and debate

The European Union Emissions Trading System (EU ETS) finds its roots in the Kyoto protocol, which went into effect on February 16, 2005. Under its provisions, the EU-15 zone agreed to act as an economic 'bubble' and committed to jointly reduce its emissions to 8% under the 1990 levels by the first committment period (2008-2012). Despite significant

CO_2 emissions abatement stemming from the structural shift from coal to natural gas in UK power generation, and the efficiency gains in Eastern Germany after the reunification, the EU-15 found itself struggling to further reduce its emissions by 2000. The European Commission started considering several policy measures to help the countries collectively realize their emissions reduction comittment, among which the idea of a carbon market capping Europe's heavy industries. With the agreement of the EU Council of Environment Ministers on December 9, 2002 over the principles of the draft directive, the Comission worked under tight time constraints and enacted the Directive 2003/87/EC (European Commission 2003) on October 13, 2003. The first phase of the scheme started on January 1st, 2005, for three years, to be followed by successive phases of five years matching the Kyoto committment periods (2008-2012 and 2013-2017).

EU ETS is a decentralized system, in which Member States themselves set the National Allocation Plans within the control and the tight guidelines of the Commission. Based on the National Allocation Plans accepted at the beginning of every trading period, companies receive a certain amount of CO_2 emissions allowances, called EUAs (European Union Allowances). At the end of each trading year, firms must surrender a number of allowances matching their actual emissions. A banking provisions allows firms to trade emissions abatement and allowances between the years of a same period; unless explicitly specified by the Member States National Allocation Plans, however, the banking and borrowing of allowances across trading periods is banned. Most importantly, the Directive allows firms to trade EUAs, which should theoretically lead to the equalization of the EUA price with the marginal cost of abatement of the firms, hence distributing the abatement burden efficiently. Firms can trade through organized exchanges, or engage in over-the-counter transactions from firm to firm. In case of non-compliance, firms face a non-liberating fine of € 40 during the pilot phase, and € 100 in the subsequent trading periods. In addition to the fine, they must surrender the missing allowances in the next period.

Allocation is based on the rules chosen by the members states, which leaves them with enough flexibility to adapt to local specificities. However, a general principle has arisen that links the right to receive allowances to the act of production, specifically through the provision for new entrants (a reserve of free allowances exists for them) and for closures (plant closure entails the loss of the previously freely allocated emissions) (Ellerman and Buchner 2006). A certain proportion of the allowances was left to auctioning, on the

19

basis of Member States' choice for the pilot phase. Finally, linkage provisions devised in the Directive 2004/101/EC (European Commission 2004)) enacted in May 2004 allow installation to convert emissions reduction certificates (CERs) received from Kyoto Joint Implementation and Clean Development Mechanisms into EUAs, up to a fixed percentage of their initial allocation, and under the condition that the CERs be certified by the UN process prior to their use and that they do not stem from nuclear or land use projects.

For a complete and thorough introduction to the history of EU ETS and its institutional design, the reader should refer to Ellerman and Buchner (2007b), Pew Center on Global Climate Change (2005) or Kruger and Pizer (2004), while UN DESA DSD (2004) provides a short overview of the scheme.

There is little question that the ETS Directive has led to the creation of a functioning carbon market. In 2006, EUR 22.4 billion worth of allowances were traded, a substantial increase from the 2005 figure of EUR 9.4 billion; by end-July 2007, daily volumes on the climate exchanges and through over-the-counter transactions had increased to an average of 6.5 million European Union Allowances. Environmental benefits of the scheme have been questioned. As the first allowance surrendering date approached it became evident that initial total emission cap set by the European Commission, based on self-reported data by firms, was higher than the actual emissions for the first year. This sent prices downward, and over the span of a few days in late April 2006, the price of 2006 allowances was divided by two, and the price of the futures contract decreased by about a third (Alberola et al. 2008). It is not clear however if this recorded decrease in emissions stems for exaggerated historical self-reports by firms, or from genuine abatement (Ellerman and Buchner 2006). From a regulatory perspective, the EU ETS is a clear achievement, because it sets a precedent, as the first creation of a functioning multinational market-based instrument for greenhouse gas emission reduction, and provides the European Commission with a tool for efficient implementation of the more stringent emission regulations to come in the future if Europe is to abide by its commitment to the Kyoto Protocol.

1.1.3 Economic analysis of EU ETS

The overarching issue that motivates the economic analysis of environmental market-based instruments is the question of their efficiency. The goal of such regulations is to reach a predetermined level of emissions abatement at the least cost possible. Under the neo-

classical positivist paradigm of regulation, the regulator would ideally assess the cost of CO_2 emissions for society through economic modeling and hedonistic methods, and seek to internalize this cost using various instruments, so as to maximize the cost-efficiency of the regulation (Viscusi et al. 2005).

The two instruments that have been most often quoted in the debate on carbon policies in Europe and in the US are a carbon tax and a cap-and-trade system. Hepburn (2006) thoroughly discusses the relative merits of market-based instruments compared to a tax or command-and-control under different situations of competition structure and uncertainty, from a political economy perspective. The conclusion of theoretical studies is that, under ideal economic hypotheses, cap-and-trade systems and taxes are equivalent, as they equalize the marginal abatement costs of firms to the carbon price signal. Under uncertainty on the actual abatement costs, quantity-based instruments (cap-and-trade systems) fare best for elastic marginal abatement cost curves, while price-based instruments (carbon taxes) fit best with inelastic abatement supply cost curves (Hepburn 2006). In the case of CO_2 emissions, the strong tie between abatement and energy consumption reduction suggests that cost curves may be steep, in which case a tax would be more appropriate. However, the most compelling argument in favor of a cap-and-trade mechanism in the case of CO_2 emissions regulation stems is grounded in political economy considerations: while the asymmetrically distributed burden of a carbon tax would elicit rent-seeking behavior by firms, leading to a complex set of specific exemptions that would undermine the efficiency and the effectiveness of the scheme, a carbon market with grandfathering separates the realization of an economic optimum (price setting through allowances trading) from considerations of equity (allocation of allowances), best left to the political process Stavins (2007). There is also some evidence from historical examples, such as the market for SO_2 emissions allowances created by Title IV of the 1990 Clean Air Act, that market-based systems are more environmentally effective (Ellerman 2003a).

However, EU ETS is a policy experiment of unprecedented scale and complexity, which commentators have referred to as the 'grand policy experiment' for market-based instruments. Never before had an MBI been applied at such a scale (around 12,000 regulated sources), across so many political constituencies (25 sovereign member states), and covering such a large and diverse span of sectors (power generation and diverse heavy industries that account for up to 46% of the total greenhouse gas emissions by the EU-25 countries). This

implies that the evaluation of the economic impact of EU ETS brings the issues of economic analysis at a new degree of importance.

A classical framework in technology policy studies, suggested by Stone (2002), analyzes political decision-making in terms of conflicting values. The policy design debate on EU ETS is shaped by the moving front-line of a fundamental conflict between the various stakeholders' concern for distributional equity, economic efficiency, and environmental effectiveness. This framework leads to the following underlying dimensions of economic analysis:

- Is the scheme effective in helping the European heavy industry participate in the Kyoto emissions abatement effort? This poses a problem of measure (are we measuring actual abatements, or are firms cheating with the reporting process?), as well as a potential problem of leakage (changes in trade patterns may lead to the off-shoring of process emissions of greenhouse gas linked to production, eventually threatening the effectiveness of the scheme).

- Is the scheme efficient, leading the desired outcome in the least costly manner? This poses a problem both of static efficiency (do firms realize all gains from allowance trading?) and of dynamic efficiency (do the provisions for closures and new entrants, and flawed incentives from updating of the grandfathered allowances allocation plans, that link allocation to production, hinder divestment of inefficient plants and investment in more efficient technologies?).

- Is the scheme equitable, sharing the burden between different stakeholders with a sense of equity acceptable by all? This raises the issue of windfall profits from the pass-through of the opportunity cost of grandfathered allowances to customers, and issues of loss of competitiveness, market shares and profits to foreign companies that can export their products to the EU while facing no cost for their carbon emissions.

A large literature has developed to tackle these questions through economic simulation, and researchers have delineated broad directions for further inquiry into the functioning of EU ETS. Betz and Sato (2006) provides a thorough overview of the theoretical problems at work and of the literature on the subject. However, answering those questions ultimately means conducting specialized studies of the responses of each sector to the introduction of the scheme. This is what this research project intends to do. The next section turns to the European refining sector, and its relevance to the study of EU ETS.

1.2 The refining sector as an object of study

This thesis studies the reaction of the refining sector to the introduction of EU ETS, to help better understand the economic impact of the scheme. I chose to study the refining sector under EU ETS for three specific reasons: it was not yet well understood, my advisers and I saw it as a very interesting tool to study the broader response of industries to cap-and-trade systems, and it appeared as a key sector for the European economy.

Missing body of empirical sectoral studies

First, this research project is intended as part of a broad multi-sectoral effort to understand the economic impact of EU ETS. Previous and on-going research projects have thoroughly studied the sectors of power generation, which is the sector most strenuously affected by the allocation process, and the sectors of steel and cement, which present the highest potential exposure to competitiveness impacts from the carbon market (see extensive literature review in (Hourcade et al. 2008, Chap. 1)). However, the refining sector has not been the subject of a detailed ex-post analysis up to date. This thesis aims at adding to the body of empirical studies of EU ETS and its impact 'on the ground', by providing a window on the functioning of European refineries and their response to the introduction of the Emissions Trading scheme.

Studying the reaction of industrial sectors to cap-and-trade systems

More importantly, the European refining sector presents specificities that makes it an important instrument of study to better understand the response of industrial sectors at large to cap-and-trade systems. Refining is a heavy industry with very long time cycles for investments, and relatively long lead times for operational changes. Compared to the power generation sector, where dispatch decisions can vary with time constants as low as of the order of the minute, refineries plan their runs up to months in advance, and operational changes during the course of a run are highly costly (see 2.2). We can hence expect this sector to offer a very low reactivity to carbon price changes.

Second, the European refining sector is highly exposed to international trade. The rise of commodity finance over the last three decades has deeply integrated the world petroleum products markets, and the potential for passing-through the cost of carbon to end-use

consumers is largely limited by arbitrage opportunities (Favennec 2001, pages 88 and 94). The refining sector is hence exposed to a large extent to the competitiveness impact of EU ETS, which makes it an interesting object of study to empirically assess those effects and the response of the industry.

Finally, refineries are often thought of as massive 'optimization machines'. They consist in highly integrated grid of separation, conversion and treatment units, that have grown so complex that refiners have developed optimization techniques to schedule and control operations. Nominally, refiners use comprehensive linear programming models to optimize the choice of petroleum product output, taking into account prices of outputs, costs of inputs, estimated demand elasticities, and technical production constraints. Moreover, because of the rising sophistication of commodities markets, oil and gas companies are well versed in the arts of financial risk management and complex financial instruments linked to commodity trading. It is interesting to see whether an industry that refined the art of operations optimization to such an extent, and has access to financial trading skills reacts to emissions markets in the rational way predicted by neoclassical economic analysis.

Key sector to understand the economic impact of EU ETS

Another important point is that the study of the refining sector is highly relevant to the understanding of the macroeconomic impact of EU ETS on the European economy.

A first specificity of the refining industry is that the products of petroleum refining, are still quintessential to the economic activity in Europe. Oil prices spikes have classically been thought of as the textbook example of exogenous macroeconomic shocks, even though a growing body of literature questions their genuine historical impact and points at evidence that modern economies have become more resilient to them (Blanchard and Gali 2007). For that very reason, the refining sector holds an important place in the study of the effects of the European cap-and-trade mechanism.

Moreover, the sheer size of the refining sector in the European economy puts the issue of 'carbon leakage', the mechanism through which the capital stock for carbon intensive manufacturing activities is off-shored to non-carbon-constrainted regions of the world, in a particular light. In 2004, petroleum refineries in Europe (EU-27 zone) generated € 33 billion of value added (or 0.6 % of the total value added in non-financial businesses in 2004), and employed 140,000 persons (Eurostat 2007). Moreover, because of the high excise

taxes on petroleum products that prevail in most of the EU, the refining industry has a strong relevance to public finances: the sales of refined petroleum products in the EU-25 zone generated € 240 billions in tax revenues in 2005, which accounted for 8.6% of the total tax revenue of the zone (Europia 2006c). The most compelling case for studying refining under EU ETS stems from the fact that this sector of the European economy is the single most important pathway of exposure of the European economy to the introduction of the carbon price, as revealed by figure 1-1.
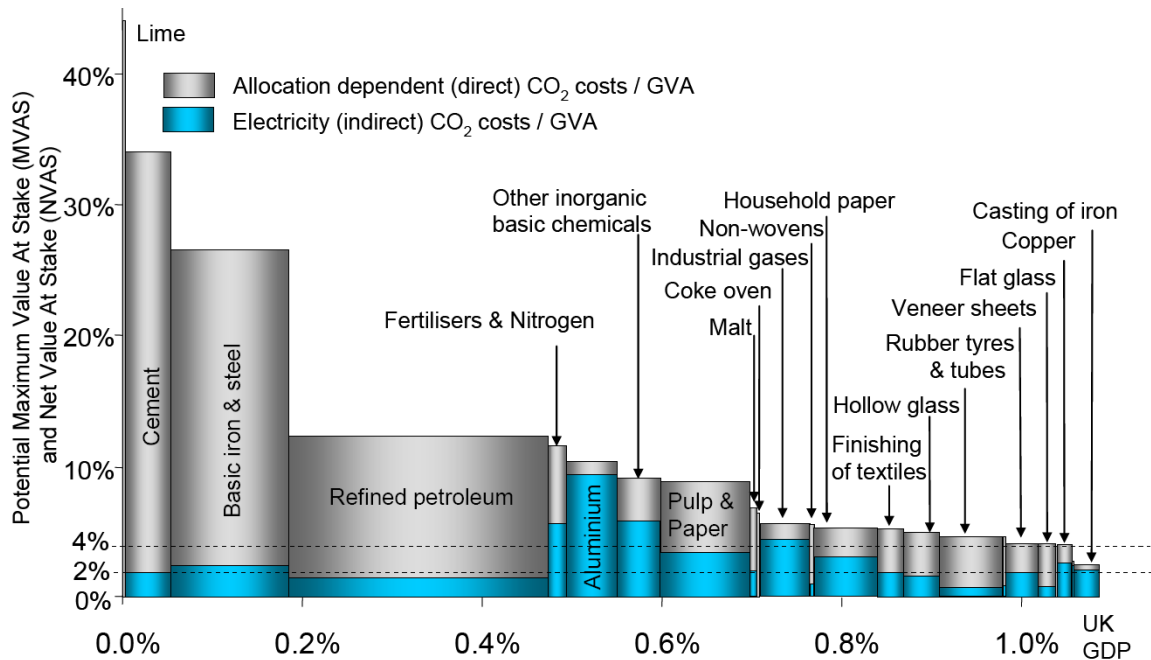
Figure 1-1: Exposure screening: subsectors potentially exposed (Hourcade et al. 2008)

Finally, the refining sector has a tremendous importance for the issue of anthropogenic carbon emissions in the long run. In 2005, petroleum products were responsible, through combustion by end users, for 39% of the 28,192.74 million metric tons of carbon dioxide emitted globally by the consumption and flaring of fossil fuels (EIA 2008). Emissions from the combustion of the end products of the refining sector are not covered by EU ETS. However, there has been talks in the U.S. to include them in a tentative cap and trade system (see notably the draft of the Bingaman and Specter (2007) bill). Such figures underline the importance of the refining sector in the energy system, and identify the sector as a major part of the link between the global carbon cycle and the economy.

25

1.3 About this research project

1.3.1 Context and objectives

This thesis is the conclusion of my year and a half long involvement in the research program of MIT's Center for Energy and Environmental Policy Research at the intersection of petroleum markets and carbon policy, under the guidance of Dr. John E. Parsons and Dr. A. Denny Ellerman. I cannot thank John and Denny enough for letting me pursue my interests, by pursuing successively a project on the future of oil production (Lacombe and Parsons 2007), a project on the econometrics of oil markets integration, and this last project on the economic impact of EU ETS in the petroleum refining sector. This last research project fits into a much broader effort, led by Dr. Denny Ellerman at MIT, with the participation of Richard Baron at the International Energy Agency (IEA), Christian de Perthuis at the Mission Climat of the Caisse des Dépots et Consignations (CDC) in Paris, and Frank Convery from University College Dublin (UCD), among other contributors. The joint project is aimed at producing an ex-post analysis of the various economic aspects of the scheme and its impact on the European industries, based on the observation of the pilot phase.

The objective of this thesis is two-fold: to analyze the economic impact of EU ETS on the European refining sector, and, reciprocally, to study the functioning of EU ETS based on findings on the refining sector:

- From a positive stand point, to measure the economic impact of EU ETS on the refining sector based on empirical evidence from the pilot phase: the aim is to conclude on how the scheme has fared so far on considerations of equity, effectiveness, and efficiency for the refining sector.

- From a normative standpoint, to identify potential improvements to the scheme, and to draw lessons on the design of future phases and markets for emissions trading, based on the observation of the refining sector during the pilot phase of EU ETS, and forecasts for future evolutions.

1.3.2 Methodology

This study of the economic impact of EU ETS on the refining sector is based on empirical evidence at hand from the pilot phase of the scheme. A first stream of assessments are based on the statistical analysis of the price, production, and trade flows data from 2005 and years prior to the beginning of the scheme, up to the latest figures available. I mostly based the assessment of the competitiveness impact of EU ETS on the refining sector on historical quantitative evidence detailed in chapter 3.

However, because of the strong technological background needed to understand the effect of EU ETS on an industry, it is inherently difficult to meaningfully infer its economic impact from aggregate data. The real changes on the European petroleum market and the environmental consequences of EU ETS are ultimately shaped by the operational changes and investments realized at the plant level, which in turn are shaped by the organizational structure deployed by oil and gas companies to address EU ETS, the perceptions of the different actors involved, and the incentives they face. Regulatory constraints as well as technico-industrial limitations are also of the utmost importance, and it is impossible to understand their impact on operations and the potential for CO_2 emissions abatement without meeting the actors in charge of these different aspects. Most of the research work for this thesis is hence based on a series of interviews with participants from the European refining industry. I led these interviews based on a standard methodology, detailed in this section.

Framing questions

The objective of these interviews was to understand what happened 'on the ground' in the refining sector as a result of the introduction of EU ETS. I devised a standardized questionnaire that supported the interviews, and determined the survey method based on four overarching themes of interest: the multiplicity of stakeholders, the real impact operational changes, the changes in business organization and strategy, and the perception of the scheme by the industry.

Stakeholder multiplicity

An important characteristic of EU ETS is that it is a highly transversal strategic issue for oil and gas companies: it involves production decisions at the level of plants (short run

technico-commercial choices), strategic planning (for middle run production decisions and long run investment decisions) both at the level of the plant and the headquarters, regulatory relations between headquarters and policymakers, compliance monitoring, and the trading of CO_2 allowances. As such, EU ETS is likely to engage a large number of actors with very different roles and potentially competing positions and incentives.

A first step was hence to identify exactly whose actors of the refining sector were the most involved in the response to EU ETS. This meant identifying the key actors in charge of the response to the introduction of the carbon pricing scheme at the different levels of the organization. The final list of potential interviewees targeted the following participants:

- At the level of plants: Business Unit Leaders, environmental compliance managers (often called Health Security and Environment officers), employees in charge of operational choices and or scheduling, employees in charge of monitoring and measuring GHG emissions

- At the level of the refinery division: managers in charge of compliance monitoring, carbon projects management, product marketing, operations oversight

- At the level of the trading division: traders in charge of CO2 trading, traders in charge of electricity trading

- At the level of the environmental compliance division: regulatory compliance officers, regulatory relations officers

- At the level of headquarters or strategic planning: chief economists, managers in charge of investment decisions, managers in charge of external growth.

Real operational changes

A second question is to understand what exactly happened in real terms at the level of plants. That meant understanding the technical challenges for refinery operators as well as the organizational constraints linked to their potential response (e.g. limited resources for abatement investment, competing regulatory obligations, workforce availability, uncertainty). The objective for the interview on that point was to understand the options at hand for the operators, and the constraint they faced, both as a result of regulations and

economic contingencies, and as a result of the way their mandate for action is shaped by the organizational structure of oil and gas companies.

Business strategy and organization

A third question is to understand the business decisions linked to EU ETS. What were the trading and compliance strategies used by companies? How have industrial develop,ent strategies evolved because of the introduction of a carbon price in Europe? How has this new regulation and its future evolutions been approached by companies? These questions are interesting from the point of view of strategy as well as from a technical and investment point of view, since the way EU ETS shapes the refining investment planning will largely determine its impact on competitiveness in the long run.

Industry perceptions of the scheme

A final section of the questionnaire is linked to the perception of the scheme by the industry. A potential flaw of market-based instruments of environmental regulations is that firms perceive such markets as an additional regulatory burden rather than an opportunity for profit. This can prove a very serious issue for the efficiency of the scheme, since it can lead to under-optimal firm behavior, which results in inefficient market conditions. The objective of the interviews regarding perception was to understand how oil and gas executives perceive this regulatory system, and how the type of company or the role of the interviewee among the organization shapes these perceptions.

1.3.3 Interviews

Based on this set of questions, Dr. Denny Ellerman and I designed a questionnaire, detailed in the appendix D, to be sent to our contacts in the European refining industry to serve as a basis for the interviews I conducted.

Because it is not possible to contact and obtain interviews with all executives in charge of the many different aspects of the response of refineries to the introduction of EU ETS, at all the different companies impacted by the sector, I cannot pretend to have led an exhaustive survey of the issue. Especially, most of the interviews I conducted were made possible only by privileged contacts between the MIT Center for Energy and Environmental Policy

29

Research and the industry, which excludes many companies, that may have had different experiences related to EU ETS. However, the panel of companies I was able to interview accounts for 36.9% of total CO_2 emissions from refineries in Europe in 2006, and is fairly balanced between large international integrated companies and smaller national actors.

In terms of the roles of the participants, I constructed the interviews in such a way as to assess a large span of points of view on the issue. Most of the interviewees have been willing to engage in in-depth discussion of the issues at hand, provided they would remain anonymous. As a conclusion, the broadness of the panel and its diversity provide a fair assurance of the relevance and quality of the themes discussed with interviewees, and the major trends that emerged.

I was specifically able to interview in depth the following interlocutors:

- Company A: International integrated oil company, with a significant share of European refining production.

    - Manager in charge of regulatory relationships on carbon issues

    - Manager in charge of compliance

    - Manager in charge of long-run investment impact research

    - Business Unit Leader of a refinery

    - Manager in charge of environmental compliance of a refinery

    - Monitoring engineer at a refinery

    - Operations engineer at a refinery

    - Trading manager and deputy trading manager

- Company B: International integrated oil company, with a significant share of European refining production.

    - Executive in charge of refinery strategy

- Company C: International integrated oil company, with a significant share of European refining production.

    - Power and Gas Trading manager

    - Environmental Products trader

- Company D: local company with refineries in only one European country (but Exploration & Production operations across the world).

    - Chief Economist

    - Manager in charge of CCS projects

- Industry organization:

    - Analyst in charge of refinery technologies

Later in the text, I refer to companies A, B and C as the 'majors', and to company D as the 'national company'.

Structure

Part I of this thesis sets the background for the problem at stake. This chapter underlined the reasons why it is important to think about the economic impact of EU ETS on European refineries as a current issue in Technology Policy. Chapter 2 provides some background information on the European refining industry. It describes the technology involved and its implications for CO_2 emissions. It analyzes the main economic trends that shape the sector today, and the evolving regulatory environment it faces.

Part II delves into the positive economic analysis of the pilot phase of the European Union Emissions Trading System.

Chapter 3 focuses on equity issues in the EU ETS, namely by assessing the competitiveness impact of EU ETS based mostly on the quantitative evidence available from the pilot phase. I draw upon the existing literature to describe a theory of the industrial competitiveness impact of regulations. I summarize previous ex-ante studies of the effect of the cap-and-trade system on the refining sector, and contrast the forecast results with what is apparent from aggregate data, and the situation described by the industry. I conclude that the competitiveness impact of the carbon market can become significant in the future if the industry is exposed to the full cash cost of allowances, but that we do not observe significant changes in market shares and profits directly due to EU ETS during the elapsed trading period.

Chapter 4 focuses on the effectiveness of the scheme. I study the actual operational changes on the ground, and the way change has been implemented by companies. The

chapter describes how companies have sought carbon emissions abatement through changes in their operations, and how their investment strategies have taken the carbon price in consideration. I conclude that, because of the high margin environment, the low cost of carbon prevailing during a large part of the trading period, and other competing binding constraints such as petroleum products sulfur content regulation and tensions on the specialized labor market, no significant operational changes have yet been undertaken. However, Phase I has allowed companies to build institutional capability to respond to further tightening of the emissions cap.

Chapter 5 focuses on the efficiency of the scheme. I study the perception of the scheme by the industry, to show that in addition to techno-economical barriers to abatement investments, flawed incentives stemming from policy design and corporate organization may undermine the efficiency of the response of firms. I observed during the interviews that the industry does not seem to recognize the opportunity cost of allowances, but to act as compliance cost minimizers rather than profit maximizers. I conclude that this departure from the hypothesis of standard economic theory, which is translated in the organizational design chosen by firms, can be solved by setting incentives right at the level of plants.

Part III of this thesis focuses on the normative economic analysis of the future of the EU Emissions Trading System.

Chapter 6 addresses the debate on the design of the next phases EU ETS. In light of what was learned from the observation of the pilot phase, I suggest solutions to improve the outcome of the scheme in terms of distributional effects, efficiency and effectiveness. Finally, the chapter closes on some concluding thoughts on the future of refining and petroleum fuels in a carbon conscious world.

Chapter 2

A primer on the European refining sector

With a daily intake of slightly more than 14 million barrels per day (Oil & Gas Journal 2008), the European refining industry represents around 18% of the world production of petroleum products. As described in chapter 1, both the importance of the industry for the study of the competitiveness impact of EU ETS, and its technical complexity as a highly integrated industry shaped by the evolving global supply and demand imbalances and regulatory constraints, call for a 'ground level' study of the sector. In this chapter, I provide a succint overview of the refining sector in Europe, intended to give enough insights for non-insiders to grasp the main technology and policy challenges at hand. I refer the reader to the existing body of literature for further developments on the technological aspects of the subject.

2.1 Refinery technology

At the most basic level, oil refineries process crude oil into a variety of petroleum products, from gasoline and light transportation fuels to road tar and bunker fuel. The role of the refinery is threefold (Muehlegger 2002b):

1. Isolate the different streams of petroleum products, from light to heavy molecules

2. Remove the impurities, such as sulfur and nitrogen

3. Convert and blend the different compounds to create outputs with valuable properties

To match the demand for petroleum products, refiners have two main levers of flexibility. Their choice of crude oil intake determines the natural yield of the refinery, and hence the relative quality and quantity of the different streams that refiners can work with to manufacture end products. The choice of refining units and their settings affects how streams are converted to each other and blended into final products. This section first discusses the characteristics of the end products, and how the choice of crude oil affects the output mix. I then succinctly describe the equipment at a modern refinery, and how it can affect the mix of final products.

2.1.1 Products

The choice of crude oil is the first way a refiner can influence the output mix. Crude oil is a heterogeneous good, with different standards of quality. Based on the chemical content of the crude oil it processes, each refinery is limited in the blend of petroleum products it can produce based on its installed units. I investigate the link between crude intake and product output in this first section.

Crude oil and product streams

Crude oil is the feedstock of the petroleum refining industry. Its main characteristic is that it is not a pure chemical substance, but rather a complex mixture of a large number of different hydrocarbons, with between 1 and 60 carbon atoms per molecule. The level of structural complexity of the molecules is also largely varying, from paraffins (linear chains of carbon atoms fully saturated by hydrogen atoms) to aromatics and naphthenes (cyclical structures), and various isomers. A consequence of this complex structure is that oil, contrary to pure chemical substances, does not boil at a fixed temperature. Heating up oil results in a gradual evaporation of the different chemical components of the crude as temperatures increases, from the 'lightest' to the 'heaviest' chemical components of the crude - a denomination that stems from the fact that, generally speaking, molecules with long carbon chains will vaporize at higher temperatures and have higher density than short hydrocarbons (see table 2.1).

Because of the importance of boiling temperature as a determinant of the characteristics of compounds, and hence their desirability for different end uses, and because compound separation methods are based largely on temperature gradient (see next section for a de-

34

Table 2.1: Examples of light and heavy compounds (Leffler 2000)

Compound	Formula	Boiling Temperature	Weight lbs/gal
Propane	C_3H_8	$-44°F$	4.2
Butane	C_4H_{10}	$31°F$	4.9
Decane	$C_{10}H_{22}$	$345°F$	6.1

scription of the distillation process), chemical engineers group chemical compounds in six families, or 'fractions', based on their evaporation temperature (see table 2.2). Lighter fractions evaporate at the lower temperature, and heavy fractions evaporate at high temperatures.

Table 2.2: Crude oil fractions and boiling temperature range (Leffler 2000)

Temperature range	Fraction
Less than 90°F	Butanes and lighter
90°F - 220°F	Gasoline
220°F - 315°F	Naphtha
315°F - 450°F	Kerosene
450°F - 800°F	Gas Oil
800°F and higher	Residue

Each type of crude oil, depending on the mix of chemical compounds that it consists of, has a specific 'distillation profile', which determines the volume of each fraction stemming from a barrel of crude. Based on the distillation process, refiners will separate the different fractions and use them to manufacture different products.

End products

The refining sectors produces a wealth of different products, from staples such as the different types of fuels, to specialty products such as lubricants, special oils, petrochemical feedstock etc. However, the main products manufactured by the industry, and on which this economic analysis will bear, are the transportation and heating fuels listed in table 2.3 (net production designates the total inland production, net of fuel consumption in refineries).

Distillation curve and product quality

The distillation curve of a crude determines the amount of the different fractions that are naturally recovered after the distillation process. Generally speaking, lighter fractions and

Table 2.3: Petroleum products net production in Europe (EU-27) (Eurostat 2008)

Product	2006 Net Production (thousand metric tons)
Refinery gas	3,077
Liquefied petroleum gas	18,932
Motor gasoline	151,032
Kerosenes and jet fuels	46,569
Gas/diesel oil	268,159
Heating oil	103,498
Sundry products	57,891

products such as gasoline and jet fuels are the most valued products, while heavy products such as coke and tar (sundry products) are of lower value to consumers. Based on forecast prices, refiners can try to increase profitability by converting some of the heaviest streams into lighter products, through the use of conversion units described in the next section. However, the choice of crude has a large impact on the potential output mix realizable by each refinery. The quality of the crude is hence of the primary importance for refiners.

End products such as gasoline and diesel fuels are highly complex blends of hydrocarbon compounds, that must fulfill standardized quality requirements to be sold on the marketplace. A certain number of these requirements are of regulatory nature, and I come back to them in the subsequent section on the regulatory environment for European refineries. However, some of these quality requirement are necessary in order for gasoline and diesel blends to correctly power the internal combustion engines and diesel engines in which they are used.

Gasoline product specifications

The Reid Vapor Pressure (RVP), which measures the volatility of the gasoline blend, is a direct indication of how ignitable will the gasoline/air mixture be after vaporization. If the number is too low, the engine will not cold start, because gasoline is not volatile enough to ignite. If it is too high, it will not restart when heated, because gasoline will expand in the injection apparatus so much that no air can enter. To adapt the RVP of gasoline to location and season, refiners blend it with different agents, most often normal and iso-butane.

The octane number is an important dimension of the quality of gasoline blends. It is linked to the issue of knocking, that designates the phenomenon by which gasoline may self-ignite during the compression phase in a hot engine. For a given blend, at a fixed functioning

temperature, this phenomenon occurs when the compression ratio (volume at atmospheric pressure to compressed volume) reaches a given level. As iso-octane is a compound that exhibits good tolerance to large compression ratios, while normal heptane knocks at a much lower compression ratio, refiners attribute to each gasoline blend an *octane number*, which is defined as the volume percentage of iso-octane in a pure iso-octane/normal heptane blend that would knock at the same compression volume. The octane number of a gasoline stream generally acts as a constraint on refiners, as it forces them to blend specific compounds such as aromatics and special blends such as reformate (see section on the catalytic reformer) that increase the octane number of the stream.

Diesel fuel product specifications

For gasoline engines, self-ignition is to be avoided at all cost. For diesel engines, on the contrary, it is the essence of the mechanism at work. Symmetrically to the octane number, that measured the ability of gasoline blends not to self-ignite, the cetane number measures the propensity of diesel fuel to self-ignite when compressed. It takes its name from the test fluid used to determine the minimum compression ratio needed to obtain self-ignition, a mixture of cetane (C_6H_{36}) and alpha-methyl-naphthalene ($C_{11}H_{12}$). Contrary to gasoline blending, diesel blending usually requires more paraffin streams and less aromatics in order to reach acceptable cetane numbers.

Another important characteristic of the diesel fuel used for road transportation is the pour point, which measures the temperature under which diesel oil crystallizes. Long paraffin chains form solid wax particles in cold conditions, and can potentially clog the fuel lines in diesel engines. A balance must hence be stricken between increasing the cetane number and decreasing the pour point.

Finally, the diesel fuel oil blends used in furnaces does not need to comply with any pour point and cetane numbers requirements, since it is used in in-house burners. However, the flash point, the lowest temperature at which enough vapors are given off to form a combustible mixture, is extremely important for the safety of domestic boilers. Streams such as gasoline and kerosenes have low flash points, which makes them potentially dangerous if mixed with the diesel furnace oil.

Crude oil quality metrics

API gravity

A first metric of the quality of crude is the amount of light fractions they can yield. Crudes with inflated heavy fractions are called 'heavy crudes', while crudes with an excess of light fractions are called 'light crudes'. This metric of quality is generally expressed by the specific gravity of the crude, measured by the arcane 'API gravity' formula introduced by the American Petroleum Institute:

$$\text{API Gravity} = 141.5 \times \frac{\text{Volumetric weight of water}}{\text{Volumic weight of compound}} - 131.5$$

Typical API gravities for different products are given in table 2.4.

Table 2.4: Typical API gravities of petroleum products (Leffler 2000)

Compound	API Gravity
Heavy crude	18°
Light crude	36°
Gasoline	60°
Asphalt	11°

Sulfur content

Another important characteristic of petroleum stems from the fact that crude oil contains amounts of other compounds, such as sulfur, nitrogen and other elements. This is specifically important with regard to air quality, because the sulfur contained in the crude is passed through to petroleum products and, at the time of combustion, results in the emission of SO_x, a major air pollutant. Large amounts of sulfur in the crude intake imposes two constraints on refiners: it limits their ability to use the heavy fuel oil stream stemming from the crude intake to fuel the refinery, as they may transgress regulation on the amount of SO_x they can release in the atmosphere; and it forces them to treat the streams to remove sulfur in order to comply with sulfur content regulation. The second most important metric of quality is hence the sulfur content, referred to in the market as the 'sourness' of the crude – the high sulfur content crudes being designated as 'sour', and the low sulfur content crudes as 'sweet'.

PONA number

Finally, the nature of the chemical content of the crude oil is very important for refiners, as it determines the relative scarcity of the compounds with which operators will manufacture end products. The product streams in refineries are often characterized, in addition to their density and sulfur content, by their PONA number, which gives the relative fraction of the stream under one of the four following chemical forms:

- Paraffins: saturated linear or non-linear carbon chains

- Olefins: non saturated paraffins, which exhibit a double bond:

$$C_nH_{2n} = CH_2$$
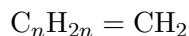
  Olefins are man-made chemicals that appear during the different processes in the refinery, but do not exist in natural crude oil.

- Naphthenes: saturated cyclical carbon rings (example: cyclopentane C_5H_{10}), sometimes with a methyl radical

- Aromatics: saturated carbon rings (example: benzene C_6H_6)

Interestingly, aromatics and naphthenes, which are found in higher proportion in product streams that have undergone conversion processes, have particular chemical properties that make them highly desirable or undesirable based on the type of end-product that is sought. This is a constraint that refiners have to bear in mind while optimizing their refining tool to match demand.

2.1.2   Refinery units

Once a crude oil intake is chosen, the specific technology deployed at refineries also allows a refiner to influence the output mix. In this section, we describe the units used by refiners to separate, alter and purify the different streams of petroleum products stemming from crude oil.

Distillation

Distillation refers to the separation of the fractions of the incoming crude oil stream.

Atmospheric distillation

The basic unit of any refinery is the atmospheric distillation tower. The distillation unit separates the different fractions of the crude based on the principle of distillation. The crude input stream is heated in a column, and the different fractions naturally separate at different heights, as the temperature decreases with height. The different fractions are hence separated. By playing on the height of the different platforms at which the condensed streams are retrieved, refiners can adapt the 'cut' of the crude intake, i.e. modify the properties of the different streams. The different streams coming directly from the atmospheric distillation tower are called 'straight-run' (e.g. straight-run gasoline or straight-run naphtha, as opposed for example to the 'cat cracker gasoline' and 'cat cracker naphtha' streams that stem from the catalytic cracker unit described below).

Vacuum crude distillation

Depending on the crude input, some residue may remain at the bottom of the atmospheric distillation tower if its vaporization temperature is higher than the crude flow temperature. This happens because the temperature in the distillation tower is limited by the phenomenon of cracking: above a certain temperature, hydrocarbon chains break up, which is undesirable if it is not controlled. Most refineries use a secondary unit, called vacuum distillation, or 'vacuum flashing', that uses the same process but under artificially lowered pressure, and in presence of vapor, to separate the different fractions of the atmospheric residue. The lighter fractions that stem from this process are called 'flash tops', and include light flashed distillate and heavy flashed distillate, used to manufacture fuel oil. The heavier fraction is called the vacuum residue, or 'flasher bottoms'.

Upgrading

The refiner can try to further convert the flasher bottoms in useful products, by using different upgrading units that convert the heavy residue in lighter fractions that can be blended with straight-run fractions to increase the yield of valuable light end products. Three main options have been developed by the industry.

Thermal cracking

Thermal cracking units reduce the amount of residue by enabling the 'cracking' of molecules, which designates the process by which the long heavy hydrocarbon chains break at high temperature. The flasher bottoms are first run into a reaction chamber during which the cracking happens, at very high temperature (from 950°F to 1020°F). A second chamber acts as a flasher, and separates the lighter molecules, that result from the reaction, from the rest of the residue.

Visbreaking

Visbreaking units are equivalent to thermal cracking units, but based on cheaper and simpler design. This economic advantage, however, comes with a disadvantage linked to the output of the unit, as a smaller proportion of the vacuum residue is transformed.

Coking

Using a coker unit is another method for residue reduction that relies on another process, known as coking. The duration of exposure to heat plays an important role in the breaking of the hydrocarbon molecules. While cracking, at a basic level, consists in a short run exposure to high temperatures, coking would be best described as a 'slow cooking', a prolongated exposure to temperatures of a lower level. The main characteristic of this process is that it creates a solid residue, coke, that refiners can sell but have to handle with specific processes because of the fact that it is solid.

A characteristic of the streams that exit the deep conversion units is that their qualities are degraded compared to straight-run light streams. Specifically, because heavier molecules in the crude oil stream have more complicated structures with aromatic cycles, that tend to act as breaking points during the cracking process, the aromatic content of cracked streams is higher, which complicates their integration in the remaining streams. Overall, however, upgrading units help refiners significantly increase the yield of their tool.

Conversion

Once these distillate streams have been separated, the refiner tries to convert them to lighter products such as gasoline and diesel. A number of different options exist and have been

developed by the industry.

Catalytic cracker

The catalytic cracker unit (CCU), or cat cracker, uses the same process as the thermal cracker to the straight-run heavy fuel oil and vacuum distillates, in the presence of carefully chosen and designed catalysts that foster the cracking reaction. Such catalysts, called zeolytes, have been synthetically designed to present an unusually large surface area. This means that hydrocarbon molecules have more contact with catalysts, which accelerates the cracking process. Conversely, it means that the coke that forms when hydrocarbon chains are repeatedly cracked eventually deposits on the catalysts, thus 'poisoning' it from the point of view of the reaction. This calls for a specific process called regeneration, an open cycle process through which the spent catalyst is piped to a combustion chamber where the coke is burnt, and then piped back in the cat cracker as fresh catalyst. This process of coke combustion is highly CO_2 intensive, and an inconvenient is that the catalyst is slowly degraded with the number of cycles, and must be changed every two or three years.

The process variables include feed quality, feed rate and recycle rate, and reaction temperature. Cat cracker runs have the same quality issues than the streams coming out of the thermal cracker, namely that they have a higher than usual aromatic content, which calls special care when blending them with the straight-run streams to produce petroleum products.

Catalytic reformer

Catalytic reformer uses specific catalysts to perform a *reforming* reaction on the straight-run naphtha, or heavier streams from atmospheric and void distillation, which consists in the following transformations:

- Paraffins are converted to iso-paraffins

- Paraffins are converted to naphthenes, releasing hydrogen

- Naphthenes are converted to aromatics, releasing hydrogen

- Some of the paraffins and naphthenes crack and form butanes and lighter gases

- Some of the side chains get broken off the naphthenes and aromatics and form butanes and lighter gases

The typical yield of such a reaction is detailed in table 2.5. These complicated reactions stem from the use of specific catalysts, notably palladium and platine, in large amounts (several million dollars worth of these metals in one process unit (Leffler 2000)). Catalytic reforming is an important process for modern refineries, because it transforms low octane naphtha streams in high-octane gasoline streams, while producing hydrogen and methane as byproducts.

Table 2.5: Typical reformer material balance (Leffler 2000)

Content	Feed	Product
	(Volume percentage)	
Paraffins	45	20
Iso-Paraffins	5	15
Olefins	0	0
Naphthenes	40	10
Aromatics	10	5
Hydrogen	0	2

Catalytic hydrocracker

Catalytic hydrocracker units (HCU) use the same general principle as a catalytic cracker unit (CCU), but in the presence of hydrogen, which is usually made available in large and affordable amounts by the development of cat reforming units in modern refineries. Similarly to cat crackers, HCUs transform low octane naphtha streams in high-octane gasoline streams, while producing hydrogen and methane as byproducts, but offer higher flexibility to refiners (Gary and Handwerk 2001).

Treatment and blending

Alkylation unit

The alkylation unit in the refinery produces addresses the issue of the light ends produced by the cat cracker, such as butylenes and propylenes. These molecules have interesting characteristics for gasoline blending, but are too volatile and in too large a volume to stay dissolved in the gasoline blend. From these streams, the alkylation unit forms a high-octane iso-paraffin called alkylate, which proves helpful for gasoline blending.

Other required blending agents, such as oxygenates or Methyl Tetra Butyl Ester (MTBE) are manufactured in different units in the refinery, or bought from petrochemical plants. An important aspect of the integration of all these different processes is to increase the amount of blending agents produced by the refinery itself, and the ability to integrate the different streams to produce high value products (Favennec 2001).

Hydrotreater

Hydro-desulfurization (HDS) is a process that removes sulfur from the streams to be treated, by exposing them to hydrogen at high temperatures (500°F to 800°F), in the presence of catalyst pellets. The catalysts promote the following reactions (Leffler 2000):

- The hydrogen combines with the sulfur atoms to form H_2S

- Some nitrogen compounds are converted to ammonia

- Metals entrained in the oil deposit are captured

- Some of the olefins and aromatics get saturated with hydrogen

- As the contaminants crack away from the hydrocarbon, some gas (methane to butane) form.

The hydrotreating unit cleans the stream from its main impurities. This is very important relative to the compliance with sulfur content regulations, as the excess sulfur content can be recovered under the form of H_2S. HDS units are hence a staple of modern refineries, and the sector as a whole has undertaken a large effort to develop its desulfurization capacity over the last years.

However, tightening the sulfur content regulation most often means more CO_2 emissions stemming from the increased HDS capacity utilization. HDS emits carbon dioxide because of its reliance on fuel oil combustion in boilers, and for flow capacity. Increasing the amount of sulfur that is removed from the streams means increasing the dihydrogen consumption, the flow of streams in the unit, and the overall heat consumption, which results in increased CO_2 emissions.

Utilities

Finally, a number of ancillary units and utilities inside the refinery are key to refineries, which heavily rely on the consumption of energy, under the form of fuel oil for boilers, of electricity, and sometimes as natural gas and LPG. The refinery gas plant is also particularly important in that respect, as the hydrogen production plant uses methane as its primary reforming feedstock.

2.1.3 Refinery complexity and classification

The preceding sections have presented only the main options for conversion and treatment at hand for the industrials. However, a refinery is a complex integrated network of such units, starting with distillation units separating the different fractions of the crude oil stream that will then enter the different conversion and treatment units, based on the optimized schedule devised by refinery operatives. This section presents how all these units come together, and how the installed capital base shapes the possibilities of the refinery, and ultimately its profitability.

Refinery typologies

Because of the diversity of these options, and the long time cycles at play in the industry, refineries often have very different designs, and it is difficult to compare them, and hence their performance. To distinguish between the different types of refineries, industry analysts have developed the notion of complexity, which denotes the amount to which the refinery can convert heavy hydrocarbon feedstock to light products. The main typologies of refineries are the following:

- Simple refinery: topping refinery, or 'hydroskimming' (HSK) refinery. Consists in a simple distillation refinery (sometimes only atmospheric distillation), with treatment units for the straight-run streams (e.g. catalytic reformer and hydrotreating units). The produced fuels are almost entirely determined by the crude intake. Many simple refineries have added an upgrading unit, under the form of a coker or a visbreaker, in order to increase the amount of light fractions they can recover; however, once the fractions are separated, they can't convert distillate streams to lighter gasoline or diesel products. The general organization of a hydroskimming refinery is detailed in

figure C-1.

- Complex refinery: a simple refinery with added conversion capacity. For example, a structure such as HSK + catalytic cracker (CCU) or hydrocracker (HCU) + residue reduction installation, such as a thermal cracker (TCU), a coker (CKU, or DC for delayed cokers) or a visbreaker (VB). This configuration allows a higher conversion rate of the heavy fuel streams to gasoline, diesel and light products. The general organization of a complex refinery is detailed in figure C-2.

- Ultra complex refineries: HSK + CCU + HCU + deep conversion residue reduction unit. This configuration enables a superior flexibility, and the ability to process heavier fuels without sacrificing the quality of end products, and hence to command higher margins. The general organization of a ultra complex refinery is detailed in figure C-3.

Annex A lists all the European refineries by country, and details their capacity, complexity, and their allocated allowances and declared emissions during the first two years of the scheme.

Marginal and average yield

The yield of refineries vary greatly depending on the technology developed at the level of the plant and the crude intake. I compute in table 2.6 the average yield in Europe during Phase I of EU ETS.

Interestingly, as the primary distillation capacity of a refinery is filled up to capacity by the crude intake batches, the downstream conversion units are progressively saturated. This results in a particular situation, where refiners cannot command the same conversion capability on the last unit of crude processed by a refinery as on the average barrel of crude intake. The petroleum products yield that best represents how refiners respond to the local demand for products is the average yield of a barrel of crude throughput. As economic choices are made at the margin, however, it is interesting to distinguish the marginal yield from the average yield. The following table (table 2.6) shows the average and marginal yield of the European refinery park [1]. The table makes clear that refiners struggle to match the demand for diesel, a claim that is backed by the petroleum products trade imbalance

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[1]To compute the average yield, I average the ratio between the production of each given petroleum

described in the following sections: schematically, Europe imports diesel on a large scale, mainly semi-finished products from Russia, and exports gasoline to the U.S.

Table 2.6: Average and marginal yield in the European refining sector, 2005-2007 (computed from Eurostat (2008))

Product	Average EU-27 refinery yield		Marginal EU-27 refinery yield	
	Raw	Net	Raw	Net
Refinery gas	0.45%	0.48%	0.41%	0.46%
Liquid petroleum gas	2.58%	2.76%	2.47%	2.76%
Gasoline	20.46%	21.93%	20.92%	23.37%
Kerosenes and jet fuel	6.30%	6.75%	6.66%	7.44%
Naphthas	5.77%	6.19%	7.05%	7.88%
Diesel oil	35.95%	38.55%	26.93%	30.09%
Residual fuel oil	14.08%	15.10%	19.36%	21.63%
Sundry products	7.68%	8.24%	5.70%	6.36%
Losses	6.74%	-	10.50%	-

Typical refinery profitability

As described along the typology of refineries, the typical yield of a plant depends heavily on the type of crude it processes, and the conversion capacity installed. Schematically, hydroskimming refineries can hardly upgrade the heavier streams stemming from the distillation towers, and must process light crudes in order to produce the lightest, most profitable products such as gasoline and diesel. Complex and ultra complex refineries, however, especially the ones that have developed deep conversion capacity, can still match the demand for light products while processing heavier crudes, which, because of the price discount of heavy crudes compared to light crudes (Lacombe and Parsons 2008), is more profitable. Leffler (2000) and Favennec (2001) provide examples of the impact of complexity on the

product and the crude oil intake at a refinery over time:

$$\text{Average yield} = \mathbb{E}_t \left(\frac{\text{Product}_t}{\text{Crude intake}_t} \right)$$

To compute the marginal yield, I try to approximate, for each different product, the derivative of the gross weight of product output with regard to crude oil intake, the refining configuration being kept constant:

$$\text{Marginal yield} = \left(\frac{\partial \text{Product}_t}{\partial \text{Crude intake}_t} \right)_{\text{Constant configuration}}$$

To approximate this marginal yield, I run a constrained regression of the first difference of the gross weight production time series for each product on the crude oil intake time series:

$$\text{Marginal yield} = \hat{\alpha} \quad \text{estimated in:} \quad \Delta \text{Product}_t = \alpha \times \Delta \text{Crude intake}_t + \epsilon_t$$

crude input-product output choices, and the consequences for plant profitability.

Generally speaking, the profitability of a refinery is set by the following formula:

$$\text{Net benefit} = \text{Crack spread} - (\text{Operational costs} + \text{Capital cost and taxes})$$

The crack spread designates the differential between the market value of the product slate and the crude intake:

$$\text{Crack spread} = \sum_{i \; Products} p_i Q_i \; - \; p_{Crude} Q_{Crude}$$

The industry has developed benchmark of the crack spread, such as the '3:2:1 crack spread', based on the price of 3 barrels of Brent crude, 2 barrels of gasoline and 1 barrel of fuel oil for delivery in Rotterdam. Ultimately, however, the crack spread depends on the exact yield of the plants. I present the recent trends for crack spreads and profitability in the section on the economic environment of the European refining industry.

2.2 Refinery operation and management

2.2.1 Scheduling

Because of the interconnected nature of a refinery, and the complexity of the problem at hand, maximizing the profitability of a plant is a complicated task. Operators have hence developed linear programming (LP) models, that incorporate all the constraints of the refinery and its price environment, and finds the optimal configuration in terms of profitability. Since it is costly for operators to adjust day to day to the evolving price environment, refineries act as a batch process, organized in 'production runs' of 2 to 4 weeks. The following process takes place between the refinery and headquarters:

- Up to six months before the beginning of a batch, the marketing branch of the company starts reviewing the potential options for crude intake available on the market, and their profitability for refineries based on demand forecasts.

- In the last weeks before the run, the crude oil delivery contracts are finalized, and the complete LP models are run to finalize the configuration of the plant in the next run.

- Once the previous run draws to its end, the refinery operators diminish the crude oil intake flow, start adapting the refinery to its new configuration, and jump start the new crude oil input batch.

- The refinery is progressively brought to its maximum throughput in the new configuration. In this situation, any change would necessite a decrease of the throughput of the plant, and would hence prove costly. Minor tunings can be performed, but the operators try to minimize the configuration changes during the 2 to 4 weeks of the 'run'.

2.2.2   Monitoring

Monitoring is an important aspect of the operation of refineries, not only for obvious reasons of safety and profitability, but because it is necessary to ensure, once a run is finished, that the refinery made the most of the available crude intake. An office at the refinery is hence in charge of running *ex-post* simulations of the run, to learn from operational mistakes and identify potential improvements. In order to perform these post-cycle performance assessments, and to control the plant, refineries have developed an extensive network of flow measurement, automated controls and numerical monitoring and control stations.

The complexity of this tool is important to understand in the context of EU ETS, because declared CO_2 emissions are extrapolated from the measured flow of fuel to the boilers of the refinery. As detailed in chapter 4, one of the main impediments to a rapid response to EU ETS by refineries has been the difficulty for them to accurately track and report their emissions. It is worth noting, for example, that a huge effort had to be undertaken to decrease the uncertainty on the evolutions of physical flow measurement devices with age. Some of the components of the monitoring systems can be as old as 20 or 30 years, and may have experienced structural changes due to fatigue, which creates an uncertainty of the fuel throughput that flows to boilers, hence ultimately on the declared emissions.

2.2.3   Maintenance cycles

Maintenance cycles in the industry are especially long. Because of the capital intensity of the industry, shutting down a plant is highly costly. It is hence necessary for operators to plan

the maintenance cycle long in advance. The usual cycle is a major maintenance shutdown every five years, and a minor maintenance shutdown every two years and a half (source: private interviews). In the case of unexpected maintenance needs, or for necessary and time sensitive investments (such as the de-bottlenecking of conversion units or the expansion of HDS units to comply with sulfur content regulations), refiners sometimes take advantage of downtime during runs to realize the necessary improvements. However, because extending such downtime is costly, and because it is precisely at those periods that the workforce is under time pressure to adapt the refinery to the coming run, operators tend to use these options as little as possible. This creates long lead times for investments that are not considered a priority, which is often the case for CO_2 abatement investments.

For more details on the management and operations of a refinery, I urge the reader to refer to Favennec (2001).

2.3 The European refining sector: the market

2.3.1 Installed refining park

As detailed in table B.2, the countries with the two largest refining capacities in Europe are Germany and Italy, with around 2.4 and 2.3 million barrel per day of atmospheric distillation capacity. Refining capacity is otherwise fairly distributed over the territory of the EU-25 area, with 104 plants (the headcount can vary due to twin installations). Plants tend to be located near points of access such as harbor on coastal areas. Refineries enjoy strong economies of scale, which pushes the average capacity up, with an average of 145,000 barrels per day of primary distillation capacity in Europe (WBCSD 2003). Most European refineries are complex, or considered ultra-complex. The annex A lists all the European refineries by country, and details their capacity, complexity, and typology. A general breakdown of the primary refining capacity, and the emissions of the different plants, by complexity level as defined in section 2.1.3, is detailed in the annex. Generally speaking, the complexity of the European refineries allows them to process medium heavy crudes profitably while mostly matching demand. The reliance of the European refining park on trade to match production and demand is however increasing, as detailed in the next section.

The bulk of the European refineries was built in the 1960s, as evidenced by table 2.7. The installed park is hence mature, and most projects since the late 1980s have consisted

in capacity expansion for primary distillation, upgrading, conversion and treatment units. Depressed margins over the period from the 1980s to the early 2000s, coupled with tightening environmental regulations, have impeded the ability of the industry to build new capacity. Today, the construction of a new refinery in Western Europe does not seem possible to most refiners (source: private interviews), because of the environmental and regulatory liabilities that this would imply. However, two main trends have shaped the investment pattern over the last years: the necessity to produce cleaner products to comply with regulation, and the shift of the automotive park to more diesel engines. This creates a situation where the main investments for the next years are either desulfurization units, or advanced conversion units in order to adapt to the rising demand for diesel (Oil & Gas Journal 2007), while all greenfield investment happens outside Europe (and outside the U.S. too), mostly in the Middle East and Asia. I detail these economic and regulatory trends in the next sections.

Table 2.7: European refineries construction during the 20th century (European Commission 2001)

Time period	Number of refineries built in the time period	Percentage of refineries built during the time period (%)	Cumulative percentage
Before 1900	1	1	1
1900 - 1910	2	2	3
1911 - 1920	1	1	4
1921 - 1930	9	9	13
1931 - 1940	7	7	19
1941 - 1950	8	8	27
1951 - 1960	17	17	44
1961 - 1970	41	40	83
1971 - 1980	12	12	95
1981 - 1990	3	3	98
1991 - 2000	2	2	100

2.3.2 Economic environment

The economic environment of the refining sector is marked by two main trends over the last years: the shift of demand toward more diesel and less gasoline, and the rapid rise of crude oil prices, with sustained high refining margins.

Demand and trade flows evolutions

The market for petroleum products in Europe is very diversified, with literally hundreds of different products stemming from the refining of crude oil and its conversion in petrochemical products. A wealth of details on the industry can be found in Eurostat (2008) and Purvin& Getz, Inc (2008). However, the market is dominated by transportation fuels such as jet fuel, gasoline and diesel gas oil.

Over the last years, the most marking evolution has been the evolution of trade flows, as evidenced by figure 2-1. As they tried to reduce the amount of greenhouse gas emissions, most governments in the EU-25 area have devised tax incentives that favor diesel engines for light duty vehicle transportation power trains. For example, the excise taxes on diesel oil and on gasoline sales have been adapted to provide an economic advantage to diesel systems. This has led to higher sales of diesel-fuel passenger cars, which in turn has increased the demand for diesel. Tax policies of European Member States toward diesel and gasoline, and their effects on the dieselization of the car float, are detailed in Verboven (2002).

Trade flows over the last half-decade have undergone significant changes. Consequently to the evolution of demand, shifting strongly toward diesel, the production of petroleum product has evolved in this very direction, but was constrained by the availability of the conversion capacity. As it takes very substantial investments and long construction lead times to significantly alter the installed capital basis for petroleum product streams conversion, refiners have turned, over the last five years, to trade, specifically importing finished diesel products and semi-processed diesel streams (mostly from Russia), and exporting the excess gasoline produced in Europe. In turn, the excess gasoline produced in Europe but not locally marketable has been sold abroad, mostly shipped to the US where the diesel/gasoline imbalance is reversed compared to Europe.

Figure 2-1 shows the evolution of gasoline and diesel trade flows as percentage of domestic production in the EU-25 area.

A statistical analysis of monthly gasoline and diesel trade flows evolutions from 2000 to 2007, investigating pattern changes after the introduction of EU ETS on January 2005, is detailed in section 3.4.2.
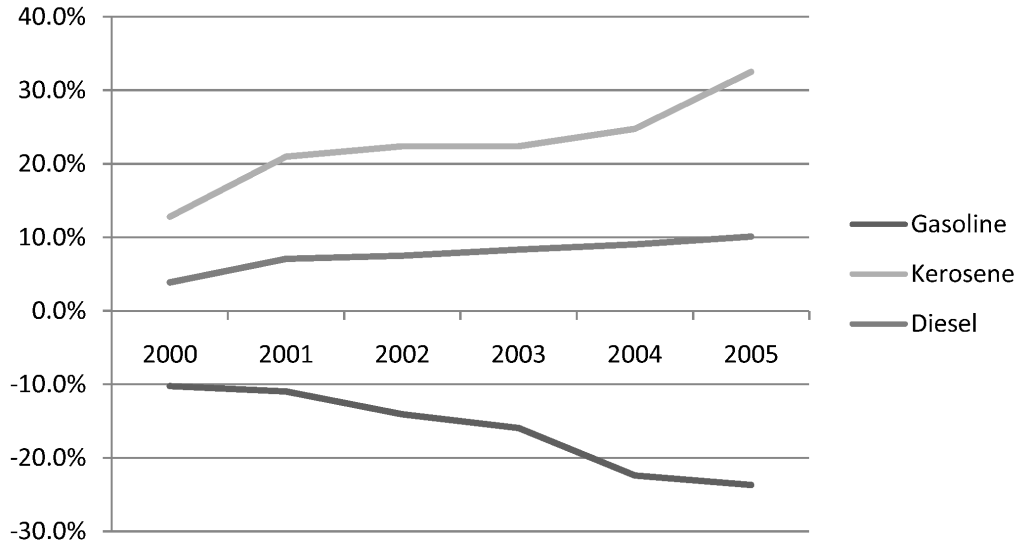
Figure 2-1: Petroleum product trade as percentage of domestic production - EU-25 area (adapted from Eurostat (2008))

Margins, cost and benefits evolutions

The cost structure of a refinery is very specific. It is completely dominated (up to 95%) by the price of the crude oil processed by the plant, bought at market prices that are largely determined by the financial transactions on the world commodity exchanges. Refineries profitability hence depends on a very large extent on the market conditions prevailing on the crude oil market and the petroleum products markets. I provide in this section a historical assessment of the operating costs of a refinery, to contrast it with the role of product prices. I then summarize the historical evolutions of refining margins, and the current margin environment.

Refining cost structure

The refining cost of a plant designates the overall costs paid to process a barrel of crude oil, excluding the cost of acquiring the barrel. The estimated figures in table 2.3.2 are based on updated figures from the McKinsey report on competitiveness prepared for the European Commission (McKinsey& Company 2006). They rely on aggregate estimated data for a complex refinery processing Brent at a 85% utilization rate with 50% of in-house electricity production (the average proportion of in-house electricity production in Europe being estimated at 57%), based on disguised client examples. However, the main cost for a

Table 2.8: Refining cost structure (updated from McKinsey& Company (2006))

Cost item	Expenditure (EUR per barrel processed)
Electricity	0.10
Chemicals and catalysts	0.10
Labor and maintenance	0.55
Materials and others	0.20
Capital depreciation	0.20
Total transforming cost	1.15
Comparison: crude purchase	80.00
(of which consumed in refinery:)	2.70
Comparison: transformation margin	≈ 3.30

refinery is the cost of the crude oil it processes. I update this cost estimate on the following new assumptions:

- Brent crude oil price: €80 per barrel

- Fuel consumption: 6.8 % of crude intake (average across Europe according to table 2.6)

- Average margin: USD 5 per bbl of crude processed (average across Europe based on IEA (2008)

The refining margin, i.e. the crack spread for the given crude intake and the petroleum product output slate chosen by the refinery is hence tantamount to profitability.

Reinaud (2005) provides a detailed analysis of refining costs based on the different configurations and location of refineries in Europe. Chapter 3 also updates these costs under the carbon markets.

Refining margins

Over the last years, the main event of the petroleum market has been the spectacular rise of international crude oil prices, from around $ 40 a barrel of WTI in 2005 to $ 100 at the end of 2007. However, in a context of tight demand for petroleum products, the refining margin have stayed high, and the industry has enjoyed growing margins, or around $ 5.00 a barrel on average for the complex refinery of which most of the park comprises. The evolutions of refining margins as evaluated by the International Energy Agency for European refineries processing Brent are detailed in figure 2-2.
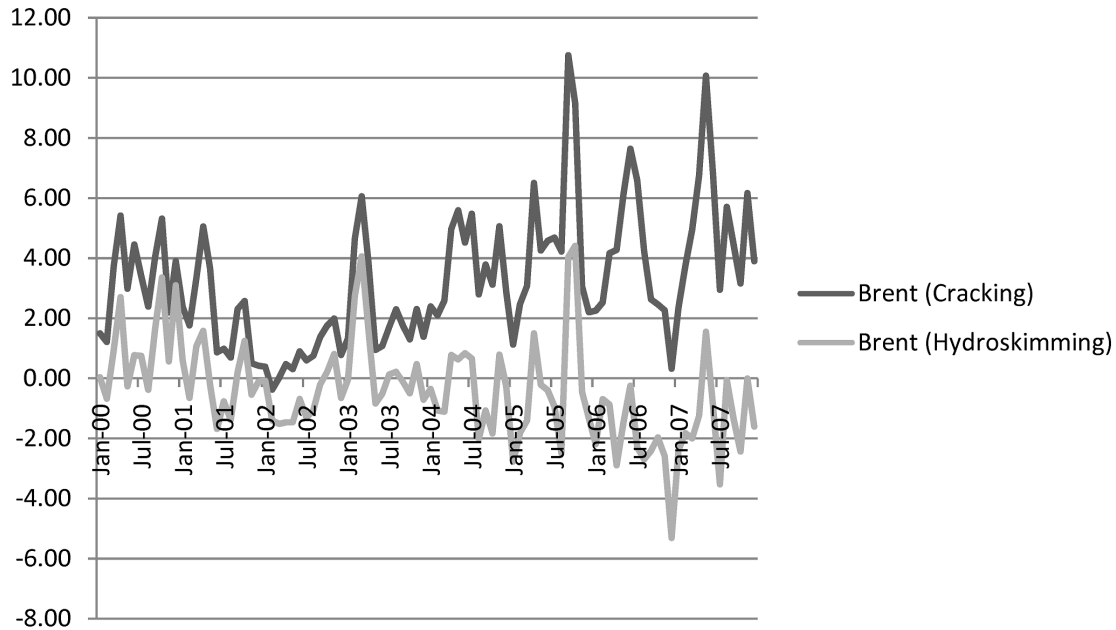
Figure 2-2: European historical margins - USD per barrel (IEA 2008)

A statistical analysis of petroleum prices and refining costs evolutions after the introduction of EU ETS in January 2005 is provided in section 3.4.3.

Workforce constraints

During the long period of low prices and depressed margins that spanned from the 1990s to the early 2000s, the global oil and gas industry has largely failed to attract young hires and renew its workforce. Today, a massive proportion of oil and gas companies employees are close from retirement. A large number of trade journal articles, as well as interviews with refiners and oil and gas executives, have confirmed that the industry as a whole faces a major human resources challenge. A study by Parry et al. (2006) quantifies the scale of the issue for upstream and downstream petroleum operations. They summarize the situation in the following blunt manner:

'With the average retirement age for the industry being 55 years, it is obvious that the industry faces a crisis in the next 7 to 10 years as more than half of the employee base leaves the work force,' said the [United States Interstate Oil and Gas Compact Commission (IOGCC)] Blue Ribbon Task Force.

55

Indeed, refinery executives confirmed during the interviews that shortages of experienced workforce were a major constraint, and the primary impediment to the acceleration of the capital base turnover that tightening sulfur regulation, evolving demand and incentives for greenhouse gas abatement call for. Specifically, as operatives have difficulties to staff their teams with experienced engineers, they need to focus on the most pressing tasks, which are limited to regular maintenance needs and the new investments that are absolutely needed, such as HDS capacity increases needed to comply with tightening sulfur content regulation. As a conclusion, workforce constraints are an important element to keep in mind when analyzing the response of the industry to the introduction of EU ETS.

2.3.3 Regulatory environment

In the industrialized world, the major constraints that bear on refining operations are regulatory limits on emissions and fuel content. Refineries are now operating under strict scrutiny of regulators from the standpoint of NO_x and SO_x as well as greenhouse gas and volatile hydrocarbon emissions. The maximum allowable level of SO_x emissions is an important operational constraint for refineries, and forces refineries to switch from burning sulfur-rich fuel oil to sulfur free refinery gas in the plant's boilers. Apart, obviously, from EU ETS, which regulates the direct emissions of refineries, the major regulatory evolutions of the coming years pertain to the emissions stemming from the consumption of petroleum products by the end users. The successive Euro 3, Euro 4 and the proposed Euro 5 standards, as well as the other recent and upcoming content regulation directives, are part of a severe tightening of fuel content regulation aimed at improving the emission outcome linked to product combustion.

The EU is preparing to impose stricter emissions limits for sulfur oxides (SO_x), nitrogen oxides (NO_x) and particulate matter (PM) which pose the most serious health problems. In order to reach the 10 ppm sulfur specification, complex refineries converting heavier products or crude oils may face the most difficult technical and economical challenges, as they will need to drastically increase the severity of hydrotreatment units for gasoline and diesel.

Table 2.9 summarizes the recent and upcoming evolutions of petroleum products content regulation in Europe. A detailed summary of the regulatory environment for refineries, and the investment needed in the years to come in order to comply with the projected legislation,

is given in Europia (2006b).

Table 2.9: Evolution of the European petroleum product content regulation (Reinaud 2005)

Regulation	1998	2000	2003	2005	2008
Gasoline					
Sulfur (max.)	500 ppm	150 ppm		50 ppm*	10 ppm
Benzene (% vol.)	5% max.	1% max.		1% max.	**
Aromatics (% vol.)		42% max.		35% max.	**
Olefins (% vol.)		18% max.			**
Oxygen (% m.)	2.5-3.7 max	2.7 max.			
Diesel					
Sulfur (max.)	500 ppm	350 ppm		50 ppm*	10 ppm
Cetane (min.)	49	51		51	**
Polyaromatics		11% max.		11% max.	**
Specific gravity (max.)	860	845		845	**
Heating oil					
Sulphur (max.)	0.2% max.				0.1% max.
Fuel oil					
Sulphur (max.)			1% max.		

* Motor fuels meeting the 10ppm sulphur limit must be available on the market
** Current draft

2.4 Sources of CO_2 emissions and potential for abatement

This section presents the main sources of CO_2 emissions in refining complexes, and summarizes the main abatement options available to refinery operatives.

2.4.1 Sources of emissions

Three main sources of CO_2 emissions can be distinguished (detailed figures in table 2.10):

- Heat, steam and power needs: most heat and steam needs, and on average 55% of the power needs of refineries are met by burning fuel oil streams coming from the distillation units in boilers and furnaces.

- Process emissions: the necessary regeneration of catalysts produces CO_2 emissions, since it consists in burning the coke that accumulates during the life cycle of the catalysts. Process emissions also include the emissions of CO_2 linked to chemical processes, such as hydrogen production through steam methane reforming.

- Flares and effluents: refineries may not always have proper outlets for refinery gas and LPG. It is not always possible for refineries to market them, and they may choose to burn them in flaring towers. Effluents of greenhouse gases may also simply leak along the various circuits of the refinery.

Table 2.10: Sources of global refinery CO_2 emissions (Gale and Freund 2001)

Source	Fraction
Oil and gas fuel firing of furnaces and boilers	65%
Regeneration of cat. cracker catalyst	16%
Flares	< 3%
Methane steam reforming to make hydrogen	2%
Incineration and effluent processes	1%
Power (on average 55% outsourced)	13%

Flares an effluents are a minor portion of emissions. In some cases, such as flaring of refinery gases, they may be purely motivated by the lack of outlets for such products. Such a practice is however usually undertaken for technical reasons that cannot be ignored, such as temporary overflows of the buffer capacity. It is not clear whether ETS has helped decrease this practice significantly, as it is already considered as a loss of energy by refiners. However, as described in chapter 4, the introduction of a carbon price has increased the awareness of refinery management on such issues, and has spurred 'leak-plugging' that may help eliminate most of these unnecessary emissions.

Process emissions seem to be the most unavoidable type of emissions, since they are mostly determined by the stoichiometry of the reactions at hand. For example, emissions stemming from catalyst remediation in cat-crackers are determined by the choice of catalyst, and unless chemical engineering innovations introduce new catalysts on the market, such carbon emissions won't significantly decrease. CO_2 emission from steam methane reforming in the dihydrogen production unit are also fixed by the stoichiometry of this reaction, that is the main option at hand to refiners. Efficiency gains on those units are hence ultimately dependent on heat process efficiency in the short run, and potential new catalysts or production reactions in the long run. Given the increasing demand for lighter products and the forecasts of decreasing gravity of crude input, which entail increased reliance on cat crackers, and the tightening constraints on sulfur content of fuels, which entail increased utilization of sulfur removal units which directly rely on hydrogen feedstock, such sources of emissions are bound to remain fixed or slightly increase in the future.

The bulk of emissions, and hence of abatement opportunities, predictably lies in increased efficiency for heat, steam and power generation and consumption in the refinery. We discuss the options at hand in the next section.

2.4.2   Abatement options

Based on the literature available in academic journals, as well as technical and policy reports, this section presents a list of options to reduce greenhouse gas emissions from refineries.

- Process optimization: without changing the infrastructure of the refinery, a first step is for refiners to incorporate the price of carbon emissions as a constraint in their linear programming models. This would have the effect of optimizing the processes of the refinery based on the new carbon constraint.

- Reducing the amount of wastes flared: as described above, such an option seems easily accessible when not dictated by technical circumstances.

- Optimizing the efficiency of heat and power production: there is a number of different options at hand for refiners to improve the efficiency of their energy supply.

  – Switching from fuel oil to natural gas or refinery gas: this option could reduce CO_2 emissions linked to heat generation by up to 25%. However, the economics of such a transition are not yet favorable to natural gas. It is notable, however, that refiners already switch from fuel oil streams (which contains high amounts of suflur) to refinery gases (virtually suflur free) when they are close to trespassing the ceiling for SO_x atmospheric emissions.

  – Combined Heat and Power (CHP) is a very interesting option for refiners. However, its profitability would be largely dictated by local circumstances, specifically the existence of potential customers for the excess electricity or steam, and the potential to use both products in refineries (the power needs vary tremendously based on the original design of the plant). Moreover, issues linked to the design of EU ETS, described in chapter 5, make the economics of this scheme highly dependent on the institutional setting.

  – Switching to the grid entirely for power generation may prove more efficient in some countries, but again this depends on the local circumstances, and the

economics of such a choice may not be favorable to the grid, as power generation sector has passed through the full marginal cost of allowances to its customers (Sijm et al. 2006).

- Optimizing the efficiency of heat and power use: increasing the efficiency of the use of heat and power is an objective that could be furthered by several different options.

  - Develop better catalysts: a constant stream of innovation seeks to improve the quality of the catalysts used in various processes in the refinery. However, refiners have always been interested by such improvements, because of the energy savings they entailed.

  - Improve the distribution of steam: this is a very substantial abatement option, that refiners have indeed pursued successfully during phase I of EU ETS (see chapter 4).

  - Improve reflux circulation in reaction chambers and distillation towers.

- CO_2 capture and storage: ultimately, one of the advantages of the refining sector regarding carbon storage and sequestration is that the sources of CO_2 emissions are well known and closely controlled. Because of the process control and optimization culture of refinery operatives, and the existing capability for liquids and gas handling, refineries could leverage their expertise to accelerate the deployment of CO_2 recovery pipelines and systems. However, apart from the reforming operations, the streams of CO_2 produced in refineries stem mostly from the combustion of a fuel/ambient air mixture, and are hence not specially concentrated, which is a suboptimal situation for carbon capture.

Some papers tackle specific technical aspects of the issue. Szklo and Schaeffer (2007) provide a thorough technical description of fuel use in refineries, and the corresponding CO_2 emissions and abatement opportunities. White (2005) describes how automation technologies can help reduce the energy consumption of refineries. Babich and Moulijn (2003) describe new technologies for deep desulfurization of refinery streams, which could have a significant impact in terms of efficiency improvement for the HDS units, and hence lead to CO_2 emissions reduction. WBCSD (2003) summarizes the best environmental practices of the industry, and gives an overview of the different sources of all potential emissions in a

refinery, from greenhouse gases to hydrocarbons, NO_x, SO_x etc. Finally, European Commission (2001) presents a thoroughly detailed overview of the best available technologies for each process inside the refinery, and Worrell and Galitsky (2005) provide a complete guide to potential energy saving options inside refineries.

More generally, a number of papers present a broader economic analysis of the abatement options at hand. Gale and Freund (2001) presents a breakdown of the different types of emission abatement opportunities, and the global outcome that would derive from the adoption of these technologies. Because of the diversity of the designs of refining plants across Europe, it is however hard to produce a clear bottom-up marginal abatement curve, and no report to my knowledge has specifically developed quantitative analyzes, either in terms of cost-benefit, or of abatement potential at the European level.

2.4.3   Impact of economic and regulatory environment

The EURO5 fuel content regulation calls for a strong tightening of the allowed sulfur content of diesel and gasoline, as described in a previous section. This will have a strong negative impact in terms of CO_2 emissions, because it means that refineries will have to drastically increase the utilization of HDS units, increasing their energy consumption directly in the HDS unit, and in the refinery gas plant or the catalytic reformer, in order to produce the additional dihydrogen needed for de-sulfurization. One of the main concerns of the industry is that this increase of CO_2 emissions, triggered by regulatory decisions, will not be considered by the European Commission in its assessment of the economic impact of ETS on the refining sector. Figure 2-3 presents the expected increase in CO_2 emissions at a European level stemming from the tightening of the regulation.

Another important variable that determines the CO_2 output of refiners is the Gas Oil to Gasoline ratio (GO/G), which measures the ratio between the demand for diesel and the demand for gasoline. As the refining park in the EU-25 has been historically tailored to maximize the production of gasoline from the crude intake, the trend for diesel demand increasing faster than gasoline demand over the last decade, pushed by tax incentives motivated by the lower CO_2 emissions of diesel engines, has had the effect to force on refineries a production configuration that is not optimal from a design standpoint. This translates in an increase in carbon emissions at the level of refineries, which, under certain scenarii, may offset the savings due to higher efficiency, and result in an actual increase of well-to-wheel

61
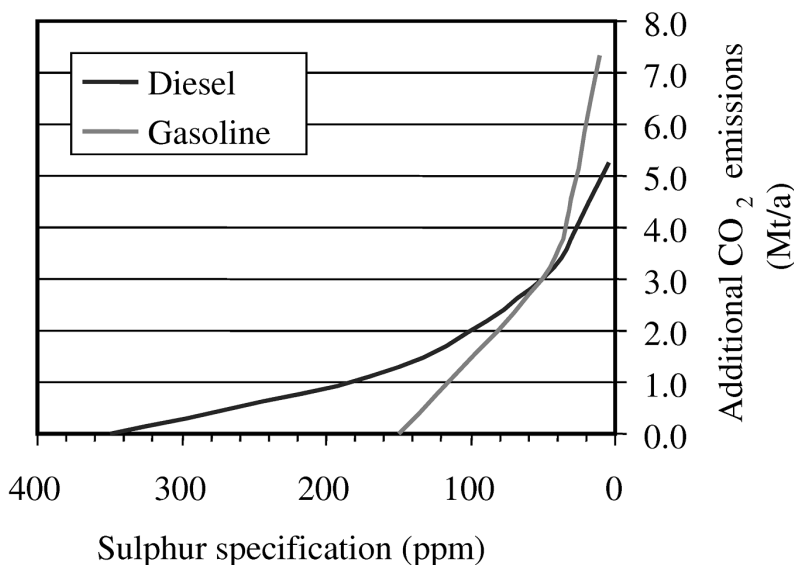
Figure 2-3: Impact of sulfur content regulation on CO_2 emissions in the EU-25 area (Concawe 2005, Reinaud 2005)

emissions (Concawe 2007).

As refiners have pointed out, the draft directive 2008/0014 on the European comprehensive policy for greenhouse gas reduction, branded as the '−20% by 2020' proposal (European Commission 2008b), that suggests a decision to mandate at least a 10% volume of biofuels for road transportation by 2010, would rely mostly on the increased use of ethanol, blended with gasoline. As it would mechanically depress the demand for gasoline, this would increase the GO/G ratio, and hence increase the risk that the fast dieselization of the automotive park would lead to increasing well-to-wheels CO_2 emissions. While the European Commission has shown concern for the environmental soundness of biofuel subsidies, it is not clear that such an effect has been taken into account in the legislation impact assessment of the Commission (European Commission 2008a).

2.5 Further analyzes: literature review

A very good introduction to the technology developed in the refining sector, accessible to the layperson but presenting in clear and thorough details the role of the different units of a refinery, is *Petroleum Refining in Non Technical Language* (Leffler 2000). A book that covers the same broad topics in more technical depth, with an emphasis on the economics of plants, is *Petroleum Refining: Technology and Economics* (Gary and Handwerk 2001).

Erich Muehlegger, a former graduate student at MIT Center for Energy and Environmental Policy Research now on the faculty of the Harvard John F. Kennedy School of Government, produced high quality technical summaries of the technology and management of refineries in his papers on the economics of gasoline content specification (Muehlegger 2002a;b). Finally, *Petroleum Refining: 5 - Refinery Operation and Management* presents a thorough overview of the issues at stake in the management and operation of refining plants (Favennec 2001).

A great source of insight on the industry, on which I extensively relied for this analysis, is the publications of the two public relation bodies of the sector, Europia (European Petroleum Industry Association) and Concawe (CONservation of Clean Air and Water in Europe, the European Oil Company Organization for Environment, Health and Safety), two think-tanks funded by the industry and located in Bruxelles. Europia publishes annual activity reports (Europia 2006a), with statistics (Europia 2006c) and a detailed explanatory guide of the functioning of refineries (Europia 2006b). Concawe produces research and analysis reports on the industry and funds research projects. I specifically drew on their industry road map for the next decade, *Oil Refining in the EU in 2015* (Concawe 2007).

The worldwide reference for statistics on the industry is the Oil & Gas Journal. It specifically publishes a yearly survey of the installed park of refineries, and the capacity of their different units (Oil & Gas Journal 2008). Another interesting survey regarding refining is the yearly report on planned investment in the sector, which gives an advanced snapshot of the direction where the industry is heading (Oil & Gas Journal 2007). A large number of institutions, such as the International Energy Agency (IEA 2005), Eurostat (Eurostat 2007; 2008), the U.S. Energy Information Agency (EIA 2008), and others listed in the bibliography, also publish data of relevance to the European refining sector. Another forward looking study that provides readers with a wealth of statistics is the study realized by Purvin& Getz, Inc., for the European Commission (Purvin& Getz, Inc 2008).

On a more anecdotal note, the petroleum industry has inspired historian and geopolitical analysts. More than many other industries, the oil and gas sector has shaped and been shaped by the geopolitical events of the last century and a half. Its history strangely echoes the struggles and evolutions of our time, and, from the early moments of the discovery of petroleum, to its central role in the modern geopolitical scene, oil has deeply shaped the economic evolution of the world, and revealed a long stream of larger-than-life characters,

such as John D. Rockefeller, Winston Churchill or Joseph Stalin to name a few. In a mesmerizing Pulitzer-winning book, *The Prize*, Daniel Yergin retraces the history of oil, its role in the evolution of our societies, and the passioning story of the characters and companies that took part in this modern saga (Yergin 1991).

Part II

EU ETS Phase I: *ex-post* analysis

Chapter 3

Measuring the competitiveness impact

One of the most important questions raised by the introduction of such a broad and ambitious scheme as the European Union Emissions Trading System is that of its cost to the global economy. The unilateral decision by the EU to act on the issue of global warming by enforcing a binding legislation is unarguably a strong signal of environmental leadership and seriousness about the European commitment to the Kyoto Protocol. However, if the costs of the scheme are too heavy compared with other nations' abatement efforts, or too unevenly distributed among European countries and industries, this may create public uproar which could eventually undermine the political consensus around the carbon market.

In this chapter, I investigate the equity issues linked to the cost of the scheme, with a specific emphasis on evaluating the competitiveness loss incurred by the European refining sector. I attempt to summarize the literature of ex-ante studies regarding the economic impact of EU ETS on the refining sector, and to confront it to the ex-post data available for part of Phase I.

3.1 Distributional equity: European industries under EU ETS

As a carbon pricing scheme, EU ETS attributes a cost to a factor of production that was previously free: the emission of CO_2 in the atmosphere. As such, it is prone to impose

67

different costs on the different sectors that fall under EU ETS. This raises questions of equity between the different firms that will bear the costs of the measure, or alternatively profit from the scheme under the current 'grandfathered' allocation system.

Namely, the proposal for a carbon market was widely denounced by the industry as potentially too costly for the European economy. The scheme is designed to internalize the costs of emitting carbon in the atmosphere, which should mitigate the potentially catastrophic future costs created by the effects of global warming. However, it is enforced only among heavy industries in the European Union. This creates an asymmetric situation between some producers in the EU, which face additional carbon costs, and their competitors abroad, or other industries in the EU not subject to ETS, which do not face these costs.

The different sectors of the European industry that fall under ETS are subdivised as follows:

- Combustion installations with a rated thermal input exceeding 20 MW, and other activity opted-in pursuant to Article 24 of Directive 2003/87/EC (*heat & power*)

- Mineral oil refineries

- Installations for the production of pig iron or steel (primary or secondary fusion) including continuous casting, metal ore (including sulphide ore) roasting or sintering installations, and coke ovens (*iron, steel & coke*)

- Industrial plants for the production of (a) pulp from timber or other fibrous materials (b) paper and board (*pulp & paper*)

- Installations for the production of cement clinker in rotary kilns or lime in rotary kilns or in other furnaces (*cement & lime*)

- Installations for the manufacture of glass including glass fibre (*glass*)

- Installations for the manufacture of ceramic products by firing, in particular roofing tiles, bricks, refractory bricks, tiles, stoneware or porcelain (*ceramics, bricks & tiles*)

Table B.1 shows how the National Allocation Plans of the Member States have distributed the grandfathered allocations among these different sectors for the first phase of the scheme. It must be noted that the allocation decisions have been taken on the basis

of imprecise plant-level baseline data for 2004, and faced serious uncertainties, such as the growth rate of the different sectors, the impact of the world economic conjecture on production, and the role of weather on energy consumption. The difficulty to compute a proper counterfactual scenario of what would have happened without EU ETS makes it difficult to state whether or not there was over-allocation of allowances, or simply a generous allocation combined with genuine abatement efforts (Ellerman and Buchner 2006).

The only sector that was overall short on allowances is the power and heat sector, while all others have enjoyed long net allowances holding positions. However, this does not necessarily imply a lack of equity toward the power generation industry, for three reasons. First, allowances in the first phase were mostly grandfathered, hence handed out for free to the plants. This mitigated any issues with the cost of carbon, since plants hence faced only the cash cost of any missing allowances they would have to buy, and the opportunity cost of surrendering allowances rather than selling them. Second, on the selling side, industries such as power generation, who face very little foreign competition, were able to pass through the marginal cost of carbon to their end-users, while being handed out allowances or free, hence realizing profits from EU ETS. Sijm et al. (2006) estimate that utilities in Belgium, France, Germany and the Netherlands realized windfall profits of € 5.3 to € 7.7 billions per year over the first phase of ETS. Finally, while most sectors were overall long on allowances, the situation for individual plants is very different, as exemplified in annex A.2, with significant discrepancies between long and short holders inside each sector.

This example reveals two important factors to keep in mind when considering equity issues. First, the relative situation of different sectors with regard to the costs created by the carbon price are very different; beyond the potential cash costs that may stem from the allocation process, some sectors face indirect cash costs due to the rising price of raw material or energy inputs, and have widely contrasted abilities to pass these costs to their customers. The real equity issue hence lies not so much in the comparison of the absolute share of the abatement cost visited upon different sectors, but in the relative competitiveness burden incurred to domestic firms, compared with the foreign firms with which they compete. Eventually, what matters is for the EU ETS to minimize the consequences, for its economy, of its commitment to reduce greenhouse gas emissions.

Even though refining was eventually around 7% long on allowances, it may have incurred real costs to abate its emissions to this level, or have suffered from the indirect costs linked to

the introduction of a carbon price in other sectors of the economy such as power generation, on which some refineries rely to fulfill their energy needs. Moreover, in a tighly arbitraged world market, it is uncertain whether or not firms will be able to pass on some of the added costs to their customers (Favennec 2001, pages 88 and 94). The rest of this chapter will hence focus on these questions, and the broader concern of the competitiveness impact of EU ETS on the refining industry.

3.2 Toward a theory of competitiveness

3.2.1 Competitiveness: a definition

The concept of competitiveness is treacherous for economists and economic commentators. In the past, it has given way to harsh debates, mainly over the extent of the relevance of competition as a positive and normative paradigm of the behavior of economic actors across the micro-macro spectrum.

With the Sherman Anti-trust Act of 1890 in the US, and subsequent legislation in European states, perfect competition among firms emerged as one tenant of the efficient organization of economic activity at the microeconomic level. By extension, commentators have often called upon the concept of competition to make sense of the evolutions of national economies in a global interconnected world. There is indeed substantial evidence that governments can engage in regulatory competition with their counterparts, in an attempt to influence the global trade and investment flows (Murphy 2002).

However, in a famous paper in Foreign Affairs (Krugman 1994), Paul Krugman reacted against the pervasive reliance of economic commentators on the idea that nations compete as firms do.

> (...) Trying to define the competitiveness of a nation is much more prob-
> lematic than defining that of a corporation. The bottom line for a corporation
> is literally its bottom line: if a corporation cannot afford to pay its workers,
> suppliers, and bondholders, it will go out of business. So when we say that a
> corporation is uncompetitive, we mean that its market position is unsustainable
> – that unless it improves its performance, it will cease to exist. Countries, on
> the other hand, do not go out of business.

The important determinant of a nation's standard of living, he argues, is not its trade balance, which is mostly determined by the exchange rate, but the growth rate of domestic productivity in the traded as well as non-traded sector. For Krugman, the only relevant concept of competitiveness hence exists at the micro-economic level, and pertains to the ability of firms to gain or maintain market share, while realizing profits. Since the effects of EU ETS are focused on a subset of heavy industries, it makes all the more sense to use a micro-economic definition of competitiveness to study the economic impact of the European carbon market.

The research project to which this thesis seeks to bring insights adopted a working definition of firm-level competitiveness (Baron 2004):

> The ability to produce high-quality, differentiated, products at lowest possible cost, to sustain market shares and profitability.

Armed with this definition of the competitiveness at the micro-economic level, we can produce a theory of the sectoral competitiveness impact of carbon markets.

3.2.2 A theory of the sectoral competitiveness impact of EU ETS

Product substitution and geographical substitution

The crux of the issue is linked to the price distortion created by the introduction of EU ETS in the EU-25 zone. The scheme discriminates between firms, by imposing a carbon cost on only a subset of them, the domestic heavy industry producers. Because only specific lines of products (iron and steel, cement, petrochemicals and refining, power generation etc.) inside the EU-25 zone face the added cost of allowances, their producers may be at a cost disadvantage compared to the firms outside EU ETS, either because these competitors don't fall under the regulated product categories, or because their production facilities are geographically outside the EU-25 area.

The sectoral divisions established by the European Commission encompass large groups of commodities whose domestic producers are all subject to the carbon price. This ensures that substitutions across products triggered by the price distortion are virtually irrelevant. The major issue for the competitiveness of the sectors affected by EU ETS is hence that they compete on the domestic and international markets with a cost differential linked to the price of carbon introduced in the EU-25 area. I will hence focus on the effects of the

price distortion on the competitiveness of the firms under EU ETS ('ETS firms', 'domestic firms', or 'EU firms') compared to firms non subjected to EU ETS ('non-ETS firms', or 'foreign firms'), in each of the different traded sectors that fall under the trading scheme.

At the level of an industrial sector producing standardized commodities, such as petroleum products, product differentiation is rarely an option for firms. In the refining sector, most of the options for product differentiation are standardized, either linked to discreet characteristics of the products such as compliance or non-compliance with regulations on fuel content, or standardized performance levels, that act as *de facto* market segmentations. The relevant aspects of the OECD working definition of competitiveness are hence the ability of the EU firms in the specified sector to maintain market share, as well as their ability to retain profits. EU ETS acts on both of these dimensions simultaneously.

Effects of the price distortion

The ultimate effect that is feared is carbon 'leakage', defined as the relocation of emissions-intensive economic activity outside the boundaries of the carbon market. This can happen through two separate mechanisms: trade flows changes (a loss in domestic and international market share of domestic firms, directly replaced by a gain in market share by foreign firms); and investement flows changes (a progressive displacement of the domestic production capacity by foreign production capacity). Carbon leakage is a negative outcome on two distinct levels: from an economic standpoint, it entails a cost to the European economy, since it means that domestic profits are lost to foreign firms; from an environmental standpoint, it undermines the effectiveness of the scheme, since it means that emissions reductions achieved in the EU ETS area are offset by increases abroad. Static leakage is the simple mechanism whereby domestic production is replaced by foreign production, hence leading to direct leakage of emissions. Dynamic leakage represents the geographical substitution of emissions that stems from the movements of the capital stock, and the substitution of foreign capacity to domestic capacity.

The first potential effect of EU ETS is a loss of market share from EU firms to foreign firms. This is initially a case of direct static leakage of greenhouse gas emissions outside the jurisdiction of EU ETS, as it does not involve the transfer of capacity between the two zones (inside EU ETS, and outside), but only an immediate rebalancing of market shares at the advantage of the least cost producer (non-ETS firms). However, if the cost imbalance

persists, and if this static effect is important, it is likely that the unused domestic capacity will be relocated, leading to the apparition of dynamic leakage.

A second potential effect of EU ETS is a loss of profits for domestic firms, compared to the profits of foreign firms. This is different from the first effect, as it is restricted to a redistribution of profits, and does not lead to carbon leakage in the short run. However, a structural imbalance in profits is likely to draw the highest-cost domestic producers out of business in the middle to long-run, or to force them to reduce their market share, hence triggering the first effect. Moreover, such a persistent profitability differential is likely to drive production capacity out of the ETS area, and to lead to long run dynamic leakage.

As it leads to direct static leakage, the effect on the market share of domestic firms is of prime importance to the study of the competitiveness impact of EU ETS. However, effects on profits have a direct cost to the domestic economy. Since they also act as early predictors of the future displacement of domestic capacity by foreign capacity, I will focus with specific attention on profit changes, through the study of price changes and the impact of the price of CO_2 on the cost structure of refineries.

Ex-ante evaluation of competitiveness impact

An *ex-ante* evaluation of the short run competitiveness impact amounts to modeling the economic system at hand. Such a study necessarily builds upon three fundamental elements of economic analysis: the structure and conduct of the market, the technologies deployed by firms, and the international organization of the trade flows.

Hypotheses on the market structure and conduct pertain to the nature of the competition at hand. A few typologies include perfect competition (e.g. power generation, which functions under marginal pricing), Hotelling competition (e.g. cement, for which transportation costs are tantamount), and other varied blends of oligopolistic competition. As the structure and conduct of the market is widely thought to determine the performance of firms - and indeed under the neoclassical framework the profits of firms are of oligopolistic nature -, such hypotheses determine the changes in firm profits caused by changes in the cost structure of domestic and foreign firms.

Secondly, hypotheses on technologies are represented under the form of production frontiers and cost curves, under the framework of neoclassical economics. Parameters such as price elasticity of input and product substitution, and the marginal emissions abatement

73

cost curve, determine the options at hand for the firms to respond to the changing input, products and carbon price environment. In an idealized setting, firms would adapt by translating along their optimal production frontier. The analysis is made more complex by an interesting aspect of carbon prices, which is that they often reveal 'free-lunch' abatement options (e.g. previously ignored energy efficiency investments that pay for themselves), as revealed by Lord John Brown as a conclusion to the BP ETS experiment (Akhurst et al. 2003).

Finally, hypotheses on the structure and determinants of international trade ultimately determine the gravity of the threat to competitiveness stemming from an asymmetric carbon constraint. The issue of competitiveness is international by nature. In a sector that is not exposed to international trade, the only effect of the scheme would be a redistribution of corporate profits. In the face of international competition, however, the ability of firms to pass through some of the added cost of carbon to their customers while maintaining their market share will depend on a large extent to the barriers to trade between domestic and foreign companies. Specifically, transportation cost is likely to play an important role for some of the commodities impacted by the scheme. Taxes and tariffs may hinder the ability of external producers to compete with domestic ones, even though the basic materials produced by the heavy industries that are encompassed in EU ETS are most often subject to global free trade agreements. Because of such agreements, however, the second most important source of protection for domestic producers after transportation costs is undoubtedly non-tariff barriers to trade - *de facto* barriers to trade based on non-fiscal regulation. For example, the stringent quality requirements for petroleum products sold in the Common Market, such as high minimum content of oxygenates or ultra-low levels of sulfur content, act as trade barriers that deter Russian companies to sell most of their products directly on the European market.

As a conclusion, the evaluation of potential competitiveness is a theoretically complex and practically challenging issue, because of its reliance on broad economic hypotheses, and the difficulty to model complex technical change phenomena such as carbon emissions abatement at a sectoral level.

Ex-post **evaluation of short run competitiveness impact**

The difficulty of forecasting the economic effects of a scheme of the size and complexity of EU ETS calls for a systematic monitoring of its impact on domestic competitiveness. The relevant variables for an *ex-post* evaluation of the short run impact of the market-based instrument are the ultimate manifestations of the price distortion, i.e. the market share of domestic firms, and their profits. For each sector under ETS, the key variables are hence:

- The changes in global market share of intra-EU firms vs. non-EU firms, as evidenced in changes of domestic production (EU-25 area), imports and exports, and the evolution of global supply and demand. This leads to investigating the link between carbon price and:

  - domestic production changes

  - trade flow changes

  - domestic and foreign capacity and capacity utilization changes

- The changes in the profitability of the intra-EU firms as compared to non-EU firms. This leads to evaluating the changes in the cost and revenue structure of EU firms stemming from:

  - direct costs of carbon allowances

  - indirect effects of the introduction of the carbon pricing scheme

  - changes in prices for the final products

  An essential question is hence to measure the cost pass-through, i.e. the proportion of the added costs linked to the carbon price that can be passed by EU firms to the consumers.

It is important to notice that properly singling out the impact of EU ETS among a complex set of economic drivers would require the use of random experiments or the construction of accurate counterfactual scenarii, which is not practically feasible. A major hurdle for the empirical evaluation of the effects of EU ETS is hence the identification of causal links between the introduction of a carbon price and the observed behaviors.

The view from Bruxelles: evaluating the long run competitiveness impact

In the long run, finally, the main effect of a sustained price distortion would be to induce relocation of the capital stock outside the EU ETS area, and hence to job losses. The main concern of the European governments, both from an environmental effectiveness and an economic point of view, is hence to minimize such relocations of productive capacity.

As noted by Baron (2004), three important parameters will drive the leakage of carbon-intensive production capacity:

- The mobility of the industry, and its capital intensity (hence the amount of sunk costs invested in capacity) determine the responsiveness of investment flows. In the heavy industries subject to EU ETS, unless carbon prices reach heights yet unheard of, it is doubtful that capacity would ever be divested before the end of its productive life, and it is more likely that what will be observed is a shift of expansion and new capacity projects outside of EU ETS, leading to a slow and gradual relocation.

- The extent to which the impact of the price distortion on profits is likely to hold is highly important. If structural trade barriers protect the domestic firms, a high amount of relocation is unlikely. If the asymmetric carbon cost significantly hinders domestic profits, incentives to relocate will lead to important leakage in the long run.

- The evolution of international climate policy agreements is fundamentally important. At the time horizon at which relocation becomes a serious threat in most sectors (likely not in the next five to ten years), it is widely expected, and certainly hoped by EU officials, that the trade partners of Europe will have set their own carbon constraints for emissions-heavy industries, which should even the playing field for domestic firms.

Because of the long lead times involved by such issues, it is unrealistic to expect ever to have firm answers to the questions raised here. Economic forecasters should hence engage in a back and forth movement from model forecasting and *ex-post* evaluation, in order to confront their hypotheses on the economic structure of the sector with what is observed in reality. The lessons from ex-post analyzes should prove helpful to refine long run impact assessments. Early indicators of capacity relocation, such as changes in the patterns of worldwide construction projects, should also be monitored in order to identify the potential for harmful effects on competitiveness.

3.3 Competitiveness impact on the refining sector: *Ex-ante* previsions

In this section, to lay the scene of the competitiveness impact of ETS on the refining industry, I attempt to summarize the predictions of several *ex-ante* studies based on data collected prior to the beginning of the scheme. The creation of EU ETS and the debate around the draft directive spurred an intense effort by the research community to predict the potential effects of the scheme on competitiveness. This section engages in a short literature review of the different efforts to predict *ex-ante* the economic effects of the scheme.

An official *ex-ante* study of the impact of EU ETS was commissioned by the European Commission to Ecofys and McKinsey& Company (McKinsey& Company 2006). They conclude that under the first phase of EU ETS, refining would be under a net neutral position, with allowances and potential pass-through expected to offset the costs of carbon.

Several partial equilibrium studies, with economic models such as PRIMES and other programs have been used to infer results on the different sectors. Smale et al. (2006), for example, realizes a partial equilibrium study of steel, pulp and paper, cement, petroleum and aluminum. Hourcade et al. (2008) reviews the theoretical and empirical literature, and provides a detailed analysis of the competitiveness impacts of ETS on cement and steel. Sijm et al. (2006) focuses specifically on the electricity market, which is of prime importance for the competitiveness of the refining sector since most of the indirect costs of CO_2 stem from the purchase of electricity to the grid. While it is interesting to compare the different sectors, these studies provide little insight on the dynamics of competitiveness impact in the refining sector, as they stay at a broad top-down level that does not fit well the complexity of the technologies at stake in refining.

The most authoritative study to date of the competitiveness impact of EU ETS is Julia Reinaud's *ex-ante* analysis of the potential impact of the European carbon market on the European refining industry (Reinaud 2005). The paper builds on a model of European refineries developed by Accenz, an oil and gas consultancy, to assess the changes in costs stemming from different scenarios. I strongly recommend the reader to refer to the original report to understand the detailed results of the simulation process, and as an authoritative and thorough source of data on the industry. I report in this section a summary of the results on competitiveness stemming from the report. Table 3.3 gives an overview of the

costs of the scheme for refineries in Europe based on their configuration, location (hence differential access to crude and product markets) and technologies, with a hypothetical allowance price of €20 per ton of CO_2 equivalent and based on a full cash cost basis (no grandfathering of allowances).

Table 3.1: *Ex-ante* prevision of the impact of direct and indirect costs of CO_2 on refinery margins - Full cash cost hypothesis (Reinaud 2005)

Configuration	Emissions	Direct carbon cost	Refinery margin
	Ton CO_2 per ton of crude	USD/ton CO_2	USD/bbl
North West Europe			
HSK	0.078	1.93	-1.77
+VB+FCC	0.149	3.68	2.58
+VB+HCU	0.129	3.19	-1.42
+DC+HCU	0.131	3.26	5.46
+VB+FCC+HCU	0.154	3.82	4.69
Mediterranean Europe			
HSK	0.079	1.96	-2.46
+VB+FCC	0.144	3.57	2.65
+VB+HCU	0.131	3.26	4.16
+DC+HCU	0.133	3.29	3.51
+VB+FCC+HCU	0.149	3.7	4.94
Central Europe South			
HSK	0.083	2.12	-0.33
+VB+FCC	0.141	3.5	5.08
+VB+HCU	0.149	3.7	6.05
+VB+FCC+HCU	0.153	3.79	4.42
Central Europe North			
HSK	0.083	2.12	-3.25
+VB+FCC	0.141	3.5	4.51
+VB+HCU	0.149	3.7	5.4
+VB+FCC+HCU	0.153	3.79	4.35

Reinaud concludes that:

> The opportunity cost of CO_2 allowances is not trivial for the refining industry (...) - at €10/ton CO_2, the CO_2 cost would amount to 15 to 30% of total running expenses. At €20/ton CO_2 the cost of carbon would reach about USD 1 per barrel of crude oil entering the refinery, a substantial part of projected refining margins. (...) The picture differs substantially once grandfathered allowances are taken into account on the cost side. In our 10% [allowance] shortfall scenario, CO_2 costs would amount to 1-3% of running costs. Companies' perception of

the cost of CO_2 in a long-term perspective is therefore crucial to understand how emissions trading will eventually affect refiners' investment decisions (Reinaud 2005).

The conclusions of all these studies is that, though the sector is largely exposed to trade, refining should not bear high costs from the introduction of the carbon price, as the cost increases are minimal compared to the margins of the industry, and are set to be offset by allowances in the first period. This means that any detrimental effect on competitiveness during phase I will be difficult to measure, and that *ex-post* analyzes should focus on confronting the prior *ex-ante* studies with measured data, in order to improve their predictions for the subsequent phases. I investigate the effect on trade flows and prices in the next section, and then turn to the study of the perception and response of the industry in the next chapters.

3.4 Competitiveness impact on the refining sector: *Ex-post* assessment

3.4.1 Effective abatement?

The *ex-ante* studies I have detailed were based on the assumption that no abatement investment would occur at the refinery level during the first phase of EU ETS. Based on the empirical results I present in the subsequent chapters and sections, this hypothesis is largely relevant for the first years of the scheme. However, as emphasized by Ellerman and Buchner (2007a), 'if there is one lesson from the US experiment with cap-and-trade systems, it is that unexpected forms of abatement appear when a price is imposed on emissions'. It is hence interesting to study the actual emission outcome of the first years of the scheme. In appendix B, tables B.2 to B.6 present the emissions outcome for the European refining sector in 2005 and 2006, based on public emission data disclosed by the Community Independent Transaction Log (CITL 2008), on capacity estimates (Oil & Gas Journal 2008) and petroleum refinery intake figures (Eurostat 2008).

The first important measure is the outcome for CO_2 emissions from the refining sector in Europe. As exposed in table B.4, the industry was long on allowances by around 7% , both in 2005 and 2006. More important, between 2005 and 2006, the amount of emissions

by the industry decreased by 0.84 million tons of CO_2, or about 0.56 % of the 2005 total emissions of the sector. The drivers of change have been Germany and Italy, the two major emitters in the refining sector, which curtailed their emissions by around 3% , or more that 1.5 million tons. This curtailment was however largely offset by increased emissions from the smaller producing countries, despite significant abatement from other major producers.

To investigate whether or not the observed decline in emissions is actually an abatement, I constructed an estimate of the emission intensity of the refineries of each country, based on the crude and petroleum feedstock intake of the plants and the disclosed emissions. The results are reported in table B.6. Emission intensity of refineries can be misleading. Indeed, a higher emission intensity can stem either from lower efficiency, or from increased complexity. There is no clear pattern that emerges from the table, except that the overall emission intensity increases slightly. In the absence of micro-level data on the sources of this change, it is difficult to state whether this stems from a change in the product slate, additional treatment efforts to comply with the tightening sulfur content legislation, or other unknown factors. However, the fact that emissions decreased slightly between 2005 and 2006 is consistent with the hypothesis that firms respond to the carbon price signal by curtailing their emissions.

3.4.2 Impact on trade flows and market shares

A first aspect of *ex-post* competitiveness impact assessment is the question of immediate carbon leakage materialized by trade flow changes, and specifically by a loss of market share of intra ETS companies compared to extra-ETS companies. In this section, I investigate the extent to which such changes have happened in direct relation with the introduction of EU ETS. As described in chapter 2, the overarching trading pattern in petroleum products markets is the export of gasoline and the import of diesel. I hence concentrate on the net import figures for motor gasoline and for diesel oil, and investigate changes in trade flows evolutions at the introduction of EU ETS. The goal of this section is to exhibit trends and seasonal patterns in monthly gasoline and diesel net imports, and to test for structural breaks in January 2005, that could potentially be introduced by the beginning of EU ETS.

A look at the data

Since gasoline and diesel net imports monthly data was not available on the Eurostat webpage at the time of study, I computed trade flows based on the difference between monthly inland deliveries and monthly production figures for motor gasoline and diesel oil, from January 2000 to September 2007 (data available on Eurostat (2008)).

An issue with this methodology is that the difference between inland delivery and domestic production is the net imports, corrected of net stocks withdrawals. I refer to this quantity as the net excess demand (NED) for gasoline and diesel. To correct for this effect and eliminate short term shocks to stock holding levels, a methodology could be to use a 5 month centered moving average of the NED. With L as the lag operator, the estimate of the net import data for gasoline and diesel oil would hence be computed as follows:

$$\text{Net Import Est.}_t = \text{MA}_5(\text{NED}_t)_t$$

$$\implies \text{Net Import Est.}_t = \frac{1}{5} \sum_{i=-2}^{2} L^i \times (\text{Inland delivery}_t - \text{Production}_t)$$

Figure 3-1 presents the actual net excess demand and the estimated net import data for gasoline and diesel from 2000 to the end of 2007.
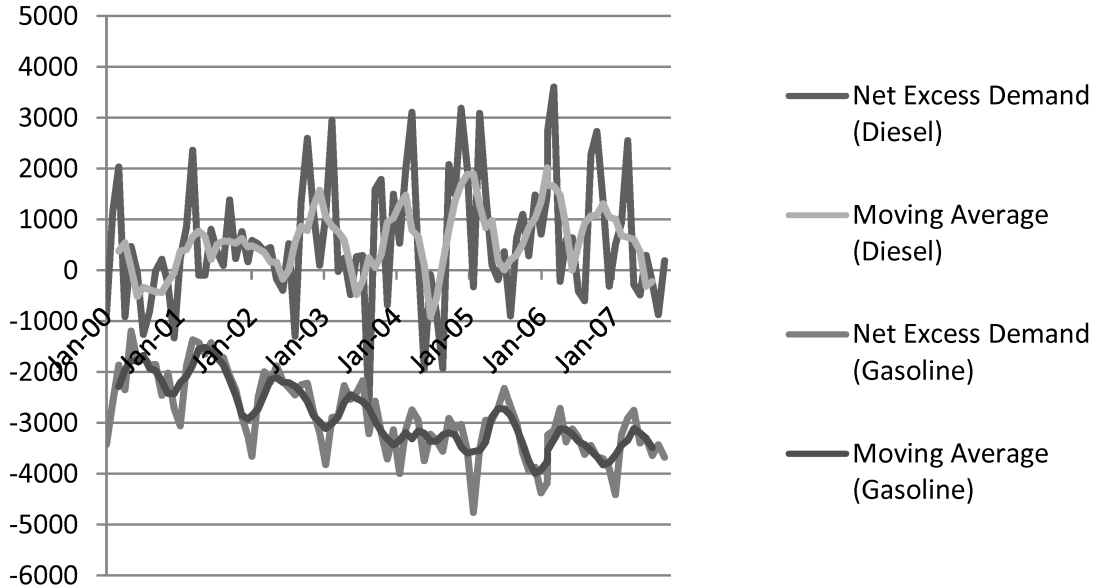
Figure 3-1: Net excess demand for gasoline and diesel (Thousand tons per month)

This methodology has the merit of exhibiting trends and seasonality. Based on the

moving average data, we can assess the seasonality of gasoline and diesel consumption. As the demand for motor transportation fuels and heating fuel oil changes with the seasons, refiners adapt their tool to the demand and change their production patterns across the year. Analysts distinguish two typologies of plant configurations, between which actual plants evolve across time:

- Full-gasoline mode, in which refineries maximize the production of gasoline and diesel oil, usually adopted during the spring and early winter in preparation for the summer holiday season.

- Full-heating oil mode, in which the production of heating oil is maximized, usually adopted during the fall and early winter, in preparation for the home heating season (Leffler 2000).

It is striking in figure 3-1 that both cycles are in phase opposition, with two configurations between which markets oscillate:

- High imbalance phase: high gasoline export and diesel import, during the summer, which corresponds to the automotive fuel maximization configuration.

- Low imbalance phase: low gasoline exports and negative net diesel imports, during the winter, which corresponds to the heating fuel maximization configuration.

The European market hence oscillates between a tight supply situation on the automotive fuels market during the summer, that is offset by increased imports, and a looser situation during early winter, during which trade imbalances are less marked.

In order to derive meaningful conclusions from the study, we must hence take this seasonality into account in the statistical model used to describe the evolutions of trade flows. I hence use seasonal variation variables $S_{i,t}$ coding for the purely seasonal variations observed in net import flows, chosen to maximize the fit with the peaks and troughs of the cycle of net import moving averages for the different products:

$$i = \underset{i \in [0;5]}{\text{Argmax}} \, R^2 \quad \text{in the regression:} \quad \text{MA}_5(\text{NED}_{p,t})_t = \alpha_{p,i} + \beta_{p,i} \times t + \delta_{p,i} S_{i,t} + \epsilon_{p,i,t}$$

$$\text{for product } p \text{ with } \quad S_{i,t} = \cos\left(2\pi \times \frac{(t-i)}{12}\right) \quad i \in [0;5]$$

Table 3.2: Trade flow trends and seasonality (January 2000 to September 2007)

Variable	Coefficient	Standard error	t-Statistics	p-Value
Gasoline NED	$R^2 = 0.6955$			
Constant	-1966.792	87.71426	-22.42	0.000
Time drift	-19.91694	1.647896	-12.09	0.000
S_5	513.6529	62.94247	8.16	0.000
Diesel NED	$R^2 = 0.7092$			
Constant	175.6894	228.5696	0.77	0.444
Time drift	8.429992	4.296083	1.96	0.053
S_0	736.1757	162.2651	4.54	0.000

For gasoline, the seasonal variable that maximizes the fit is S_5, while it is S_0 for diesel. This confirms that both cycles are in phase opposition, and that the demand for transportation fuel is hardest to meet in the summer, at which point refineries maximize the transportation fuel output, but still have to import diesel while exporting the excess gasoline - and easiest to meet in the winter, where supply hence shifts to heating oil.

The use of the moving average net excess demand figures allows to approximate the actual net imports and reveal their seasonality. In terms of statistical analysis, however, using a moving average would induce a serial correlation between the residuals of the regression used to assess the trend and seasonality parameters. I hence conduct the structural break test on the original net excess demand series, but using the seasonal variables uncovered by the moving average equations.

Trends, seasonality and unit roots

Because the Chow test explores structural breaks on the trend of only trend-stationary series, I start by verifying that the deseasonalized time series are indeed trend stationary. I regress the level variables on a time drift parameter and the seasonality variables on the full time span of analysis (January 2000 to September 2007), and then perform a unit root test on the residual de-trended and de-seasonalized series:

$$\text{NED}_{g,t} = \alpha_g + \beta_g \times t + \delta_g S_{g,t} + \epsilon_{g,t}$$

$$\text{NED}_{d,t} = \alpha_d + \beta_d t + \delta_d S_{d,t} + \epsilon_{d,t}$$

The results of the trend and seasonality regression are listed in table 3.4.2. I use a standard Dickey-Fuller unit root test for autoregressive time series (Dickey and Fuller 1979)

Table 3.3: Dickey-Fuller unit root tests for deseasonalized trade flows

| Variable | Test statistics | Critical value | | | Approximate p-Value |
		1%	5%	10%	
Des. Gasoline NED	-3.597	-3.521	-2.896	-2.583	0.0058
Des. Diesel NED	-9.255	-3.521	-2.896	-2.583	0.0000

on the deseasonalized time series. The results, reported in table 3.4.2, indicated that both series are trend stationary, which makes it possible to use the Chow test for structural breaks based on the levels of the variables.

Chow test for structural break

The goal of this section is to test the net gasoline and diesel oil import time series for a structural break in January 2005. The essence of the Chow test is to estimate whether there is a statistically significant change in the coefficients of the trend and seasonality for the time series before and after specific dates at which the structure of the endogenous variable is believed to experience a break (Chow 1960). In this case, I investigate changes happening on January 1st, 2005, at the introduction of the EU ETS system.

I proceed by adding a dummy variable X_{ETS} coding for the introduction of ETS on January 2005, and incorporating it in the trend regression. I then test whether or not the coefficients of the trend perturbation term are significantly different from zero (Chow 1960). Results are listed in table 3.4.2:

$$\text{NED}_{g,t} = \alpha_{g,1} + \alpha_{g,2} X_{ETS} + \beta_{g,1} \times t + \beta_{g,2} \times X_{ETS} \times t + \delta_g S_{g,t} + \epsilon_{g,t}$$

$$\text{NED}_{d,t} = \alpha_{d,1} + \alpha_{d,2} X_{ETS} + \beta_{d,1} \times t + \beta_{d,2} \times X_{ETS} \times t + \delta_d S_{d,t} + \epsilon_{d,t}$$

The conclusion of these regressions is that, after January 2005, the increasing trend of excess gasoline production has paced down, as has the increasing trend of diesel imports. Overall, the trends of gasoline net excess demand and of diesel net excess demand are found to be converging, and are overall decreasing faster after January 2005, which is positive for European refineries, as it means their market share is increasing. Figure 3-2 sketches the trend of the de-seasonalized component of net excess demand for gasoline and diesel, before and after the break. However, the most important question is whether this structural break in the trend is statistically significant. The Chow test consists in an F-test for the

Table 3.4: Trade flow trends and seasonality with break in January 2005

Variable	Coefficient	Standard error	t-Statistics	p-Value
Gasoline NED	$R^2 = 0.7092$			
t	-24.20572	3.142496	-7.70	0.000
S_5	503.3063	62.41271	8.06	0.000
X_{ETS}	-922.4169	600.8959	-1.54	0.128
$X_{ETS} \times t$	15.35585	8.341859	1.84	0.069
Constant	-1856.048	107.4825	-17.27	0.000
Diesel NED	$R^2 = 0.2200$			
t	15.23747	8.298952	1.84	0.070
S_0	722.3888	163.5877	4.42	0.000
X_{ETS}	1511.915	1592.318	0.95	0.345
$X_{ETS} \times t$	-24.98497	22.06807	-1.13	0.261
Constant	-.3547398	283.8487	-0.00	0.999

hypothesis that the coefficient of the dummy variables be null in the estimated models.

- For gasoline, the hypothesis that $\alpha_{g,2} = \beta_{g,2} = 0$ leads to the following F-statistics:

$$F(2, 88) = 2.07$$

$$\Pr > F = 0.1319$$

- For diesel, the hypothesis that $\alpha_{d,2} = \beta_{d,2} = 0$ leads to the following F-statistics:

$$F(2, 88) = 0.78$$

$$\Pr > F = 0.4638$$

The test hence concludes that there is no significant structural break in the patterns of petroleum products trade occurring in January 2005.

Even though the data shows that the increasing trend toward trade flows imbalance in the European refining sector seems to have been pacing down after January 2005, structural break tests conclude that this effect is not significant. EU ETS does not seem to have led to any significant carbon leakage, and the marginal effect captured by the regression analysis would imply a positive effect for the market share of European companies. An issue left for further analysis is the fact that the introduction of EU ETS in January 2005 has not been the only significant event to take place in petroleum markets at that time: the fast
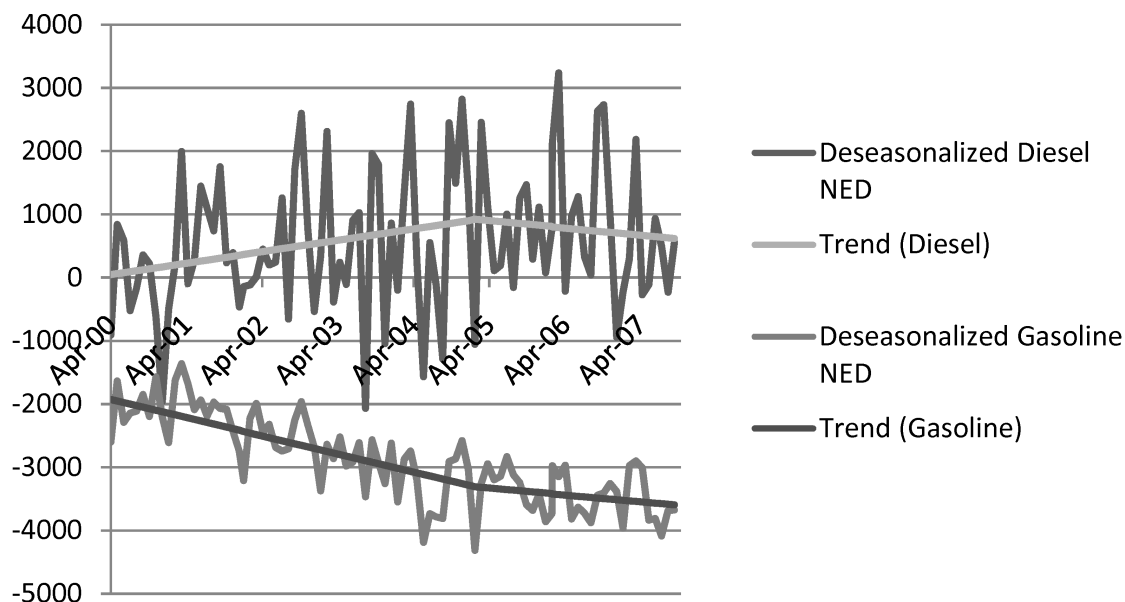
Figure 3-2: Trends of deseasonalized net excess demand for gasoline and diesel (Thousand tons per month)

increase of crude oil prices and petroleum products, on the one hand, and the changes in refinery regulations, on the other hand, may also have played important roles, that are hard to disentangle based on the mere trade flow data.

However, and this is the most important quantitative conclusion regarding the topic of this thesis, it appears that ETS clearly did not cause short term carbon leakage. We now turn to the long term leakages, with the question of the profitability impact.

3.4.3   Impact on profitability

The previous section concluded that no significant change in trade patterns and market share could be detected at the outset of EU ETS in January 2005. This means that carbon leakage is not an apparent issue in the short run. However, as described in previous sections, in the long run, profitability differentials between Europe and other regions of the world may lead to relocations of the refining capacity outside the ETS zone, or to constraint the growth of the industry in Europe in the long run. To assess the potential future carbon relocation that could stem from the scheme, we must hence understand what has been the impact of EU ETS on the profitability of refineries.

Production cost impact

The table of average refining costs (table 2.3.2) in chapter 2 presented a break-out of the averages costs of transforming a barrel of crude oil in petroleum products, based on general assumptions on the refineries in the European sector. It is inherently difficult to gather data on operating costs for refineries, for reasons linked to the very versatile design of refineries and the strategic nature of this kind of information. I present here an updated version of the cost structure of refineries, for the case where plants are subject to EU ETS. It is based on the following assumptions:

- CO_2 cost: € 20 per ton.

- Pass-through of CO_2 costs to electricity prices: 20 % of baseline electricity prices (cnnsistent with the *ex-ante* empirical findings of Sijm et al. (2006) and Reinaud (2005)).

- Net allowances position: 7% long (average *ex-ante* position of European refiners).

- No significant abatement costs (the assumption is that at the limited scale to which they were deployed, abatements, whether costly or paying back for themselves, have no significant impact on costs, which is coherent with the focus on energy efficiency investments described in the following chapters).

Table 3.4.3 presents the new estimated average cost structure of refineries under the simplifying hypotheses that were made regarding technologies, pass-through rates in the electricity sector and other assumptions on costs. The results largely confirm the *ex-ante* results of Reinaud (2005) detailed in a previous section. Overall, the introduction of EU ETS has had no impact on cash costs for refiners according to this simple analysis. In the first phase, the net cost of carbon was negative on average for refineries. However, with full auctioning, the transformation costs of refineries could increase by on average more than 50%. In the current margin environment, this would not lead to any major consequences, as the full cash cost of allowances is of the order of 1% the cost of the crude oil processed, while margins are currently closer to 5%.

This result should of course be balanced by two observations. First, a reversal of the margin environment, driven by global demand and factors largely out of the control of

Table 3.5: Refining cost structure under EU ETS (updated from McKinsey& Company (2006))

Cost item	Expenditure	
	EUR per bbl processed	EUR per ton processed
Electricity	0.10	0.75
Chemicals and catalysts	0.10	0.75
Labor and maintenance	0.55	4.00
Materials and others	0.20	1.50
Capital depreciation	0.20	1.50
Total transformation costs	1.15	8.50
Added cost of electricity	0.02	0.15
Net cost of allowances	-0.04	-0.30
Full cash cost of allowances	0.59	4.30
Total cost after EU ETS (Phase I)	1.13	8.35
Projected total cost with full auctioning	1.72	12.75
Comparison: crude purchase	≈ 80	≈ 585
(of which consumed in refinery:)	2.70	19.80
Comparison: transformation margin	≈ 3.30	≈ 24.40

European refiners, is always possible and could make the added costs critical for refiners. Second, these figures stem from a top-down analysis that is based on average figures, while plants have very diverse technologies and related economic situations. As emphasized by Reinaud (2005), the impact of EU ETS is very different depending on the technologies developed at each plant and the associated margins commanded by the operating companies.

As a conclusion, it was not possible to exhibit detailed *ex-post* analyzes of the impact of EU ETS on the operating costs of refineries. However, a top down assessment of the cost changes based on empirical *ex-post* data shows that, while EU ETS could increase costs by up to 50% in the case of full auctionning at the current price range of around € 20 per ton, it has had no significant negative impact, if any, on the average operating costs of refineries in Europe during phase I.

The important question regarding the costs of the scheme for the industry, both direct (the cost of allowances) and indirect (increasing product prices and abatement and adaptation costs) is hence to understand from a bottom up perspective what costs were faced on the ground, which is the focus of chapter 4. From the standpoint of the profitability impact of carbon, the next question is to understand the impact of carbon on petroleum product prices.

Petroleum products price impact

Since no significant changes in operating costs have been caused by EU ETS during phase I, what remains to be understood is the propensity and ability of petroleum refiners to pass through the cost of carbon in the final price of their products. This is a key competitiveness issue since it measures the proportion of the carbon cost that companies can pass through to customers, and hence ultimately the share of the burden they face themselves.

Ex-ante studies that attempt to assess the pass-through rate of carbon usually distinguish three effects:

- Demand captivity, or the inverse elasticity of demand on the local and the global markets. A captive demand will lead to small consumption decrease effects from rising prices, and hence allow a higher pass through.

- The degree and structure of oligopolistic behavior of the industry. If companies act as cartels, they will be able to extract parts of the captivity of demand to a greater extent than in competitive industries.

- Trade barriers, which includes tariffs but also transportation, quality regulation, etc. For example, sulfur content regulation is often quoted as an example of tight regulation that virtually bars Russia from commercializing its production as consumer goods, which explains why diesel imports from Russia are often under the form of semi-finished products.

An *ex-ante* study that investigated the effect of EU ETS on petroleum prices is Smale et al. (2006). In this article, the authors develop an oligopolistic model of refineries in Europe, and conclude to a cost pass-through rate that would lead to a 0.4 to 0.6% increase of firms profits. One possibility for *ex-post* studies would be to indirectly measure the different parameters of the model to conclude on the validity of its conclusions.

However, the main task of *ex-post* analysis is to develop a framework that infers price change consequences from the introduction of the scheme. Regarding the cost pass-through, that would entail measuring the amount of carbon costs that are passed through the costs of end products. To measure this, I developed a number of attempts to capture the cointegration relationship between crude oil price and petroleum products prices (more on the subject in Denni and Frewer (2006)). I attempted to find changes and structural breaks in

the cointegration relationship between the pre-ETS and the ETS Phase I periods. While I found significant changes in the long run relationship between crude oil and gasoline, diesel, jet fuel, heating oil and fuel oil prices, they all hinted at the large price hike of crude oil over the period. An event of this magnitude hides all other effects and makes it difficult to base inferences on structural break analyzes.

The lesson from such measurement difficulties is that competitiveness impacts are not a mono-dimensional issue, and their severity is largely determined by market conditions on a global scale. An interesting topic for further research would be to imagine natural experiments or econometric settings that allow one to find a way to measure exactly how the price of carbon feeds into petroleum prices, unimpeded by the changes in crude oil price environment. Data stemming from the next period, with higher cash costs for the industry and a tighter supply of allowances, should help researchers capture more meaningful results.

The conclusion of this section on profitability effects is that, as carbon costs have been very limited for refineries, while margins have stayed high, no significant detrimental effect of ETS was noticed during the period. Regarding the pass-through rate, the overarching event on the petroleum products market has been the explosion of petroleum prices, and that the *ex-post* data is consistent with the *ex-ante* analysis of the cost pass-through, that concluded that the introduction of a carbon price would not lead to significant price changes. However, this subject calls for further scrutiny during the next stages of the scheme, as competitiveness issues may arise if the industry moves to full auctioning.

3.5 Conclusion and corporate perception of competitiveness impact

As a conclusion to this chapter, nothing tangible can be measured in aggregate data on trade flows so as to the impact of EU ETS on the refining sector during the first phase of the scheme. The effect if any has been non significant at best, and maybe even positive for the industry in some cases, with the observed pace down of the growing petroleum product trade imbalance. Regarding the profitability of refineries, margins have stayed high during the whole scheme while refineries were on average long on carbon and did not face significant cost increases linked to the direct and indirect cash costs of carbon. An overarching observation is that it is especially difficult, in the realm of petroleum prices econometrics, where the

skyrocketing price of crude oil has dwarfed any other measurable effect during the last few years, to disentangle the effects of ETS from other phenomena, and to attribute clear and unambiguous causality to the scheme. As the scheme develops in the next years, and the Europe Commission, as detailed in the provisional draft (European Commission 2008c), will assess and regularly monitor the competitiveness impact of the carbon trading system on the sectors that it decided to expose to progressive full auctioning, there will be some interesting space for further studies of this issue. So far however, the overall conclusion on the competitiveness impact of ETS Phase I is that it has indeed been a 'carbon trading simulation', as described by one interviewee, rather than a binding experiment in carbon permits scarcity.

In the short run, all strategists I interviewed agreed that oil and gas companies have limited options to face potential competitiveness impact. All studies that considered the potential for cost pass through so far have concluded to a very limited pass-through potential. Strategists and analysts quoted different private studies realized by hired consultants that all concluded that the price setting mechanisms for most staple petroleum products were global and left little if no room to mitigating the costs of the scheme by passing them over to end users. In the long run, the industry seems concerned about the potential for leakage. As evidenced by the Oil & Gas Journal construction survey update (Oil & Gas Journal 2007), most of the construction projects are located outside North America and Europe, and investments in these zones are mostly limited to small de-bottlenecking projects and investment demanded by tightened sulfur content regulation. The scale of the new projects coming on line in the Middle East and Asia, as well as the recent trend of divestment from major oil and gas companies in European refineries, seems to concur with the opinion expressed by most of the industrials I met, which is that risks of leakage are of concern to them in the long run, through capacity relocation, rather than in the short run. Overall, this is consistent with the extreme caution the industry demonstrates regarding the scheme and its potential costs for the industry.

Because the aggregate quantitative analysis of the first phase of the carbon market has not been a source of insight for the future of the scheme and its impact on the European industry, it appeared necessary to develop a plant level approach that would answer the two overarching questions relevant to the past and future impact of the market based instrument: what *really* happened 'on the ground' in the plants, trading floors and headquarters

of refining companies? And how does the industry perceive this scheme, its strategic implications, and the direction to which it is evolving? These two questions set the stage for chapter 4 and 5 respectively, to which I now turn.

Chapter 4

Operational changes and price signal effectiveness

To understand to what extent the pilot phase of EU ETS has been effective in inducing emissions abatements in the European refining sector, it is necessary to understand how refineries have responded 'on the ground' to the introduction of the price signal. This chapter analyzes the results from the survey of firms regarding their preparation to the beginning of the scheme, and the operational changes that followed, as well as the impact of a carbon price on their investment strategies.

My main conclusion is that EU ETS has been effective in inducing firms to build the technical and institutional capability to respond to a carbon price signal, but has not led to significant emissions abatement so far. Based on the responses from the survey participants, I suggest various constraints that have borne on the ability and willingness of firms to curtail their emissions.

4.1   Preparation to the introduction of EU ETS

A first question is to understand how firms prepared to the introduction of EU ETS on January 1st 2005. This means understanding the relevant aspects of the regulatory and economic context they faced at the time, and the technical challenges involved before taking action. It appears that, while firms seem to have had an early understanding of strategic implications of a carbon price, resources at the plant level are still focused on tackling measurement issues rather than devising elaborate abatement opportunities.

4.1.1 Context

The context of the European refining industry at the time of the launch of EU ETS is of prime importance to understand refiners' preparation for and response to the introduction of a carbon price. Chapter 2 delves in details on the current state of the industry and the major trends it faces. Two salient points that emerged from the interviews are worth mentioning: the specificity of the industrial organization of the refining sector, and the interaction between the newly created carbon market and other emerging regulatory and financial constraints.

Structure of the refining sector

Arguments of specific industry structure were often stated, notably by the analyst community. The widespread view is that there exists a significant difference in preparation between majors (BP, Shell, Total etc.), who had the capability and strategic foresight to predict the coming carbon price and adapt to it early enough (starting from circa 2000), and national companies and independent actors. Major companies have extensive experience of commodities trading, and are widely assumed to have the scale and management capabilities necessary to address such a transversal issue with efficacy. The chief economist of Company D asserted that such information asymmetry between actors is stronger in the refining sector than in other sectors such as electricity, were most actors have been using marginal pricing since the widespread deregulation of the industry, and are more proficient with the tools and concepts of financial trading.

However, the argument could also go that smaller firms are characterized by a stronger leverage on operations by the central decision maker than in large, complex international operations such as the major IOCs. The argument that majors are better prepared to the introduction of a carbon signal also contradicts with our findings, since the smaller independent firm in the interview series - Company D - was found to have internalized the opportunity cost of carbon allowances and aligned managerial incentives with emissions abatement in a more efficient manner than what was observed in majors.

Finally, whether or not early action on carbon abatement has provided an edge to refining companies is unclear. We describe in section 4.1.3 the voluntary commitment schemes developed by oil and gas companies.

Prevailing constraints at the time of introduction

Most interviewees singled out the fact that the phase I of EU ETS has been a special period for the refining industry. Three main phenomena have had an overwhelming impact on downstream oil & gas operations: the rise of crude oil prices, the tightening of petroleum product sulfur content regulations, and the demographic evolution of the industry.

The industrial organization analyst we interviewed emphasized the changing nature of the refining business. Over the last 15 to 20 years, limited access to self financing for investment created by low operational margins was an important binding constraint. In the context of low energy prices, not much energy efficiency investment had been pursued. Since a large source of energy in a refinery is the fuel oil stream stemming out of the distillation towers, energy price is directly correlated to the price of crude oil. The recent rise of crude oil prices, from around \$30 in early 2005 to \$100 at the end of 2007 for a barrel of Brent, has been a prevailing factor in energy efficiency investment decisions. It is hence hard to disentangle the incentives stemming from the introduction of a CO_2 price with those linked to rising energy prices.

All participants underlined the fact that the introduction of EU ETS came at a bad timing for the refining industry, since it was concomitant to the strong tightening of European sulfur content regulations (see Chapter 2). These regulations are of the command-and-control type, and threaten to close plants if objectives are not met. This means that investment in de-sulfurization capacity gains priority over CO_2 related capital expenditures. Moreover, because de-sulfurization processes involve large amounts of Hydrogen, usually produced by steam methane reforming (an energy-intensive process), such constraints have the potential to lead to overall increases in GHG emissions by the refining sector in the years to come.

Finally, participants cited the aging demographics of the profession as a challenge to the pursuit of large scale investment schedules. Managers explained that as a relatively important portion of the profession retired, the pool of experience that refineries can tap into to conduct large scale transformation projects has dwindled. One company announced an average tenure for their Senior Chemical Processing Engineers or no more than 2 years. This explains the difficulty for refineries to engage in large-scale CO2 emissions abatement, especially since sulfur-related investment are prioritized over EU ETS induced projects.

4.1.2 Measurement issues

An important issue on which the ambitious schedule of introduction of EU ETS tumbled was the lack of reliable baseline data for CO_2 emissions. For most installations, no historical data had ever been collected at all. An accelerated process of assessment and third-party certification based on extrapolations from the estimated fuel consumption of refineries took place in the months leading to the beginning of the scheme. The haste with which such process was conducted has led to the widespread belief that baseline emissions were often inflated (private interviews, and Ellerman and Buchner (2006)). However, the measurement issue was generally considered as a one-time issue, that has now been largely overcome.

A very interesting finding arising from the interviews is the fact that, contrary to this view, emissions measurement at the level refineries is a much more complex problem than what is assumed by policymakers, and still mobilizes a considerable amount of human and material resources.

Indeed, after three years under the scheme, the refinery that I visited was still focusing much of its EU ETS-related efforts on improving the reliability of its emissions reporting. Declaration of CO_2 emissions at the refinery level is based on an extrapolation from the quantity of fuel entering the boilers, measured through a complex mass flow measurement system involving mechanical mass flow-meters, analog devices and numerical controllers. The long capital cycle of refineries entails that the age of the measurement system can reach an average of 20 to 30 years. It is hence understandable that the initial uncertainty range over declarations reached 6% (a figure quoted by some interviewees as representative of the industry in general), while they are required to decrease to 1.2% to meet the regulatory requirements for Phase II. The main challenge in decreasing the uncertainty is linked to structural uncertainty on the accuracy of such measurement systems, and its evolution as the system ages. Moreover, the complexity of a refinery makes it hard not to miss some sources of greenhouse gases. An interviewee cited the number of 140 different sources in their typical refinery, stating that the initial declarations had missed a significant number of them. Finally, the complexity of the issue at stake is compounded in the case of processing Joint Ventures, where CO_2 liabilities have to be allocated based on marginal contributions of each of the owners to the plant emissions.

The Business Unit Leader of the refinery I visited emphasized the fact that a positive

unintended consequence of EU ETS was to force plants to commit significant resources to the audit of their mass balance measurement systems, thus gaining a better control of the industrial tool and a better ability to detect deteriorating conditions early on, which improves overall plant reliability and profitability.

4.1.3 Voluntary emission trading schemes

Two very interesting case studies of the preparation of oil majors to the apparition of carbon markets are the internal GHG emission systems developed on a voluntary basis by the BP Group (analyzed by Akhurst et al. (2003)) from 1998 to 2001, and by the Shell Group (described by Hoffman (2006)) from 2000 to 2002.

Shell Trading Emissions Permit System

Shell started STEPS (Shell Trading Emissions Permit System) in 2000, as an internal emission trading system designed to last 3 years. The program was based on voluntary participation of individual Business Units. 70% of Shell's emissions in Annex I countries were eventually covered by the scheme. Business Units received absolute allocations based on their historical emissions, and the voluntary goal was to reduce emissions below -2% under the 1998 baseline. The scheme's success was mixed, mainly because voluntary participation meant a scarcity of participants and a lack of liquidity. Moreover, tax liability issues prevented cross-country monetization of greenhouse gas abatements, and the fact that some Business Units filed for additional allocations during the scheme threatened its overall credibility. However, Shell considered that STEPS was a success as a learning experience, as it helped its Business Units adapt to carbon trading and abatement curves computation, and allowed Shell to gain an environmental credibility that proved useful in the industry consultations during the design phase of EU ETS. The scheme was terminated in 2002 when the UK emissions trading market started (Hoffman 2006).

BP Emissions Trading

BP started to design its Emissions Trading (ET) project in 1998, as a mandatory internal emission market, intended to help the group reach its voluntary reduction target of 10% below 1990 levels by 2010 in the most cost-effective way. BP ET was much closer to EU ETS, as it was mandatory (for all BP Business Units in upstream, downstream, chemicals

and power & gas), based on grandfathering linked to historical production with provisions for new entrants and closures, and involved external audits of reported emissions. An interesting feature of the program is that it took into account not only CO_2 emissions, but also CH_4, accounted for under the form of 'CO$_2$ equivalents' based on its relative Global Warming Power. From a design standpoint, the close participation of the NGO Environmental Defense confered credibility to BP's scheme. It is worth noting that emission allowances were part of the performance contract of Business Unit Leaders, thus leading to direct financial incentives for GHG emissions abatement. Transaction volume was significant, reaching 4.5 million tons of CO_2 exchanged at an average price of $36 per ton in 2001. The scheme helped BP reach its voluntary reduction target 7 years before schedule. It was terminated in 2002 when the UK emissions trading market started (Akhurst et al. 2003).

Conclusions

The conclusions from the authors of both case studies are interesting with regards to the design of ETS. Namely, BP concluded from its experiment with carbon markets that the most important features for emissions markets design were to:

- Keep the design as simple as possible

- Strive for high data quality

- Privilege consistency over equity in the grandfathered allowances allocation process ('no allocation process is perfect')

BP researchers emphasized that ensuring the linkage between compliance in the trading system and managerial performance reporting is key to efficiently participation in the scheme. They pinpointed that multi-year trading is more conducive to abatement investments, as only a credible commitment to a long run carbon price can induce the changes in the capital cycle that can spur long-lasting benefits.

<p style="text-align:center">* * *</p>

As an overall conclusion regarding the preparation of oil and gas companies to EU ETS, it appears that even though corporate headquarters had enough time to think through the strategic implications of the introduction of a price for carbon emissions, the complexity

of the operational consequences of the scheme for data collection and monitoring had been underestimated beforehand.

4.2 Operational changes

A crucial question to understand the response of the industry to EU ETS is the way the carbon constraint was translated 'on the ground', at the level of plant operations. In this section, we focus on how the new carbon constraint impacted the short run operational decisions by refinery managers. Namely, three over-arching questions were presented to interviewees:

- Was the carbon price internalized by operators, and, if yes, how?

- Were production decisions impacted by the carbon constraint?

- What emission abatement opportunities have been undertaken due to the carbon constraint?

4.2.1 Internalization of carbon price

Interviews with company strategists, engineers and traders revealed that all the companies we interviewed had taken into account the carbon price in the schedule planning decision step.

This means literally modifying the linear programming models used to maximize plant profitability, by adding new constraints representing the cost of every ton of CO_2 emitted as a result of operational decisions. For example, traders at Company A revealed that the spot price of EUAs was used as a parameter for the carbon constraints in their refineries LP models; this means that the product mix choice is optimized with regard to CO_2 emissions. The energy consumption and associated CO_2 emissions are modeled depending on the type of crude used as an input. As the crude procurement units at the level of refineries or at the marketing branch choose crudes on the market for each refinery, and later try to saturate every conversion constraint to optimize the profitability of the refineries pool, they also use such LP models; the dispatch of crude oil inputs among refineries is hence also optimized with regard to the marginal cost of CO_2.

This is very instructive, as it means that the optimization of production choices takes into account the full opportunity cost of carbon emission allowances. However, all interviewees conceded that the effect on the overall product mix had been only marginal, especially as the spot price had dwindled in the second part of Phase I. It nevertheless shows that short run production choices optimally account for the opportunity cost of carbon emissions. Within the realm of fixed capital stock and operating processes, it means that operations have been optimized to take carbon emissions into account, which is an important tenant of static efficiency of the carbon market.

4.2.2 Impact on production choices

However positive such a finding is in terms of the optimality of the industry's response to EU ETS, all interviewees conceded that the effect of optimizing production based on an unchanged refinery tool was at best marginal.

Changes in input and output product mix

The introduction of a carbon constraint in the LP scheduling models of refineries has an impact on the choice of the crude diet and of the output slate. This is so because the processing of different crudes, because of their differing qualities and varying sulfur content, leads to different CO_2 emission profiles, and that the production of different petroleum products is more or less CO_2 intensive. However, since the production of CO_2 in refineries stems for a substantial part from the combustion of fuel in boilers for process heat needs (see section 2.4), adding a CO_2 cost in optimization models amounts in effect to an increase in energy prices.

The industry analyst I discussed with produced the following back-of-the envelope computation to support this claim. Assuming a carbon price around € 20 per ton of CO_2 (hence a total cost of around € 40 for burning a ton of fuel), and an energy price of around € 500 per ton of crude oil, the introduction of the carbon constraint has at best a marginal impact on the energy expenditure of a refinery. Since the crude input and the product output would be optimized for the energy price under business-as-usual conditions, the introduction of a carbon cost has less impact than the recent rise in oil prices. This conclusion is confirmed by estimates of refining operational costs (see section 2.2).

As a conclusion, the carbon price has had an effect on the choice of crudes and the

output slate, but most interviewees saw it as marginal at most. In effect, this confirms our findings from Chapter 3.

Changes in product prices

A first question that arises, which is central to the study of competitiveness impact of EU ETS, is how much prices are impacted by the introduction of carbon. Most analysts and strategists concurred to say that the potential pass-through of carbon costs to petroleum products was virtually zero. One strategist made the hypothesis that some pass-through to customers would be possible for jet fuel and diesel markets, but not for gasoline. Moreover, because of the cheap transportation costs for crude and petroleum products, the industry assumes that the financial arbitrages are very strong. All preliminary analyzes of the pass-through rate are around 0%.

An interesting question raised by an interviewee is the project of border adjustment tax alluded to by President Nicolas Sarkozy of France (BBC News 2007), which could have sufficient impact to allow for a significant pass-through of carbon costs in the European petroleum products market. However, it must be noted (see Chapter 2) that since a significant proportion of the gasoline produced by European refineries is sold in the US, where local competitors do not face carbon costs yet, such pass-through would likely not be significant.

Overall, the industry is not forecasting any significant changes in petroleum products prices stemming from the introduction of carbon costs.

Changes in production quantity

Regarding production changes, it is interesting to note that an intended effect of emission markets is to decrease the production of CO_2 intensive goods, as industrials arbitrage between the opportunity cost of using the marginal allowance and the additional profits stemming from the marginal unit of production.

A question for the interviewees was to know whether this happened in refineries - namely, did some plant cut production down because of the carbon price. All interviewees answered that such an outcome was irrelevant for refining, because of the high capital intensity of the plants. A large part of the cost structure for refineries stems from the capital expenditures accumulated over the years. Operators see them as sunk costs, and try to maximize the

utilization of the distillation and conversion capacity of the plant whenever possible. Adding a carbon cost will not lead them to decrease production.

Finally, the industry analyst I interviewed pinpointed the fact that, because of the tendency of refineries to saturate their conversion capacity, the marginal refinery behaves like a simple refinery (see Chapter 2). This means that the marginal energy expenditure is less important that the mean energy expenditure, and hence that the marginal carbon cost per ton of crude oil processed is less important than the mean carbon cost per ton of crude processed. Hence, the incentives for changing the product mix or reducing production are weak.

Outsourcing opportunities

Refineries face two main opportunities for outsourcing that would alleviate their CO_2 related cost burden. Switching from on-site power and heat generation to grid electricity or co-generation is a potential source of energy price arbitrage for refiners, but in most cases it involves significant capital investments such as the construction of CHP plants or the revamping of ancillary utilities. We will hence come back to it in the section on investment behavior change.

An opportunity for outsourcing that is more feasible in the short run and truly amounts to an operational choice is for refineries to import some semi-refined products from zones that do not face carbon costs, or to export semi-processed products to finish their energy-intensive conversion in such areas.

Traders and managers confirmed that such opportunities are frequently undertaken by refineries, but only to a small extent in terms of volume. Historically, exporting or importing semi-finished products ahs been used to utilize the plants' conversion capacity at their full extent whenever the choice of crude diet and output product slate saturated the distillation towers but not the conversion units. The introduction of a carbon price may have increased incentives to do so, but only marginally, as such choices will remain operating decisions based on the availability of the engineering capacity. Moreover, some strategists pointed out that the main incentive to import semi-finished products stems from the imbalance between gasoline and diesel demand between Europe and the US, which leads European refineries to import semi-processed diesel streams from Russia to commercialize them on the European market. However, the incentives to do so are weakened by the need to treat

semi-finished products with high sulfur content in Hydro De-Sulfurization (HDS) units, which is a highly CO_2 intensive process.

As a conclusion, the EU ETS has not changed the existing practice of importing semi-refined products for treatment and commercialization in Europe; there is no carbon leakage effect at this level.

4.2.3 Real changes in operations

Carbon emissions schedule optimization

Taking the carbon constraint into account in scheduling models means that production choices are optimal under the added carbon constraint based on the business-as-usual use of the refining tool. This is very important for the static efficiency of the carbon pricing scheme, but translates in at best a marginal impact on production choices and emission outcomes. More important are the questions of whether or not operators modify the plant operational processes in the short run, and whether or not they invest in abatement opportunities. A large set of questions in the survey focused on investments in abatement technologies; the results are reported in detail in the next section. This paragraph specifically delves into opportunities to abate carbon emissions based on short run modifications of the operational processes.

Fuel arbitrage: environmental constraint

Arbitrage between natural gas and fuel oil for use in boilers is one example that could have an important impact on emissions. Overall, using natural gas instead of the fuel oil stream from crude input in the boilers of a refinery is estimated to lead to up to 25% GHG abatements (private interview). Even though engineers and managers at all companies agreed that there was some room to see the terms of this optimization choice modified by carbon price, the binding constraint at this level is once again linked to environmental regulations. As described in Chapter 2, the choice of natural gas instead of fuel oil for boilers is mainly guided by weather conditions, that may make it necessary to use a low sulfur fuel such a natural gas or refinery tops in the event of unfavorable wind pollutant dispersion conditions. Carbon price can change the terms of the economic trade-off, but the constraint on sulfur dioxide emissions being a command-and-control regulation which could

lead to the shutdown of the plant in cases of non-compliance, it is still the main driver of the choice of such a switch. Moreover, current carbon price conditions don't make such a trade-off profitable.

Process change: workforce constraint

Another real constraint on potential process changes is the amount of experienced workforce into which managers can tap. For example, the Business Unit Leader at the plant I visited described a situation where the aging workforce had led to a high rate of retirement over the last decade, which left plants with a deficit of experience. For example, their Senior Process Engineers have only around an average of 2 years of experience, which is considered as very short in the field. Combined with priority regulatory constraints that captured the attention of engineers, such as emissions measurement issues linked to EU ETS, but also the increasingly tightening sulfur content regulations and SOx emission regulations, this deficit of experienced labor has led to a situation where potential abatement operational changes were not pursued as a priority by Business Units.

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The conclusion of our interviews on operational changes is that, in the short run, the carbon constraint has been efficiently internalized in the operational choices optimization process. However, the impact of the carbon constraint on production choices has been at best marginal, and is hard to disentangle from other incentives for energy efficiency such as the rise of energy prices over Phase I. Finally, carbon emissions abatement through operational changes are highly constrained by their interaction with other regulatory frameworks such as the European legislation on petroleum product sulfur content and on SOx emissions. In the short run, the impact of EU ETS on operations was hence minimal. The next section turns on to long run operational changes and investment decisions.

4.3   Changes in investment patterns and decisions

The conclusion of the first part of our survey is that firms took into account the carbon price in a statically efficient way, but that this led to second-order emissions abatements rather than dynamic changes in operations. We now focus more specifically on the impact

of EU ETS on investments in emissions abatement technologies, both as we could observe it in the short run based on findings from our survey, and in the long run, as the industry approaches it based on discussion for our series of interviews.

4.3.1 Observed short-run impact on investment

In the short run, a certain number of abatement investments have been considered by the industry, but few projects have resulted in actual investments so far. Outsourcing of the power and steam generation needs is a potential lever for emissions abatement that presents a strong potential, but is subject to specific economic constraints. For both on-site and outsourcing investment, the general pattern that emerges and was emphasized by all survey participants is the fact that abatement opportunities are highly contingent on the configuration of the plants, their original design and their historical development. However, a number of common patterns have emerged from the interviews. We detail below the abatement investment opportunities that our interviewees have identified and/or undertaken.

Abatement investment opportunities

The opportunities for investment leading to emissions abatements are found at the three levels where CO_2 emissions occur in refineries (see section 2.4): process heat production, steam production, and process emissions.

For example, a strategist from Company B alluded to boilers efficiency as an area of potential investments with significant potential impact in terms of emissions. Pre-heating of the crude oil stream entering the distillation towers and improved heat circulation in the distillation towers was among the abatement opportunities identified by *ex-ante* studies which the industry has widely considered and sometimes put in place where local conditions would permit it. The potential arbitrage between natural gas and fuel oil that I discussed in section 4.2.3 could also be facilitated by investment in new boilers, as pointed out by Company D.

'Leak-plugging' in the vapor production system was quoted by all companies as an important source of abatement with positive payback even in the absence of carbon constraints. For example, in the refinery that I visited, actively researching and eliminating the sources of steam leaks allowed the plant to shutdown one of the three boilers for the vapor circuits.

Company D also emphasized on leak plugging as its prime source of emissions abatement and energy savings.

Finally, as described in 2.4, process emissions are seen as 'fatal' by the industry, since they are mostly determined by the steochiometry of the reactions at hand. Participants underlined the fact that the forecasts of increasing demand for lighter products and the forecasts of decreasing gravity of crude input and the tightening constraints on sulfur content of fuels will likely increase further the need for hydrogen feedstock and conversion capacity.

Over the last 15 years, the industry has already achieved a 13% increase in energy efficiency (interview with the industry association analyst). The question for the future is both how to find additional abatement opportunities, and how to ensure that the effect of investments in emissions intensity reduction are not offset by increased use of conversion and treatment capacity forced by concurrent regulatory constraints.

Outsourcing investment opportunities

As underlined in section 4.2.2, a vast untapped opportunity for carbon emissions outsourcing at the level of refineries lies in electricity and heat procurement. Most of the time, this entail either switching from in-house fuel oil-based power generation to the grid, or investing in Combined Heat and Power (CHP) plants. Cogeneration is interesting in terms of CO_2 emissions, because it entails a more efficient use of the power generation plant. Overall, the industry estimated that the emissions abatement potential lies around -50% when switching from in-house fuel-based power generation to CHP, compared to -25% by switching from in-house fuel-based to in-house natural gas power generation (interview with the industry association analyst). Such an opportunity was largely recognized by all participants in the survey. The trader I interviewed at company C gave the example of one of their plants, which shifted from in-house fuel oil combustion to CHP for the procurement of its electricity needs.

However, a significant issue for companies that have sought to invest in such outsourcing opportunities has been the fact that the mix between in-house electricity, refinery fuel oil, and externally procured electricity and vapor varies drastically between refineries, as emphasized by several participants to the survey. Plant design and equipment are originally designed for a specific energy mix, and may not be flexible. This strongly constraints the room of companies to use such investments to reduce their carbon footprint. The chief

economist for company D explained that one of their plants actually recently decided to switch out of a CHP third-party agreement and to build their own in-house power generation plant.

Also, the economics of EU ETS create a problem for CHP investments in the eyes of the industry. First of all, it is a problematic solution for companies that would want to switch from in-house production to a stand-alone CHP plant, because it would legally require them to file the new plant as a new entrant, or internalize the plant with the prospect of not receiving new allowances. Moreover, the industry sees the electricity sector as particularly difficult in terms of allocations to new entrants.

Finally, the extent to which the carbon price signal can prove determinant in such investment decisions is still largely unclear to the industry, and highly context dependent. The trader at company C recognized that the economics of the decision to switch to in-house CHP were impacted by forecasts of EUA price, but not to a great extent. The main driver was rather a question of reliability compared to procurement from the grid. The chief economist of company D recognized that the carbon price shifted the balance from an investment in a fuel oil boiler with a de-sulfurization unit to a Combined Cycle Gas Turbine (CCGT) running on natural gas. This was however mostly conditioned by external factors linked to a monopoly situation for the third party operating the CHP, and to rising electricity prices in Eastern Europe due to demand catching up with a generation capacity that had remained largely flat since the fall of the Soviet Union.

As a conclusion, outsourcing of the energy sources is a solution that has been widely considered by the industry, but whose effectiveness and profitability are highly context-dependent. Moreover, it is hard to disentangle the effect of carbon price from the other incentives that determined some companies to pursue these investments.

4.3.2 Short run emissions abatement investment strategies

As discussed in Chapter 2, a number of abatement investment opportunities exist, but not many of them have been developed so far. We focus in this section on how companies identify such opportunities, and the reasons why little of them have been put in practice.

Identification strategies

A first identification strategy that was used by Shell was to tap into their internal consultancy service, Shell Global Solutions. The consultants devised the Energise program, designed to provide BUs with on-site resource to identify abatement opportunities, implement change and track progress. The program focused mainly on energy savings and energy intensity improvement, and worked on a zero-capex basis, meaning that the investments were financed by the energy savings they would entail. The BUs could keep 50% of the benefits of the operation for a few years as an incentive (Hoffman 2006).

It also appears that, because refineries had very little information on their actual emissions before EU ETS, a very important first step was to reassess the mass balance measurement chain and thoroughly examine all possible sources of emissions. An important source of help to identify all sources of CO_2 emissions were the external auditors that assessed the declarations of emissions of the companies as required by the EU ETS Directive, helping target potential abatement opportunities.

Finally, the widespread opinion among participants is that, while the cost of carbon in the current environment is not enough yet to create by itself strong incentives for actors to change their operations, it has compounded with the recent increase in energy prices and led companies to become much more serious about energy efficiency investments.

Barriers to abatement investments

A first barrier to abatement investments is the fact that most of the attention of management regarding further investment is aimed for the moment at keeping the pace of regulations on the sulfur content of fuels. As described in section 2.2, the new standards for fuel sulfur content imply an increased effort on product treatment, and massive investment in de-sulfurization capacity, just in order to follow regulations. As pointed out by the refinery Business Unit Leader at company A, since non-compliance with this regulation means the inability to sell products in the European Community, investments that are needed in order to comply are ranked with a top priority.

Another constraint on potential investments is the amount of experienced workforce in which managers can tap to build the new abatement investments. As described in section 4.2.3, this means that only the top priority investments can be realized by companies.

Finally, a last constraint is simply time. The availability of qualified workforce notwithstanding, the main impediment to new abatement investments coming on-line is the fact that refineries shutdown are kept as unfrequent as possible in the established framework (see section 2.2), are made as short as possible, and are used as maintenance opportunities, which mobilizes most of the workforce on regular maintenance work. The fact that EU ETS is fairly recent at the time scale of refining, and the length and complexity of preliminary operations such as the revamping of the measurement system help explain that so far only minor operational changes and rare investments have been undertaken.

4.3.3 Case studies in abatement strategies: adaptation to local conditions

Participants strongly emphasized the fact that the most important levers of emissions abatement would likely be determined by local conditions at the plant. A respondent stated that 'a refinery is an abstraction, as no plant will have an even remotely identical design to any other one'. Moreover, a lesson that stems from the study of abatement opportunities is that more opportunities could be found at the systemic level rather than the mere optimization of individual plants. This line of thought, that advocates a paradigm shift from abatements from technical change at the level of individual plants to life-cycle thinking at the level of industrial ecosystems, emphasizes on the need for adaptation to local conditions. Two well-known examples of such adaptation are the Shell Pernis refinery in the Netherlands, and the Kalundborg industrial complex in Denmark.

Shell Pernis Refinery

The Shell Pernis Refinery in Rotterdam recovers CO_2 emissions from the methane reformer of its hydrogen production plant, sells it and ships it to 400 large horticulture farms which use it as a fertilizer in their greenhouses. Shell has been recovering 170,000 tons of waste CO_2 per year since the start of this program in 2005. The Pernis refinery is the largest in Europe, and emits 6 Mton CO_2 annually. The capture hence represents only a small amount of the plant's emissions. However, as it is captured from the reformer stream, the CO_2 flow contains less impurity, such as the trace VOCs or NOx that would be present in a post-combustion CO_2 flow. It is also more concentrated, which, in addition to displacing the equivalent amount of CO_2 emissions that the horticulture farms would have to produce by burning natural gas, increases profitability.

Overall, this is an interesting example of industrial symbiosis and of valorization of the CO_2 stream stemming from refinery operations. For more details, the reader should refer to the original case studies as described by Petsonk and Cozijnsen (2007) or the institutional communication of Shell Group (Shell 2005). The most salient point here is that such a project would arguably not have been pursued were it not for EU ETS, which makes waste CO_2 valuable.

Kalundborg industrial ecosystem

The Kalundborg complex in Denmark is an example of an industrial ecosystem, defined as a cluster of industrial activities with highly integrated closed-loop flows of material and energetic inputs and outputs. Specifically, the industrial ecosystem consists in a network of plants whose operations are interconnected and organized around the local scare water resource - Lake Tisso. The different partner plants are the following:

- Statoil oil refinery

- Asnæs power station (the largest coal-fired power generation plant in Denmark)

- Novo Nordisk industrial enzymes production plant

- Gyproc plasterboard production plant

- Kemira acid production plant

- The town of Kalundborg's residential district heating system

All plants receive their water input from Lake Tisso. The Statoil refinery produces part of its vapor needs from the waste heat of the electricity production plant, which runs in a more efficient co-generation mode. Conversely, wasted water from the refinery is fed in the water circuits of the power generation plant. The excess refinery gases at the Statoil refinery are desulfurized and become of source of natural gas and sulfur for neighboring industries: the gas is sold to the Asnæs power plant and the Gyproc plasterboard plant, and the sulfur is sold to the Kemira plant. Finally, waste heat from the refinery and the power generation plant are fed in the town of Kalundborg's residential district heating system.

Figure 4-1 testifies to the complexity of the Kalundborg industrial ecosystem, and the length to which designers went to monetize industrial outputs and turn them in valuable

Figure 4-1: Kalundborg industrial ecosystem energy and material flows (United Nations Energy Program 2001)

inputs. Most interestingly, the complex was not designed from scratch but evolved as investors became gradually became aware of the availability of waste raw material in the system. The development of the Kalundborg industrial ecosystem is described thoroughly and analyzed as an industrial development paradigm in Gertler (1995). Erkman (1998), as quoted by United Nations Energy Program (2001), reports estimates for the energy and material savings listed in table 4.1.

Table 4.1: Kalundborg industrial ecosystem environmental benefits (Erkman 1998)

Reduction in consumption of resources	
Oil	45,000 tons/year
Coal	15,000 tons/year
Water	600,000 m^3/year
Reduction in waste emissions	
Carbon dioxide	175,000 tons/year
Sulfur dioxide	10,200 tons/year
Valorization of waste streams	
Sulfur	4,500 tons/year
Calcium sulfate	90,000 tons/year
Fly ash (for cement)	130,000 tons/year

To draw lessons from the Kalundborg ecosystem pertaining to emissions abatement in refineries is obviously far fetched, since the industrial symbiosis at work here emerged out of a specific set of local conditions and was contingent to the historical development of the

cluster. However, we can conclude that such examples show that, conditional on the nature of the local industrial landscape, and the opportunities for recycling that may stem from it, systems thinking can lead to further abatement opportunities. As it is not rare to see refineries coupled with chemical and petrochemical plants for obvious historical reasons, such potential symbiosis mechanisms could apply more broadly that one could suspect to the refining industry. It is also a guiding principle for the long run development of heavy industries in a carbon conscious world (Gertler 1995).

4.3.4 Long run carbon price signal

The previous sections have detailed the impact of the introduction of EU ETS on short-run investment behavior, and described abatement strategies followed in the past by refineries. A salient question is to understand how companies are strategically thinking about carbon constraints in the long run, and what impact this could have on their investment decisions for new refining capacity.

The dominant opinion among the interviewees is that the market system set by ETS is here to stay, and that carbon prices will remain a reality for investments in refining in the future. This means that for new distillation, conversion or treatment capacity investment on existing platforms, or new refineries construction projects, companies factor in hypotheses on such a carbon price.

Some companies do it by adding a potential carbon liability as a sensitivity parameter in the financial analysis of new projects. Others do it by directly embedding a hypothesis on the long run value of carbon in the net present value analysis of the project. The industry association analyst postulated an average figure of € 30 per ton. Indeed, company B uses € 20 per ton of CO_2 company C uses different undisclosed values varying with geographical location of the plant, and company D uses a € 25 per ton price signal before 2012, rising to € 40 per ton after Phase II due to what they foresee as the rising worldwide commitment to a post-Kyoto architecture.

The impact of this long run price on investment behavior is not yet clear. The chief economist of company D described the conclusions of their in-house analysis by saying that at the conditions that prevailed in the beginning of phase I, the carbon price was strong enough to change the utilization of the capital stock, but not it's renewal. However, above around € 40 per ton, the price signal would entail significant changes in the existing

112

industrial basis, with more investment coming on line. In such a case, fears of carbon leakage could materialize.

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Overall, there is some room for investment in abatement technologies, and the incentives created by EU ETS are mostly seen as credible and durable. However, a number of internal (workforce availability) and external constraints (sulfur content regulation), and the low price of the carbon signal during the first phase of ETS, have deterred most companies from heavily investing up to date.

4.4 Conclusion on the response to EU ETS Phase I

Clear response to EU ETS

A fundamental conclusion of the survey is that the price signal set by the EU ETS has been perceived by the industry, and that they adapted in a statically efficient and rational manner. Namely, refineries have optimized the production mix optimally by taking into account the emission-intensity of the input crude diet and the output product slate. Moreover, firms have, to a modest extent, moved toward a dynamically efficient response, by preparing for further abatement investments and by undertaking the lowest-hanging-fruits among their abatement options through operational changes, which was however mostly due to the rising cost of energy.

The response of the industry has been modest so far. The changes in operating configuration measured in chapter 3 have been at best modest. Investments in abatement technologies haven't been the norm among refineries over the pilot phase of EU ETS, and most changes in the operations of the refineries have been 'leak plugging' activities, or increased awareness of energy efficiency and potential arbitrage opportunities about refinery energy procurement.

However, a capital point is that, at the end of this first phase of trading, described by commentators as a 'warm-up period' (Pew Center on Global Climate Change 2005), all firms I have interviewed had built the institutional and technical capability to respond to Phase II of EU ETS. At the level of plants, this includes accurate measurement of emissions, better understanding of the sources and the levers of control on emissions, and better knowledge

of the abatement opportunities at hand and their cost. At the corporate level, trading desks and refining headquarters have learnt to coordinate their respective roles. Finally, strategists have incorporated a long term carbon price in their investment decisions. The pilot phase hence fulfilled its role and allowed firms to prepare and build the capability to respond efficiently to the more stringent cap of phase II.

Modest abatement activities

As described above, most of the abatement observed in the refining sector stemmed from second-order changes in operational configuration, and a first set of modest abatement investments when they were aligned with energy expenditure reduction. Survey participants quoted various reasons for the low level of abatement resulting from the three years of trading.

A first recurring argument was that the price of allowances was not high enough during Phase I to lead to serious operational changes. While the price during the first period evolved between € 20 and € 30 before the EUA price crash of April 2006 (Alberola et al. 2008), its price in the second part of the first phase was indeed too low to lead to significant changes or investments. One survey participant alluded to Phase I as a 'computer simulation' of carbon market. Another described the cost of CO_2 for refineries as 'effectively zero', and 'insufficient to create incentives for change'. An important point related to the growing discrepancy between the spot and the future price of allowances during the second phase of the pilot phase is that, because banking from Phase I to Phase II was prohibited by the European Commission, plants faced a perverse incentive to delay their emissions abatements before January 1st, 2008, for fear that lower emissions would decrease the amount of grandfathered allowances they would received in the Phase II Budget, which reduces the economic appeal of early abatements.

A second reason is that the current margin environment is too favorable to refiners for CO_2 price to make a difference in their operational decisions. This statement blatantly disregards the opportunity cost of allowances. However, as emphasized in the first point, in the second part of the pilot phase the marginal price of carbon was indeed too low to matter to plant managers.

Finally, analysts, traders and managers alike recognize that the carbon was compounded to the rising energy costs, and helped dramatically increase management's awareness of

energy efficiency issues. The real incentive for change was however not the price of carbon *per se*, but the rising cost of crude oil.

Main constraints: weak incentives, inertia and interaction issues

The pilot phase has however revealed two main constraints that may impede on the ability of firms to further decrease their emissions in the second phase of the scheme, even if they react as rational actors to the carbon price (which I discuss in the next chapter).

A first barrier to change is the problem of weak incentives I described in the last section. Survey participants estimated that the trigger price at which operational change would become significant is around €25, and the price at which the capital stock renewal would be accelerated and the existent facilities would start to be replaced with new, more efficient ones is at least of €40. During Phase II, with EUA prices currently (January 2008) around €20, incentives for large-scale technological change may stay weak.

A second constraint that weighs on the ability of firms to respond to carbon price incentives, even if they were to become stronger, is the institutional inertia that characterizes the refining sector. The overall life time of a plant can exceed sixty years, and investment horizons are often at least of 20 years. Because of the capital intensity of the industry, one can expect caution in the investment decision process. Finally, because of the large sunk costs related to the refining infrastructure, refineries shutdown are minimized in frequency and duration, planned years in advance, and often work on five year cycles. This may in part explain that so little abatement investments were observed during the three years pilot phase; it also underlines the issue of uncertainty and its impact on investment, and implies that the rate of capital renewal is structurally low. Finally, workforce issues are salient, and the fact that plants struggle to train and retain qualified workforce in sufficient quantity entails that large abatement investment may not be possible in many plants.

A last constraint that may undermine the ability of refineries to further curtail their emissions is the issue of regulatory interactions. The recent tightening of the fuel sulfur content regulation will lead to increased use of hydro-desulfurization (HDS) units, and investment in new ones, with a strong associated rise in CO_2 emissions due to increased heat and process emissions for the production of hydrogen and the HDS treatment. The industry quotes this as one of the main barriers to achieving further emissions abatements. Moreover, because of the lag time the industry needs to adapt to changing patterns of demand, the

gas oil to gasoline ratio of the existing infrastructure is structurally imbalanced (see chapter 2), which the industry says entails higher emissions than would be necessary if the ad-hoc conversion capacity was in place. Emerging national mandates to promote the blending of ethanol with gasoline in Europe would further depress the consumption of gasoline compared to diesel, which would entail higher emissions from conversion. Generally speaking, the industry is very concerned with interaction effects between other environmental legislation and the need to reduce emissions to minimize the cost of compliance to EU ETS.

Chapter 5

Industry perception and policy-induced distortions

One of the overarching issues on which this study intends to shed some light on is whether or not EU ETS is economically efficient. This question is obviously too broad to answer in this thesis, focused narrowly on the refining sector. However, a certain number of tangential issues, that when brought together help understand the broader question of the efficiency of the scheme, can be informed by the ground-level vision our survey of the refining sector allows one to build.

Two main questions arise at the level of this study. A first issue has to do with how firms organize to react to the price signal. Chapter 4 reports that firms have built the capability to take carbon prices into account in their operations and in the planning process for subsequent investment. However, I show that the incentive structure created by the organizational choices of firms can lead to flawed results in some cases, and may deter plant managers from fully perceiving the opportunity cost of allowances.

The other issue is to know how the potential inefficiencies inherent to the scheme have impacted the refining sector. In this chapter, I describe the provisions of the scheme that create distortions, and analyze findings from the survey of the refining industry pertaining to their perception of the scheme. I conclude that the industry focuses too much on cash cost rather than the marginal opportunity cost of allowances, a behavior which may undermine the economic efficiency of the scheme.

5.1 Organizational responses to the introduction of EU ETS

The introduction of EU ETS is an interesting experiment in adaptation to institutional change, because it has forced companies to adhere to, understand, and interact with a new market that was created *de novo* by the regulator. The need for firms to form expectations about the behavior of the regulator ('institutional learning') adds another level of complexity the analysis, as pointed by (Alberola 2007, section 5.4.2). From the point of view of organizational economic analysis, what matters is the way companies organized to respond to this new market-based regulation. Specifically, I investigate the institutional arrangements along which the responsibility for regulatory compliance and the responsibility for profit maximization were distributed. Also, because majors have a higher number of individual plants falling under ETS and the capability to handle trading separately, it is interesting to contrast their approach with smaller companies.

A key finding from the study of the organizational response of firms is that they tended to segregate trading activities, handled by the trading and marketing divisions, from the industrial aspects of the scheme, such as compliance and operational decisions. I explore in this section and the next one how the organizational arrangements deployed by firms may stem from, and influence, the perception of the scheme by the industry, and how it may affect the economic behavior of firms, and hence the efficiency of the trading scheme.

5.1.1 Compliance responsibility

In all of the companies I interviewed, compliance was the legal responsibility of the individual plants and Business Units. However, operations on the carbon market were handled by the trading and marketing arms of the companies, based on the projections of the refining branch. The usual arrangement was for the individual Business Units to coordinate with the Refining branch to forecast and dynamically balance on a monthly basis the amount of allowances held based on the emissions declared for the prior month and the evolving production forecast until the end of the EU ETS period. Based on the decision by the Refining branch, orders were passed to the trading division, which managed the access to the markets for allowances. Legal responsibility was hence pertaining to individual plants, but the supervision of allowances ownership in all the companies I interviewed was the responsibility of the headquarters.

5.1.2 Trading responsibility

As carbon exchanges and over-the-counter transactions of allowances are not a natural market for oil and gas actors, an important element of the operational response of firms to the introduction of EU ETS is their actions on the allowances market.

EUA trading strategy

While setting up a financial market for allowances relies heavily on the liquidity stemming from speculation for efficient price revelation, most companies have emphasized compliance as the primary goal of their trading policy. For example, one major company has set up a scheme whereby its trading arm, while skilled at dealing with financial risks, arbitrages and profit-seeking trading strategies, is limited in the speculative positions it can take by caps on the amount of allowances it can engage on the market. The official corporate policy, stated the refining strategy managers at company, is to avoid exposure to the carbon price risk, as it was not mandated by shareholders. The excess allowances from phase I were hence gradually sold on the market as it became clear that they would be useless to the company.

Other companies, on the contrary, have mandated their trading branch to engage in speculation on carbon markets, as they do on oil, gas, and often power markets. A trader at a major company stated that 98.5% of the trade it executes are for speculative purposes rather than portfolio balancing.

Finally, even though policies on risk exposure differ between companies, all of the traders responding to the survey were familiar with the risk management techniques and the carbon market instruments that could help improve their companies' trading strategy. One of the major companies, for example, stated that in preparation for Phase II, the traders increasingly engaged in long term allowances contracts such as EUA futures or long term CER swaps.

Involvement in other carbon markets

A specificity of the EU ETS trading directive is the linkage provision, whereby allowances gained on external carbon markets can be transfered up to a certain extent determined by the Member States. Such markets include the Joint Implementation (JI) and the Clean

Development Mechanism (CDM) provisions of the Kyoto Protocol. These markets are the two project based mechanisms of the Kyoto Protocol, under which operators in Annex I countries can realize carbon savings in another Annex I (Joint Implementation) or non-Annex I country (Clean Development Mechanism), and receive marketable allowances if the emissions abatement are certified through a regulatory process led by the United Nations Framework Convention on Climate Change (UNFCCC) - ERUs (Emission Reduction Unit) for JI project, CERs (Certificate of Emissions Reduction) for CDM projects. These allowances can then be sold on a secondary market, or converted in EUAs by firms under ETS. Because of caps on the convertibility of CERs, markets put a price premium for EUAs over CERs (de Wolff 2006), which makes it optimal to use as many CERs as possible, as all participants have recognized.

Companies interviewed were all actively seeking to gain CERs or ERUs through the development of JI/CDM projects. Most have been unsuccessful so far (especially since flaring was deemed non-eligible for CERs, and the few experimental carbon storage projects did not have a sufficient scale to justify a claim). One major company with which I interviewed was successful in developing such projects, and the national company I interviewed, recognizing they did not have sufficient resources to manage such projects nor the scale to overcome the 'very high transaction costs' entailed, outsourced its CDM/JI opportunities to be managed by that successful major. All participants agreed that the main issue of convertibility was the administrative inertia of the process, which is bottlenecked by the need for third-parties to consult on the feasibility and 'additionality' of the project (which denotes the fact that it must seek emission reductions that would not have been realized under 'business-as-usual' conditions).

5.1.3   Incentives for profit maximization

A central question for the economic analysis of the issue of refineries' response to EU ETS is to understand what incentives did each participant face, and how well they aligned with profit maximization. Specifically, because of the use of grandfathering during the first phase of EU ETS, an interesting question is to understand whether or not managers recognized the full opportunity cost of carbon. The allocation process, because it hands out allowances for free to companies, tends to mask the fact that used allowances have an opportunity cost, and hence may distort marginal emissions choices by companies, leading to inefficiencies in

the carbon market.

In the companies I interviewed, the responsibility of maximizing profits and minimizing losses in the carbon markets through abatements and operational changes was decentralized to the Business Units. No centralized transversal responsibility for CO_2 was adjudicated, and carbon liabilities were treated only as an additional responsibility for plant managers. However, transversal programs have been undertaken, such as Energize at Shell (see section 4.3.2). Overall, however, notwithstanding the profits from speculation sought by some traders, the responsibility for profit maximization fell on the Business Unit Leaders (BULs) of refineries. The question of the recognition of the opportunity cost hence boils down to the incentives faced by BULs.

In all companies, the compensation was linked to the fulfillment of profitability objectives. Hence, incentives to reduce emissions and profit from the Emissions Trading Scheme were embedded in the general profitability of the plant, to which executive compensation is tied. However, the accounting policies of the major companies and of the national company I interviewed differed in a significant way: the majors allocate both carbon assets and carbon liabilities to the balance sheet of individual refineries, while the national company allocated liabilities at the Business Unit level and assets at the corporate level.

This has theoretically an important impact on the issue of the efficiency of the response of plants to the carbon price signal. A first potential issue is the fact that, whenever carbon assets and liabilities are consolidated at the BU level, free allocation masks the opportunity cost of allowances. This can lead to situations where managers don't recognize the opportunity cost of carbon because the cash cost is not significant enough to affect the profitability of operations. This is a sub-optimal outcome, because the marginal cost of carbon is not taken into account in the production decision of the plant.

Another potential issue is the 'updating' issue (Ellerman 2006). During all my interviews, executives showed a strong concern about the allocation process, and focused much more on the incentives for abatement stemming from the allocation mechanism rather than abatement incentives linked to carbon price. This corroborates the thesis that grandfathering flaws the incentives faced by managers. On the contrary, the solution adopted by the national company I interviewed likely insulated Business Unit Leaders from allocation-related perverse incentives.

Generally speaking, I noted through my interviews that the organizational structure of

oil and gas firms in response to EU ETS was marked by a strong discrepancy between the perception of traders, that are used to commodities markets, their opportunities for profit and the risks linked to them, and industrial managers whose focus relative to allocation trading is heavily weighted toward compliance. This observation confirms the conclusion that most plants focus on minimizing the costs of compliance rather than maximizing profits from the scheme. The next section analyzes the perception of the scheme by the industry, shows that most companies indeed act as cost-minimizers rather than profit-maximizers on the market for EUAs, and highlights the potential problems this could cause for the static and dynamic efficiency of the scheme.

5.2   Perception of the scheme by the industry

To understand the reaction of the refining industry to EU ETS, it was important to get a sense of which assumptions backed the executive decisions taken by the different stakeholders. One section of the interview questionnaire investigates the perception of the scheme by the industry, and its implication for the industrial actors.

The main finding of this survey is that firms act as cost minimizers rather than profit maximizers. This means that they simply seek to reduce the cash cost they incur in order to reach compliance, but do not seem to recognize the opportunity costs linked to grandfathered allowances. Another implication of this focus on the cash cost of compliance is that the allocation system can become a tool to create incentives for emissions abatement.

5.2.1   Sources of inefficiencies in EU ETS

The theoretical literature has recognized and analyzed several potential sources of inefficiencies and market failures linked to the design of EU ETS. Betz and Sato (2006), Kruger and Pizer (2004) and Pew Center on Global Climate Change (2005) provide the reader with an overview of the different theoretical issues at hand, and the sources of inefficiencies in the EU ETS. I report here the main sources of inefficiency relevant to the refining sector.

Static and dynamic efficiency of a cap-and-trade system

The case for cap-and-trade systems, and much of their political attractiveness, is based on the idea that they are theoretically the most cost-efficient way to achieve emissions

abatements while preserving political flexibility (Stavins 2007). From a static point of view, a cap-and-trade system allows firms with the lowest abatement costs to achieve them in priority, and allows firms facing high abatement costs to buy allowances from the market and hence mitigate the cost of the scheme. At the same time, it is possible to adapt the amount of allocation handed out for free to the different firms to pursue political objectives such as equity, without theoretically distorting the efficiency of the allowance market.

The sources of static inefficiencies are the same as with classical markets: issues of market power and transaction costs are the main sources of inefficiencies. Abuse of dominant position on the EUA market has not emerged as an important issue so far. Transaction costs, however, and specifically the cost of learning about the legal aspects of the scheme, and of accessing the market for allowances, have been frequently quoted as a major factor for small firms on the market for EUAs. Most of the plants in the refining sector are owned by integrated companies, which have the capability to manage the various aspects of such a cross-functional scheme; transaction costs of this type hence do not tend to arise for refineries on the market for EUAs. However, they were widely quoted as an important factor on the market for project-based emissions reduction allowances such as the Clean Development Mechanism or the Joint Implementation program CERs, that are granted only after a tedious process of certification overseen by the UNFCCC (Michaelowa et al. 2003). Finally, a last transaction cost, which impeded on the ability of firms to efficiently participate in the market for EUAs in the first phase, is the cost associated with learning about one's own emissions. The first phase of the scheme was instrumental in allowing the firms to adapt to the need to monitor their emissions and estimate their abatement costs, and such transaction costs have now mostly been overcome.

The dynamic efficiency of cap-and-trade systems is a more complicated issue. The problem of the dynamic effect of the scheme on innovation is discussed in details in the literature. One important debate concerns the impact of market-based instruments on abatement technologies innovation; the Porter hypothesis (Porter and der Linde 1995), or induced innovation hypothesis (Richard et al. 1999), purports that tighter environmental regulation is always efficient and actually creates profits, because it induces profitable innovations by the industry. Some commentators, on the contrary, question the premises of such a hypothesis (Karen Palmer and Portney 1995), and the largely spread idea that market-based instruments would be the most efficient instruments in inducing innovation. Hepburn

(2006) also discusses the specific impact of uncertainty in a market-based instrument setting such as EU ETS. Another important issue is that of dynamic incentives distortions linked to the policy design of the scheme, detailed by Betz and Sato (2006), Kruger and Pizer (2004) and Pew Center on Global Climate Change (2005): grandfathering and the 'updating dilemma', the provisions for new entrants and closures, and the restrictions on banking all create distortions of the dynamic efficiency of the scheme.

Finally, a last issue of great importance is the prevalence of social norms and conventions that may hinder economic agents from pursuing pure rational profit maximizing. The issue of the perception of EU ETS by the industry is important for the efficiency of the scheme exactly because firms may not perceive the scheme in a manner that enables them to seek profit maximization in this particular framework.

Grandfathering: how the allocation process distorts

Grandfathering refers to the current process of free allowances allocation to the industry, based on the historical production figures. Grandfathering distorts the dynamic efficiency of the cap-and-trade scheme because of the 'updating dilemma', the fact that, because of the clear and acknowledged link between prior output level and allowance allocation Ellerman and Buchner (2007a), firms may perceive that the less they abate their emissions in the pilot phase, the more allowances they may receive in the subsequent phases. This creates a strong incentive for firms not to abate their emissions, in order to receive more free emissions later on. Such negative incentives may counterbalance the incentives to abate emissions stemming from the cash and opportunity costs of allowances.

A solution to the 'updating dilemma' would ideally insulate the allocation of allowances from industrial production decisions. The solution to which the EU seems to head (European Commission 2008c) is to shift the allocation process to full auctioning, which would make CO_2 emissions decision based only on the allowances price, rather than the amount of EUAs allocated to the firm. As shown in the last section, some firms have managed to reach the same result by using differential accounting standards for carbon liabilities and assets; this may prove to be the best solution to enhance firms' response to the carbon price while capping the costs of the measure for the industry.

Entrants and closure provisions

Provisions for new entrants and closures, specifically the withdrawal of grandfathered allowances for closed installations, create perverse incentives to keep low-efficiency plants running (Ellerman 2006). Specifically, closing down an inefficient plant translates in the net loss of the net present value of the stream of allowances that was to be allocated to the plant. Such a provision hence creates an incentive for firms not to close their old and aging installations, even though it would be dynamically more efficient for the economy to remove these installations rather than invest in additional efficiency measures for the newest plants.

Banking restrictions

Finally, restrictions on banking, the ability for firms to transfer unused allowances from one period to the next one, have a distorting effect on the market for allowances. Ellerman and Parsons (2006) explain that in the absence of direct banking, or if the available banking channels available through the linkage directive (e.g. transformation of CERs in EUAs) are saturated, the price of allowances at the end of the period will either drop to essentially zero (in the case of an excess of allowances) or jump to the price of the contract for future delivery of allowances in the next period, plus the € 40 per ton of CO_2 of non-liberating penalty. Intra-period banking and borrowing of allowances had been initially incorporated in the EU ETS Directive as a provision to avoid price spikes and provide flexibility for compliance.

The European Commission decided that inter-period banking would also be authorized, if this was explicitly mentioned by the Member States' National Allocation Plans. For the first period, France and Poland were the only countries to incude banking provision in their NAPs. However, during the negotiations on the National Allocation Plans for the second period, and as it appeared that emissions would be lower than the amount of allowances initially allocated at the beginning of Phase I - which would cause a glut of allowances to be carried over to Phase II through the banking provision -, the European Union convinced both countries to withdraw the banking provision for the transition from Phase I to Phase II, a move that was interpreted as sacrificing price stability for the sake of environmental effectiveness. The impact of the banking constraints on EUA prices is thoroughly described by Alberola (2007).

Uncertainty

Finally, uncertainty on prices may create costs for firms that may seek the use of risk management instruments to hedge against the effect of potential price spikes (Kruger and Pizer 2004). The survey sought to understand how firms chose to face uncertainty, and the results are reported in the next section.

Firms perception

Finally, a last but potentially important source of imperfection is the way the companies respond to the price incentive. Last chapter showed that the pilot phase of EU ETS has been effective in creating a price signal and inducing industrials to build the capability to respond to it. However, the ability to understand and respond to the market does not imply that firms act as purely rational decision-makers, perfectly maximizing their profits and equating their marginal abatement cost curve to the price of allowances. Indeed, their response to the first phase of the scheme in terms of abatement has been so far very modest (see section 3.4.1), which raises the question of the economic efficiency of the scheme if participants do not realize all profits available from allowances trading.

The main finding of my survey of refineries to that regard is that the industry has focused mostly so far on the average cash cost rather than the marginal cost of compliance. The refining sector in general does not seem to recognize opportunity cost of allowances, but has so far generally focused on the allocation process and the minimization of the cash cost of compliance for the industry. This behavior is evidenced by the perception of the scheme as a regulatory burden rather than a market in which profit opportunities should be pursued.

The next section describes the inner workings of the organization structure devised by firms to respond to the EU ETS. The following section moves on to the perception of the various dimensions of the scheme by the industry, to conclude on this particular potential source of inefficiency.

5.2.2   EU ETS: regulatory burden or profit opportunity?

A question in the survey aimed at understanding whether companies saw EU ETS primarily as a regulatory piece of legislation, or rather as a market in which they could realize profits

by engaging in as much abatement as would prove economic given the price of carbon. I framed this section of the questionnaire as a multiple choice question.

> *Which of these statements is closer from the perspective of your company on the European Union Emissions Trading Scheme:*
>
> - 'What matters first and foremost is to focus on profits from the petroleum product markets, and to intervene in the EUA market only to the extent that is needed to ensure compliance'
> - 'What matters is to actively take advantage of all potential profits from the trading of EUA as long as they do not force changes in traditional refinery operations'
> - 'What matters first and foremost is to realize all profits possible from the production of petroleum products and the trade of EUAs, even if it entails modifications in the traditional operation of refineries'

An overwhelming majority of the participants responded that their company focused mostly on compliance to EU ETS, rather than on the potential profits they could seek. An alternative view of the same phenomenon, described by a trader, is that companies focus mostly on the containment of costs linked to EU ETS rather than maximizing their profits from the scheme. There was a strong sense during my interviews that companies perceive the grandfathered allowances as the 'allowed emission level'. This conception stems logically from the conceptual design of the scheme, whereby the act of producing gives rights to allowance allocation (through the grandfathering process, and the provisions for closures and new entrants). However, it is strongly tangential to the lack of recognition of the opportunity cost of allowances across the industry. The industry association analyst pointed out that the need to increase management awareness of the opportunity cost of allowances is of concern to the regulators, and constitutes an important argument for auctioning.

A strategist at one company mentioned that the three features of the scheme that shaped the operational response of the industry were the absolute price of the emission credits, the amount of grandfathered allowances they received, and the refining margin. Namely, in a high margin environment, such as the current one, the impact of the carbon price on operations would be lower than in a low margin environment. This fits very well with the observed emphasis on cash cost rather than opportunity cost of allowances. Moreover,

the amount of grandfathered allowances should have no impact on operational choices if companies recognized the opportunity cost of allowances.

The study of the perception of the scheme as a regulatory burden rather than a profit opportunity draws three conclusions. First of all, the refining sector in Europe seems to focus on minimizing the cost of compliance rather than profiteering from the market for EUAs. This has a potential hindering effect on the efficiency of the scheme. Secondly, industry does not recognize the opportunity cost of allowances, and focuses only on the cash cost incurred. This is strongly in line with the observed cost-minimizing behavior. Finally, the industry seems to focus much more on their benefits from the allocation process than from potential abatements they could undertake. We delve into the subject of the perception of the allocation process in the next section.

5.2.3 Perception of the allocation system

The vision of the allocation process by the industry is particularly interesting in the context of the focus on decision makers on cost minimization. For example, In one of the most revelatory interviews I conducted, refining strategists repeatedly alluded to their allowances allocations as 'the emissions objective' they faced. Again, this reveals a mindset geared toward minimizing the regulatory burden rather than maximizing the profits from the scheme.

Grandfathering creates perverse incentives against energy efficiency improvements

One participant described the historical output-based allocation system as perverse because it creates negative incentives to invest in energy-efficiency improvements. Most of such improvements involve the debottlenecking of some processes inside the refinery, and result from the process capacity increasing more than the related energy expenditure. This means that most energy efficiency improvements involve capacity increases. For example, improvements in distillation preheating increase the inflow of crude oil and lead to a better energy efficiency. However, with quotas linked to historic production, hence not changing with the increased capacity, firms would face a net cash cost, because of the incremental emissions not being compensated by free allowances. If firms individually focus on their cash costs rather than the opportunity cost they face, some energy efficiency investments

won't be realized.

The rules for new entrants and the decision to put the emissions reduction burden on the power generation sector creates additional risks for investment in new facilities. This may deter firms from pursuing potential abatement investments when they involve new industrial entities. For example, one company revealed that they had studied an investment in a Cogenerated Heat and Power plant to meet the power needs of one of their refineries, but that the project was abandoned due to concerns over the amount of allocation that would be freely allocated to the plant. Because the burden of reductions has been placed over the electricity sector, the new plant was moreover likely to receive less allocations than under the refining sector. The team decided that the regulatory risk and the subsequent cash cost that they may incur were too high, and stuck to the external procurement of their power needs. Such energy-intensity improvements are not rewarded either in the current allowances allocation framework.

The industry calls for benchmarking to solve these issues. Several participants argued taht without moving to an intensity-based mechanism, it would be possible to incorporate some element of benchmarking in the current scheme. For example, the Benelux governments have designed such a system for refineries. They tie the reduction of free emissions allowances allocation to refineries to the energy efficiency of the plants, assessed based on the internationally recognized Solomon energy-efficiency scale. The first decile faces a smaller reduction of its grandfathered allowances from phase I to II (Belgian NAP 2006).

Current allocation plans are viewed as unfair

Some members of the industry expressed complaints about the fairness of the current distribution of allowances among firms. For example, according to some executives, strikes in France during 2004 and 2005 have meant that the emissions chosen as a baseline for allocation were lower than what they ought to have been.

Moreover, the grandfathering system used today does not reward the early efforts of emissions reductions, a feature about which the industry complains significantly. There seems to be a noted preference for benchmarking among industrials, which would indeed correct this flaw, and provide further incentives to reduce emissions, as pointed out by some interviewees.

A last complaint that emerged from interviews relates to the overall amount of CO_2

emissions allowances allocated itself, and the downward path it will likely take. Some participants fear that the additional future emissions that will stem from the tighter sulfur content regulation is not taken into account by the European Commission, and claim that this is unfair for their industry compared to others in the system.

Industry fears the effects of auctioning

On the question of auctioning, the industry seems divided. The chief economist I was able to meet had publicly called for an auctioning system, with revenue recycling, arguing that overall this would be good for the national economy as it could alleviate economic constraints with a distortion effect, such as payroll taxes. Most participants have already, or will during the second phase of the scheme, take part into public auctions, as a way to learn about the mechanism at play, and to take part in the revelation of the EUA market price.

However, most analysts and strategists I met were scared by the effects of auctioning. They seemed particularly concerned by the lack of clarity over the way the auction mechanism will be managed by the European Union and its Member States. It is still unclear how such auctions would unfold, whether or not they would be compulsory, and if non-industrial participants such as banks and hedge funds would be allowed to participate. Moreover, the recently released draft for the revision of the Directive 2003/87/EC (European Commission 2008c) has clarified the principles on which the amount of allowances to be grandfathered the amount to be sold through auctions will be based on, but leaves out some room for exceptions, as it will depend on the findings of the European Commission pertaining to the vulnerability of the sector to the competitiveness impact of EU ETS.

Overall, the industry seems to fear auctions, and considers the full-auctioning case to which the European Commission is heading as the worst possible case for their industry, which is perfectly understandable as the sector would hence incur 100% of the cash cost of allowances.

5.2.4 Regulatory uncertainty

An important question for the evaluation of the long run impact of carbon constrains on investment is understanding the effect of uncertainty. Two main types of uncertainty are recognized by the industry. Economic uncertainty pertains to the volatility of the price of

allowances under ETS, and the inflated probabilities of large outliers in price movements, as evidenced by the April 2006 sudden decrease in prices caused by the revelation that member countries were reporting lower than expected emissions. Regulatory uncertainty, consisting in potential modifications of policy design of the carbon emissions regulation scheme by the European Commission, or sudden changes in the rules of allocation of the allowances by Member States. Moreover, market's sheer existence depends on regulatory decisions by the European Commission. Hence, 'there is always the risk that fickle politicians might change the rules of the game' (The Economist 2007b), which would affect the market price for allowances.

The views of the participants to the survey on uncertainty were broadly split. The strategist at company B cited uncertainty on regulatory frame as a driver for inaction during Phase I. Refinery strategists and regulation compliance managers also cited uncertainty on the allocation mechanism, and the move by the European Commission to ban banking as the end of Phase I approached. As explained above, uncertainty has however been largely resolved in the last draft design for the allocation process of EU ETS during the two Kyoto commitment phases, 2008-2012 and 2013-2018 (European Commission 2008c).

Overall, the main concern for the industry is that the length of the investment cycle and the lifetime of assets in refining are such that they exceed the length of the current planned periods of ETS. This raises concerns about the consistency of the regulatory framework across time, and about the credibility of the regulator to commit to a level of emissions reduction path that keeps the price of allowances close from the current levels. The overturn by the European Commission of the initial French and Polish decisions to allow inter-period banking between Phase I and II was generally pointed at by the industry as an example of *ex-post* adjustments that undermined their confidence in the consistency of such features of EU ETS across time. Another example involves a refinery that had reached an agreement with the national allowances allocation authority so as to benefit from a allowances allocation that would stay constant across phase II, which was motivated by technico-economic circumstances; but the European Commission overruled the initial Member State's plan and made it similar to the allocation of other refineries. Overall, such adjustments undermine the credibility of the Commission to commit to a specific allocation design on the long run.

Another common negative conception about the economic uncertainty inherent to the scheme is that engaging in profit-seeking in the EU ETS framework leads to excessive ex-

posure to carbon price volatility. A team of refining strategy executives I interviewed, when asked about potential profits from EU ETS, stated explicitly that they are not mandated to engage in profit seeking by replying that 'it is not our job to speculate'. They pointed at the example of Rhodia, a specialty chemicals company which had invested in very profitable Clean Development Mechanisms, that involved reductions in emissions of nitrous oxide (N_2O) in two plants in Korea and Brazil (see the registration form for the Korean project: United Nations Frame Convention on Climate Change (2005)). Because N_2O has a very large Global Warming Power (a ton of N_2O is equivalent to 310 tons of CO_2), the €20 million investment yielded 15 million CERs (Meisen and Cote 2006). Because of the expectations of profits linked to the sale of these CERs on the EU ETS market, the company's stock price became strongly tied to the price of carbon emmission allowances. Rhodia spectacularly lost 17% of its stock value in a few days in the wake of the EUA price drop of April 2006 (Agence France Press (2006). In the eyes of the managers with whom I interviewed, this supported the view that bold positions on the carbon markets entail too much exposure to carbon price volatility.

However, many interviewees, especially traders, asserted that uncertainty in the carbon market was overstated, and that in reality it was of the same order of magnitude as the financial volatility of other commodities which oil and gas companies are used to rely on for their operations. Moreover, the degree of regulatory risk is arguably lower than other regulatory risks faced by oil and gas companies in some of the petroleum producing regions of the world. The main opinion among industrials is that carbon prices are here to stay under a form or another, and must be seriously taken into consideration when planning for investments. This last point is highly consistent with the fact that all companies interviewed have taken the expected price of carbon into account in their operations and their investment planning processes. Complaints over the uncertainty that remained at the time of the survey over the allocation process in the next periods were hence founded only to the extent that the process would determine windfall profits or losses for these companies, but should not have changed their response to the carbon price if companies acted as profit maximizers and fully recognized the marginal opportunity cost of allowances.

5.3 Conclusion: firms' perceptions and inefficiencies

As a conclusion, the firms' perception of the scheme are split, with some firms setting up incentives that help managers take the full opportunity cost into consideration, and most others failing to do so. However, the fact that the organizational structure of firms can have a significant impact on their perception of the scheme is a very interesting finding, as it provides a potential avenue for improvement of the economic outcome of EU ETS.

Regarding the different sources of inefficiency linked to the design of the scheme, the study of the refining sector provides researchers with concrete examples where these sources of inefficiency have played a role. On the side of uncertainty, it is interesting to note the gap between the perception of traders, who tend to see carbon price risk as well within the bounds of what the oil and gas industry is used to deal with, and the perception of managers who balk at the regulatory risks they face under this scheme. The allocation process is also very interesting insofar as it reveals the focus of the firms on cash cost minimization, and their lack of awareness of opportunity cost.

The main finding of the survey is definitely that, even though firms have developed the capability to monitor carbon emissions, assess abatement opportunities and factor in the price of carbon in short term scheduling decisions, they do not act as profit-maximizers on the EUA market yet. As one strategist summed it up, the key features of the scheme for industry are 'the absolute value of the emission allowances, the amount of grandfathering, and the industry margin'. With low margins, the carbon costs would have a strong impact on refinery operations and investment; under a high margin environment, it has indeed had a very low impact. Such a statement does not make sense unless one thinks of refineries as trying to minimize the cost burden created by regulation. I conclude that, with regards to EU ETS, refining companies act as a regulatory cost-minimizers, focusing on compliance, rather than benefit maximizers seeking to profit from the scheme.

Part III

EU ETS Phase II and beyond

Chapter 6

Policy design: learning from the refining sector

The former section has presented in detail the different dimensions of the reaction of the refining sector to the introduction of the European Union Emissions Trading Scheme, by analyzing the quantitative data available from the first two years of the scheme, and the qualitative information retrieved through a survey conducted at the end of the pilot phase. This chapter builds on this analytical work to suggest avenues of improvement and future directions of research.

6.1 The way ahead: the future of carbon markets

This *ex-post* study of EU ETS intervenes at a breaking point in the history of carbon markets. With the EU ETS at their helm and as lead example, several regions, countries and states in the world have expressed a deep interest in carbon markets, and may pass legislation to that effect in the coming years.

In the U.S., the Regional Greenhouse Gas Initiative (RGGI), the U.S. Northeastern State-led cap and trade system, has gained momentum as more and more States have joined the group. Such a model of grassroots organization, designed to be flexible enough to easily accommodate new States in the system as the pressure from the constituency pushes new members to join, could prove very powerful and end up playing a dominant role at the national and international level. The Western Regional Climate Action Initiative, backed by California and Western States, aims at replicating the same model in the months

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Table 6.1: Overview of the Carbon Markets in 2006 (King 2008)

Category	Volume (MtCO$_2$e)	Value (USD Millions)	% of value
Project-Based			
Clean Development Mechanism	475	5,257	17%
Joint Implementation	16	141	1%
Other	17	79	0%
Emissions Trading			
European Union	1,101	24,357	81%
New South Wales + ACT	20	225	1%
Chicago Climate Exchange	10	38	0%
Total	1,639	30,097	100%
World emissions in 2003	27,500		

to come. The involvement of John McCain (R-AZ) in the design of a draft bill for a national cap-and-trade system, as well as the presidential platforms of Hillary Clinton (D-NY) and Barrack Obama (D-IL) have fired up expectations that a federal legislation may be on its way after the campaign.

Other countries and regions of the world are moving as well. For example, New South Wales, a region in Australia, started a cap and trade program in 2003. Canada passed a bill setting up an intensity-based system in 2007. Numerous countries have expressed their interest in such schemes as well. Finally, non-Annex I countries have well understood the potential profits from Clean Development Mechanism and other project based carbon permits program developped under the Kyoto architecture.

King (2008) and Capoor and Ambrosi (2006) summarize the state of the carbon markets in the world, the volume of CO$_2$ at stake and the value of the permits at prevailing market prices in 2006 in table 6.1.

As a vast number of regional and national initiatives are being discussed across the world, Victor et al. (2005) posits that this diversity in policy designs and approaches, rather than being an impediment to the efficient integration of these markets, will supply the political goodwill necessary to link these markets together, and act as a laboratory of policy designs similar to the U.S. federalism for State legislation. The most likely alternative scenario seems to be the emergence of a global top-down carbon trading scheme, which the authors deem as an impediment to the emergence of the most efficient policy designs. In either case, however, drawing on the lessons of the past - and specifically of the most ambitious system so far, the European Union Emissions Trading Scheme - will be key to the success

138

and further development of cap-and-trade systems worldwide. This chapter synthesizes the most important conclusions from the analysis of the refining sector under EU ETS, to inform the debate on policy design choices that EU ETS will have to resolve in the next years, and the further global development of carbon cap-and-trade systems. Finally, the last section presents concluding thoughts on the future of the petroleum industry in the middle to long run in a carbon constrained world.

6.2 Lesson 1: The allocation process largely determines the success of the scheme

A major lesson from the first three years of this scheme is that the hardest policy design issue is not setting up a trading infrastructure and enabling trade to enhance the price revelation mechanism, but to set the allocation system right in the first place.

Chapter 4 and 5 emphasized on the perverse effects of grandfathering as a paradigm for allocation, such as updating, and the distortions of the necessary new entrant provisions that come with grandfathering. A solution to the main issue of the grandfathering system would be auctioning, as it would force companies to take the full cash cost of carbon into account when making production, abatement and investment decisions. Auctioning sets incentives right at the level of a plant, as it forces the attention of management on the opportunity cost of carbon allowances, which may not have been recognized otherwise. Indeed, the European Commission has recognized the problem of updating and the lack of recognition of opportunity costs, and the latest policy design draft for the next phases of the scheme has laid the way to a transition to full auctioning (European Commission 2008c).

Auctioning presents numerous other advantages beyond the mitigation of the updating dilemma. Hepburn et al. (2006) argue that auctioning need not *in aggregate* have a negative impact on competitiveness, as the revenue from auctions could be redistributed to companies as compensation under the form of looser constraints on the economy. Moreover, they argue that auctioning could lead the way to a border-adjustement tax that would be legal under WTO.

However, because it involves charging companies for the full cost of carbon, auctioning exacerbates fears of negative competitiveness impact and carbon leakage. The potential

for revenue recycling does not change the fact that industries that are exposed to adverse economic impacts will be in a losing situation. Moreover, the decision whether or not to consider individual sectors as subject to threats of competitiveness loss will be bitterly disputed, as companies will have a very high cash cost stake in the process.

A lesson that stems from the series of interviews is that the response of plant managers to the carbon price can be improved through organizational change alone. Without auctioning and its potential economic and political costs, policy makers could use organizational and accounting tools to devise an allocation mechanism that helps set the right incentives for abatement without imposing the burden of auctioning to firms.

A first option for policy makers is to take advantage of the strong focus of the industry on allowances allocation, to artificially correct the incentives to abate emissions that may not be properly recognized through the channel of opportunity cost alone. The example of benchmarking for the refining sector in the Netherlands comes to mind. The national allocation plans could specifically target sectors of the economy that do not recognize opportunity costs well, based on econometrics evidence, and, through a mechanism inspired from the Dutch benchmarking scheme, increase their incentives to abate and recognize the marginal costs of carbon.

Another powerful option at hand is to implement at a broad level the differential accounting standard that the national company I interviewed had devised. Namely, by allocating carbon liabilities (plant-level CO_2 emissions) at the level of the individual Business Units on the company balance sheet, while allocating carbon allowances to the headquarters of the holding, one can separate the allocation mechanism from the economic incentive to abate emissions. This means that Business Unit leaders face the full cost of carbon allowances while having no stake in the updating process of the closures and new entrant allowances allocations provisions. It forces managers to take the full opportunity cost of carbon into account, without creating flawed incentives linked to the allocation process. This is nicely symmetrical to the point made by Stavins (2007) about carbon markets, that separate equity considerations (allocation) from the price forming mechanism (efficiency).

As a conclusion, it is utterly important for Member States and the European Commission to set the allocation process right, and to balance competitiveness losses with the improved welfare stemming from properly set carbon price incentives. I suggest for further research the study of such non-cash cost mechanisms that could set the correct incentives without

forcing additional costs on firms.

6.3   Lesson 2: Industry preparation is key

Another important conclusion of this study of the refining sector under ETS is the importance of capability building, in order for firms to develop an adequate response to the introduction of carbon markets. For example, the behavioral adaptation of a firm to the introduction of a price for carbon builds on the following capabilities:

- Monitoring and measuring emissions accurately, and improving the accuracy of reporting across time.

- Integrating the financial auditing and the regulatory relations function to manage allowance ownership and compliance.

- Internalizing the spot price of carbon at all stages of production.

- Setting-up or updating the strategic outlook team to incorporate carbon price evolution scenarios in the strategic thinking of the firm. Specifically, this calls for the ability to distill down the different relevant scenarios to a sensible hypothesis on prices evolutions, to be incorporated in valuation and risk assessment computations for future investments.

- Assessing the carbon emissions abatement opportunities at the level of a plant and assessing their financial value based on price scenarios.

- Developing the capability to trade allowances efficiently, and if need be to manage financial risk through derivative instruments

- Developing the capability to earn project-based credits, which relies on transversal capacities such as project management and finance, public relations with the host country and the credit granting authorities, and operational capacities.

- Integrating the trading desk and the operational planning units.

For EU ETS, the opportunity to prepare firms upfront to this process has already elapsed. The learning curve for private firms has been especially steep because of the short time frame over which the Directive has been drafted and implemented (Pew Center on

Global Climate Change 2005), which explains why three years after the scheme, one of the burning issues for refiners was still to increase the accuracy and reduce the uncertainty over emissions monitoring. As firms are still learning on the spot some of the aspects of carbon markets, especially linked to the evolutions of its price in the long run (sometimes with substantial amounts of pain, as illustrated by the EUA price crash in May 2006), some opportunities remain for the Commission to help firms improve their response to the scheme. This study suggests that firms could learn from the experience of each other, and share best practices over these different aspects. I would suggest the creation of European-level organizations and trade associations on the basis of the example set by the French Caisse des Depots et Consignations' 'Club Tendances Carbone', which regroups researchers, academics and industrials who share insights on the developments in the carbon markets and best practices in carbon management.

For the next carbon market-based instruments potentially coming on-line, the example of the EU ETS sets a compelling example that preparation is much needed to avoid two pitfalls: over-allocation linked to flawed reporting stemming from excessively short reporting deadlines prior to the beginning of the scheme, and irrational exuberance on the carbon markets linked to a lack of recognition of such mechanism and the characteristics of the fundamental drivers of carbon markets, which lead to asset bubbles and crashes. Regulators and companies hence have a stake in preparing well in advance of the possible introduction of a scheme.

For companies that could potentially be impacted by the developing systems, I suggest the following three-fold course of action:

- Prepare workforce and start diffusing the new mindset of carbon emissions awareness

- Start monitoring emissions of greenhouse gases

- Conduct thorough audits of the abatement opportunities at hand

The costs of tracking down and monitoring emissions are usually limited compared to the benefits that increased energy efficiency awareness can bring to firms in the heavy industry sector. Moreover, starting today to build up the capability needed to respond to a potential future carbon market will provide firms with an edge over their competitors.

For governments and regulatory bodies, the consequence of this observation is that they should start today to encourage firms to build the capability to respond to a potential

carbon market. If the regulatory bodies posit that it is likely that sooner or later a market-based carbon management instrument is to be set, it makes sense to push the industry to start preparing for it. Moreover, as emphasized above, monitoring greenhouse gas emissions and the potential sources of abatements is relatively cheap compared to the potential benefits it could bring to firms by putting the focus on missed energy efficiency improvement opportunities. As a conclusion, preparation of the industry and the regulators is paramount to the success of the scheme.

6.4   Lesson 3: Interaction issues are a major constraint

Another lesson from the study of the barriers to investment abatement in the refining industry under EU ETS is the notion that interaction issues are a major threat to the efficiency of carbon markets. It is a staple of political science and regulatory studies that one major impediment to the efficiency and effectiveness of government regulation of the market is the tendency of policies to lead to unintended consequences (Grabosky 1995). The obvious example in this case is the interaction between the EU ETS, which creates incentives for firms to decrease their greenhouse gases emissions, and the tightening sulfur content regulations that will force refineries to emit more CO_2 as they utilize hydrodesulfurization units at higher rates.

The lesson for designers of future carbon markets is that it is of the utmost importance to map out the potential interaction issues that may arise. Policy makers should make clear how they strike the balance between competing environmental and regulatory goals when such conflicts appear, and upfront preparation is key in order to set such risks aside.

6.5   Lesson 4: Flexibility and credible commitment are both valuable for firms and policy makers

A last important lesson is the fact that regulators must strike a difficult balance between flexibility and credibility in order for the carbon markets to prove a successful regulatory tool.

Credibility and a long term horizon on the price of carbon and the likely policy design features of the next phases are extremely important for firms, especially in the heavy indus-

tries that fall under EU ETS, because of the long time cycles of their investment schedules. It is hence important for the regulator to set a clear path forward, especially in terms of the allocation mechanism that will be adopted, and the cap that will be imposed upon the industry.

On the other hand, however, a rigid approach to policy design raises the risk that companies incur excessive costs, or that the scheme's environmental efficiency be undermined. Allowing the banking of allowances across trading periods, for example, could allow firms to monetize their early abatements, and would improve the volatility of the carbon market during interface periods, as described by Ellerman and Parsons (2006). Increased convertibility of carbon permits from other schemes and programs into EUAs would also help firms meet their emissions allowances purchases requirements in the next phases, as the cap tightens. Moreover, a link between EUAs and CERs or other 'carbon currencies' would have a very positive effect, as it would help to smooth the price curve and help firms acquire allowances outside EU ETS. Such provisions would also obviously have to be restricted, so that they do not undermine the environmental effectiveness of the scheme.

The lesson from the study of the industry's response to EU ETS is hence that flexibility and commitment are both in high demand from the industry and ought to be provided in a balanced fashion by the regulator.

6.6 Concluding thoughts: the future of petroleum in a carbon conscious world

As a conclusion, I would like to open a window on the future of petroleum in a world dominated by global warming concerns and political constraints on carbon emissions. In the long run, three main forces shape the evolutions of petroleum markets. First, in the middle run, the main challenge for the industry will be to bridge the gap between the existing refining tool and the evolving demand for petroleum products. The second force shaping the sector will be the stringency of regulation and carbon policies. Finally, the ultimate factor that will determine the outlook for oil over the next 50 years is clearly technology. The tensions between fossil fuel based energies and new emerging technologies will likely shape the landscape of energy for the decades to come. In the end, when the dust settles, technology will most probably be the ultimate economic driver that will seal

the fate of petroleum in either direction.

As emphasized by Fatih Birol, the vocal Chief Economist for the International Energy Agency, refineries have to rise up to the triple challenge of increasingly light demand, increasingly heavy crude feedstock, and tightened environmental constraints, while projected demand will rise sharply in the next decades (Birol 2006). The match between demand and supply is threatened by three factors. The first and most important one is the change in geographical patterns of demand. Economic development in China and South East Asia is widely believed to remain strong and drive increases in petroleum products consumption worldwide IEA (2005). However, global changes in the nature of petroleum products are also close to marketability horizon. The rise of bio-fuels could deeply alter the structure of petroleum refining and petroleum product markets. Finally, as the world crude oil production shifts toward heavier products and lighter demand, the stress on conversion capacity will call for additional investment and increased awareness of carbon emissions.

Regulatory evolutions have the potential to significantly alter the financial outlook for the refining industry. Of course, greenhouse gas policies will play an important role in the further development of the industry. Of the utmost importance, in this struggle between the Madisonian vision of carbon markets and the global leadership sought by some proponents of a global system Victor et al. (2005), will be the fate of 'upstream' systems as the Bingaman and Specter (2007) draft bill, which could impose a much higher carbon cost on oil and petroleum product, as refineries would be accountable not only to their process emissions but also to the CO_2 emissions stemming from the end use of their products. Imbalances in the development and stringency of carbon regulations across regions of the globe could also lead to carbon leakages, that may have an impact on the long run demand for petroleum products. More importantly, the interaction between carbon regulations and other environmental standards such as sulfur content or other quality restrictions may impose high costs on the oil and gas industry.

Finally, the most important force shaping the future of the industry is the rise of substitutes and complements to petroleum products. Some solutions already appear at a reasonable distance from commercialization. While hydrogen fuel cells are widely believed to remain at too high a cost point to reach a critical scale in the future, electrical vehicles, such as the ones developed by Tesla Motors, are bound to hit the road in important numbers in the next years, in urban settings as a first step, and maybe at a larger scale lately, depending

on advances in battery or super-capacitor technologies. Middle-run technologies that complement the use of oil, such as ethanol or hybrid vehicles are already reaching widespread early stage development and penetration of the fleet. Such technologies also have the potential to be used in other applications, and the major aircraft constructors have experimentally demonstrated the capacity of their planes to fly on bio-fuels. However, advances in refining and exploration & production techniques have the power to dramatically shift the long run outlook for oil. The jury is still out on the potential of new technologies to extend further the supply of crude oil and petroleum products, and that of renewable energies to offer a meaningful alternative to oil.

* * *

I draw two main conclusions from this thesis on the impact of carbon constraints on petroleum. From the point of view of carbon markets, I realized during the course of this study that EU ETS is an incredibly rich laboratory to understand how companies react to the introduction of carbon prices, and how policymakers can improve the efficiency and the effectiveness of their designs. It is a passioning subject for further research in applied economics.

My second conclusion is that the issue of the economic impact of carbon constraints on the oil markets is bound to remain central to the geopolitical developments of our world over the next decades. On a personal basis, I strongly believe that the effervescence of inventors, investors and early-stage ventures in the 'clean tech' area has the potential to last and achieve large-scale results way beyond the next period of low oil prices, if such a period indeed lies in front of us. However, research and innovation in the oil production sector still has the potential to bring a large amount of additional oil supply.

What is believed to be the main challenge lying ahead for our generation, global warming and its consequences, has its roots deeply intertwined at the intersection of carbon policy and petroleum technologies. The events unfolding in this space for the next 50 years will very likely shape the story of our world in the 21st century, and promise to be an enthralling and passioning human endeavor.

Appendix A

List of refineries

A.1 Plant location and ownership

Sources for this section: Oil & Gas Journal (2008) and CITL (2008).

#	Country	Refinery name	Company
1	Austria	OMV Raffinerie Schwechat	OMV AG
2	Belgium	Esso Raffinaderij Antwerp	ExxonMobil Refining Supply Co.
3	Belgium	Belgian Refining Corporation Antwerp	Belgian Refining Corporation NV
4	Belgium	Total Raffinaderij Antwerpen	Total
5	Belgium	Petroplus Refining Antwerp	Petroplus Holdings AG
6	Belgium	Petroplus Refining Antwerp Bitumen	Petroplus Holdings AG
7	Czech Republic	Paramo Pardubice Refinery	Paramo AS
8	Czech Republic	Paramo Kolin Refinery	Paramo AS
9	Czech Republic	CRC Litvinov Refinery	Czech Refining Company
10	Czech Republic	CRC Kralup Refinery	Czech Refining Company
11	Denmark	Shell Raffinaderiet Fredericia	Dansk Shell
12	Denmark	Statoil Raffinaderiet Kalundborg	Statoil
13	Finland	Naantalin Erikoistuotejalostamo	Neste Oil Corporation
14	Finland	Porvoon Jalostamo	Neste Oil Corporation
15	France	Total Raffinerie de Normandie	Total
16	France	Total Raffinerie de Feyzin	Total
17	France	Total Raffinerie de Donges	Total
18	France	Total Raffinerie de Provence	Total
19	France	Total Raffinerie de Grandpuits	Total
20	France	Total Raffinerie des Flandres	Total
21	France	SARA Raffinerie des Antilles	SA de Raffinage des Antilles
22	France	SRD Raffinerie de Dunkerque	Societe de la Raffinerie de Dunkerque
23	France	Esso Raffinerie de Port Jerome/Gravenchon	ExxonMobil Refining Supply Co.
24	France	Esso Raffinerie de Fos-sur-Mer	ExxonMobil Refining Supply Co.

#	Country	Refinery name	Company
25	France	Shell Raffinerie de Berre	Shell
26	France	Shell Raffinerie de la Courrone	Couronnaise de Raffinage
27	France	Shell Raffinerie de Reichstett	Cie Rhenane de Raffinage
28	France	Ineos Raffinerie de Lavera	Ineos
29	Germany	Shell Rheinland Raffinerie	Shell Deutschland GmbH
30	Germany	Shell Hamburg Raffinerie	Shell Deutschland GmbH
31	Germany	Total Bitumen Raffinerie Brunsbuttel	Total Bitumen Deutschland GmbH
32	Germany	Total Raffinerie Spergau	Total Raffinerie Mitteldeutschland GmbH
33	Germany	Mineralölraffinerie Ingolstadt	Esso Deutschland GmbH
34	Germany	Raffinerie Salzbergen	HR Chemisch-Pharmazeutische Spezialitaten GmbH
35	Germany	Schmierstoffraffinerie Neuhof	HR Oelwerke Schindler GmbH
36	Germany	Mineraloelraffinerie Oberrhein	MiRO
37	Germany	PCK Raffinerie Schwedt	PCK
38	Germany	Ruhr Oel Raffinerie Gelsenkirchen	Ruhr Oel Gmbh
39	Germany	ERE Raffinerie Lingen	ERE Betriebfuhrungsgesellschaft GmbH
40	Germany	Mineralölverarbeitung Burghausen	OMV Deutschland GmbH
41	Germany	Bayernoil Vohburg/Ingolstadt/Neustadt Raffinerie	Bayernoil Gmbh
42	Germany	Holborn Raffinerie Hamburg	Holborn Europa Raffinerie GmbH
43	Germany	Wilhelmshaven Raffinerie	Wilhelmshavener Raffineriegesellschaft GmbH
44	Greece	Aspropyrgos Refinery	Hellenic Petroleum SA
45	Greece	Thessaloniki Refinery	Hellenic Petroleum SA
46	Greece	Eleusis Refinery	Hellenic Petroleum SA
47	Greece	Corinth Refinery	Motor Oil Hellas
48	Hungary	MOL Szazhalombatta Refinery	MOL Hungarian Oil and Gas Co.
49	Ireland	ConocoPhillips Whitegate Refinery	ConocoPhilipps
50	Italy	Raffineria di Sannazzaro	AgipPetroli SpA
51	Italy	Raffineria di Venezia	AgipPetroli SpA
52	Italy	Raffineria di Livorno	AgipPetroli SpA
53	Italy	Raffineria di Taranto	AgipPetroli SpA
54	Italy	Raffineria di Gela	AgipPetroli SpA
55	Italy	Raffineria di Milazzo	Raffineria di Milazzo SpA
56	Italy	ERG Nuove Centrali - Impianti Sud	ERG NuCe
57	Italy	ERG Nuove Centrali - Impianti Nord	ERG NuCe
58	Italy	Raffineria Isab Impianti Nord	ERG Med
59	Italy	Raffineria Isab Impianti Sud	ERG Med
60	Italy	Raffineria di Roma	Raffineria di Roma SpA
61	Italy	Raffineria di Augusta	ExxonMobil Refining Supply Co.
62	Italy	S.A.R.P.O.M S.p.A.	ExxonMobil Chemical

#	Country	Refinery name	Company
63	Italy	Raffineria di Mantova	IES Italiana SpA
64	Italy	Raffineria Api di Falconara Marittima	Api Raffineria di Ancona SpA
65	Italy	Raffineria di Busalla	Iplom SpA
66	Italy	Saras SpA	Saras SpA
67	Italy	Raffineria di Cremona	Tamoil Raffinazione SpA
68	Lithuania	Naftos perbirbimo gamykla	AB Mazeikiu Nafta
69	Netherlands	ESSO Raffinaderij Rotterdam	ExxonMobil Refining Supply Co.
70	Netherlands	Kuwait Petroleum Europoort B.V.	Kuwait Petroleum Europoort BV
71	Netherlands	Netherlands Refining Company B.V.	BP
72	Netherlands	Shell Nederland Raffinaderij BV	Shell Nederland Raffinaderij BV
73	Netherlands	Total Raffinaderij Nederland NV	Total Raffinaderij Nederland NV
74	Netherlands	Koch HC Partnership B.V.	Koch HC Partnership BV
75	Poland	Lotos Gdansk/Jedlicze Refinery	Grupa Lotos SA
76	Poland	ORLEN Plock/Trzebinia Refinery	Polski Koncern Naftowy ORLEN S.A.
77	Portugal	Refinaria do Sines	Petróleos e Gás de Portugal SGPS SA
78	Portugal	Refinaria do Porto	Petróleos e Gás de Portugal SGPS SA
79	Slovakia	Slovnaft, a.s.	Slovnaft Joint Stock Co.
80	Spain	Repsol Petróleo Cartagena	Repsol YPF SA
81	Spain	Repsol Petróleo Tarragona	Repsol YPF SA
82	Spain	Repsol Petróleo La Coruna	Repsol YPF SA
83	Spain	CEPSA Tenerife	Compania Espanola de Petroleos SA
84	Spain	Repsol Petronor Industrial Complex	Petroleos del Norte SA
85	Spain	BP Castellon	BP
86	Spain	Repsol Petróleo Puertollano	Repsol YPF SA
87	Spain	CEPSA Cadiz	Compania Espanola de Petroleos SA
88	Spain	CEPSA Huelva	Compania Espanola de Petroleos SA
89	Sweden	Preem Göteborgs Raffinaderiet	Preem Petroleum
90	Sweden	Preem Scanraff Raffinaderiet	Preem Petroleum
91	Sweden	Nynas Göteborg Raffinaderiet	Nynas Petroleum
92	Sweden	Nynas Nynäshamns Raffinaderiet	Nynas Petroleum
93	Sweden	Shell Göteborgs Raffinaderiet	Shell
94	United Kingdom	Eastham Refinery Ltd	Eastham Refinery Ltd
95	United Kingdom	Petroplus Refining Teesside Ltd	Petroplus International NV
96	United Kingdom	Total Milford Haven Refinery	Total UK Ltd
97	United Kingdom	Total Lindsey Oil Refinery	Total UK Ltd
98	United Kingdom	BP Coryton Essex Refinery	BP Oil UK Ltd
99	United Kingdom	ConocoPhillips Humber Refinery	ConocoPhilipps
100	United Kingdom	Esso Fawley Refinery	Esso Petroleum Company Ltd
101	United Kingdom	Texaco Pembroke Refinery	Texaco Ltd
102	United Kingdom	Shell Stanlow Manufacturing Complex	Shell UK Oil Products Ltd
103	United Kingdom	Nynas UK AB Dundee Refinery	Nynas UK AB
104	United Kingdom	BP Grangemouth Refinery	BP Oil UK Ltd

A.2 Plant characteristics and emissions

Sources for this section: Oil & Gas Journal (2008) and CITL (2008). Primary distillation capacity designates the capacity of the primary crude intake, usually an atmospheric distillation unit, but in rare cases a direct thermal flasher. The unit for capacity is the barrel per day.

#	Complexity	Typology	Primary distillation capacity	2005		2006	
				Allocation	Emission	Allocation	Emission
					(tons of CO2)		
1	Complex	HSK + CCU	208,600	2,720,740	2,826,917	2,720,740	2,829,983
2	Complex	HSK + CCU	275,000	1,869,049	1,790,991	1,869,049	1,694,078
3	Simple	HSK	115,000	512,745	559,078	512,745	514,258
4	Complex	HSK + CCU	356,629	3,971,863	3,088,102	3,971,863	3,334,682
5	Simple	Atm. HSK + VB	90,000	169,536	73,836	169,536	33,887
6	Simple	HSK	21,000	57,029	64,146	57,029	59,730
7	Simple	HSK	20,000	217,519	166,585	217,519	172,293
8	Simple	HSK	2,500	52,732	27,644	52,732	23,371
9	Complex	HSK + HCU	110,000	564,744	413,074	564,744	452,528
10	Complex	HSK + CCU	68,000	535,503	389,668	535,503	457,291
11	Simple	Atmospheric HSK	70,000	600,169	409,597	450,127	454,074
12	Simple	HSK + VB	106,400	648,450	514,584	486,338	499,266
13	Complex	HSK + CCU	51,800	387,346	398,765	353,938	324,616
14	Ultra complex	HSK + CCU + HCU	200,000	2,694,278	2,262,129	2,694,277	2,496,218
15	Complex	HSK + CCU	331,058	3,535,127	2,991,868	3,535,127	3,519,128
16	Complex	HSK + CCU	118,028	1,341,095	1,266,292	1,341,095	1,373,063
17	Complex	HSK + CCU	229,307	1,436,093	1,308,344	1,436,093	1,451,269
18	Complex	HSK + CCU	157,913	1,630,008	1,493,600	1,630,008	1,171,760
19	Complex	HSK + CCU	98,896	818,404	773,041	818,404	806,027
20	Complex	HSK + CCU	159,386	1,305,930	1,300,352	1,305,930	1,302,303
21	Complex	HSK + CCU	17,000	149,174	157,029	149,174	169,512
22	Simple	HSK	48,000	277,805	275,454	277,805	249,505
23	Complex	HSK + CCU	233,000	2,797,307	2,751,773	2,797,307	2,656,774
24	Complex	HSK + CCU	119,000	898,503	675,492	898,503	812,140
25	Complex	HSK + CCU	82,000	1,367,967	981,779	1,367,967	927,864
26	Complex	HSK + CCU	164,000	1,524,962	1,417,225	1,524,962	1,330,233
27	Complex	HSK + CCU	79,800	633,385	486,741	633,385	500,999
28	Ultra complex	HSK + CCU + HCU	207,100	1,644,240	1,454,368	1,644,240	1,385,072
29	Complex	HSK + HCU	345,861	4,929,141	4,797,503	4,929,141	4,670,857
30	Complex	HSK + CCU	101,835	950,634	993,186	950,634	921,103
31	Simple	HSK	67,829	44,226	41,628	44,226	43,602
32	Complex	HSK + CCU	225,296	2,270,096	2,277,855	2,270,096	2,079,999
33	Complex	HSK + CCU	106,000	880,013	749,692	880,013	849,239
34	Simple	HSK	6,800	33,423	35,828	33,423	37,427

#	Complexity	Typology	Primary distillation capacity	2005		2006	
				Allocation	Emission	Allocation	Emission
					(tons of CO2)		
35	Complex	HSK + HCU	15,000	78,283	90,139	78,283	103,318
36	Complex	HSK + CCU	302,000	2,785,870	3,065,557	2,785,870	2,968,474
37	Ultra complex	HSK + CCU + HCU	220,000	1,717,613	1,764,711	1,717,613	1,812,910
38	Ultra complex	HSK + CCU + HCU	271,900	4,688,417	4,882,912	4,688,417	4,679,370
39	Complex	HSK + HCU	91,000	1,199,005	1,022,454	1,199,005	955,313
40	Simple	HSK + VB	72,000	952,901	981,806	952,901	987,651
41	Complex	HSK + CCU	262,300	1,898,303	2,068,980	1,898,303	2,116,535
42	Complex	HSK + CCU	78,000	965,145	653,354	965,145	674,635
43	Simple	HSK	268,000	1,010,202	998,419	1,197,450	932,100
44	Complex	HSK + CCU	146,500	1,579,436	1,651,719	1,579,436	1,671,550
45	Simple	HSK	66,500	370,158	416,322	370,158	399,118
46	Simple	Atmospheric HSK	100,000	275,799	258,200	275,799	238,000
47	Ultra complex	HSK + CCU + HCU	100,000	1,206,609	1,310,994	1,206,609	1,994,441
48	Complex	HSK + CCU	161,000	1,383,170	1,317,231	1,383,170	1,345,427
49	Simple	HSK	71,000	398,522	411,369	398,522	376,666
50	Ultra complex	HSK + CCU + HCU	200,000	2,108,352	2,125,411	2,108,352	2,160,207
51	Simple	HSK + VB	80,000	792,577	776,347	792,577	835,004
52	Simple	HSK	84,000	619,644	574,106	619,644	469,936
53	Complex	HSK + CCU	84,000	1,045,297	1,094,580	1,045,297	1,028,806
54	Simple	HSK + VB	105,000	3,652,956	3,514,315	3,652,956	3,329,869
55	Ultra complex	HSK + CCU + HCU	241,300	1,844,010	1,822,102	1,844,010	1,772,138
56	Complex	HSK + HCU	154,624	2,141,798	1,372,201	2,141,798	1,229,761
57	Complex	HSK + CCU	82,022	715,305	676,985	715,305	592,841
58	Complex	HSK + CCU	70,376	974,824	774,042	974,824	711,380
59	Complex	HSK + HCU	142,978	1,246,905	1,339,294	1,246,905	1,048,095
60	Simple	HSK + VB	89,109	449,878	421,659	449,878	431,258
61	Complex	HSK + CCU	198,000	2,099,260	2,125,446	2,099,260	2,096,629
62	Complex	HSK + CCU	174,000	1,311,405	1,235,266	1,311,405	1,229,725
63	Simple	HSK + VB	56,600	388,579	376,150	388,579	389,621
64	Simple	HSK + VB	82,900	569,386	444,575	569,386	502,787
65	Simple	HSK	39,500	268,861	200,485	268,861	211,131
66	Simple	HSK + VB	300,000	6,160,040	6,266,748	6,160,040	6,226,940
67	Complex	HSK + HCU	94,000	504,218	428,609	504,218	457,033
68	Complex	HSK + CCU	190,000	2,649,155	1,870,375	1,986,866	1,624,066

#	Complexity	Typology	Primary distillation capacity	2005		2006	
				Allocation	Emission	Allocation	Emission
				(tons of CO2)			
69	Complex	HSK + HCU	188,000	2,493,052	2,246,172	2,493,052	2,118,828
70	Simple	HSK + VB	75,500	600,663	528,081	600,663	520,084
71	Complex	HSK + CCU	380,000	2,174,783	1,978,056	2,174,783	2,048,257
72	Ultra complex	HSK + CCU + HCU	416,000	6,627,535	5,767,819	6,627,535	5,162,072
73	Complex	HSK + HCU	152,373	1,643,340	1,534,049	1,643,340	1,527,214
74	Simple	HSK	10,000	105,495	64,498	105,495	93,545
75	Complex	HSK + HCU	90,000	705,200	722,438	705,200	860,419
76	Ultra complex	HSK + CCU + HCU	376,500	2,626,900	2,488,177	2,626,900	2,211,239
77	Simple	HSK + VB	212,895	2,313,908	2,063,717	2,313,908	2,116,194
78	Simple	HSK	91,227	951,969	945,313	951,969	902,186
79	Ultra complex	HSK + CCU + HCU	115,000	2,290,555	2,292,788	2,290,555	2,190,190
80	Simple	HSK	100,000	747,568	702,078	747,568	659,879
81	Complex	HSK + HCU	160,000	2,863,411	2,758,717	2,863,411	2,714,233
82	Complex	HSK + CCU	120,000	1,568,603	1,553,483	1,568,603	1,528,693
83	Simple	HSK + VB	87,000	443,656	481,504	443,656	478,961
84	Ultra complex	HSK + CCU + HCU	220,000	2,174,444	2,171,856	2,174,444	2,430,800
85	Complex	HSK + CCU	104,500	1,014,932	1,000,363	1,014,932	1,015,260
86	Ultra complex	HSK + CCU + HCU	140,000	2,653,107	3,118,691	2,653,107	3,086,896
87	Complex	HSK + CCU	240,000	1,840,322	1,703,245	1,840,322	1,716,609
88	Ultra complex	HSK + CCU + HCU	100,000	1,003,270	1,039,824	1,003,270	959,264
89	Ultra complex	HSK + CCU + HCU	210,000	586,130	572,487	586,130	542,867
90	Simple	HSK	106,000	1,641,278	1,169,944	1,641,278	1,704,306
91	Simple	HSK	13,000	25,725	28,862	25,725	29,180
92	Simple	HSK	28,000	179,093	145,965	179,093	138,692
93	Simple	HSK	77,000	592,048	534,435	592,048	524,195
94	Simple	HSK	27,000	58,395	51,440	58,395	49,537
95	Simple	HSK	100,000	283,874	252,553	283,874	215,420
96	Complex	HSK + CCU	104,153	1,221,437	1,038,345	1,221,437	1,234,371
97	Complex	HSK + CCU	221,286	2,115,511	1,758,034	2,115,511	1,821,223
98	Complex	HSK + CCU	163,400	2,396,984	1,997,522	2,396,984	1,931,222
99	Complex	HSK + CCU	221,000	2,580,539	2,351,567	2,580,539	2,186,559
100	Complex	HSK + CCU	326,000	3,623,758	3,149,575	3,623,758	3,088,121
101	Complex	HSK + CCU	210,000	2,175,746	2,320,641	2,175,746	2,251,765
102	Complex	HSK + CCU	296,400	2,967,273	2,959,427	2,967,273	2,946,442
103	Simple	HSK	12,000	22,624	29,523	22,624	29,392
104	Complex	HSK + HCU	195,700	1,463,785	1,607,909	1,463,785	1,449,959

Typology	Distillation capacity (bbl per day)	2005		2006		Intensity (tons CO_2 per bbl/d)	
		Allocation	Emission	Allocation	Emission	2005	2006
		(tons CO_2)					
Simple	2,901,760	26,489,433	24,806,794	26,364,527	24,879,065	8.55	8.57
Complex	9,057,021	91,943,139	84,795,064	91,247,442	83,928,211	9.36	9.27
Ultra complex	3,017,800	33,865,460	33,074,269	33,865,459	32,883,684	10.96	10.90

Appendix B

Tables

This appendix gathers the different detailed tables backing the different chapters that would not fit in the body of the text. Report to the list of tables at the beginning for a comprehensive index.

B.1   Allocation and emissions of the refining sector under EU ETS

Table B.1: Allocation of allowances by sector (Ellerman and Buchner 2006)

Allocation 2005 (t CO_2)	Emissions 2005 (t CO_2)	# of plants	Gross Short (t CO_2)	Gross Short (%)	Gross Long (t CO_2)	Gross Long (%)	Net Short (t CO_2)	Net Short (%)
Power & heat								
1,170,783,068	1,198,708,781	3570	157,660,503	13.5	129,208,590	11.0	28,451,913	2.4
Refineries								
142,553,291	132,997,989	136	2,687,055	1.9	12,204,279	8.6	−9,517,224	−6.7
Iron, steel & coke								
159,638,364	127,241,724	235	1,816,331	1.1	34,203,974	21.4	−32,387,643	−20.3
Pulp & paper								
38,635,691	30,628,002	795	771,988	2.0	8,485,611	22.0	−7,713,623	−20.0
Cement & lime								
174,663,015	161,419,401	462	7,534,377	4.3	19,873,806	11.4	−12,339,429	−7.1
Glass								
19,315,789	17,112,080	344	464,039	2.4	2,462,392	12.7	−1,998,353	−10.3
Ceramics, bricks & tiles								
16,430,329	13,257,432	1035	475,507	2.9	3,401,801	20.7	−2,922,327	−17.8

Table B.2: Allocation of allowances by country - Refining sector (CITL 2008)

Country	2005 Allocation	2005 Emissions	2006 Allocation	2006 Emission
Austria	2,720,740	2,826,917	2,720,740	2,829,983
Belgium	6,580,222	5,576,153	6,580,222	5,636,635
Czech Republic	1,370,498	996,971	1,370,498	1,105,483
Denmark	1,248,619	924,181	936,465	953,340
Finland	3,081,624	2,660,894	3,048,215	2,820,834
France	19,360,000	17,333,358	19,360,000	17,655,649
Germany	27,147,523	27,214,000	27,334,771	26,502,825
Greece	3,432,002	3,637,235	3,432,002	4,303,109
Hungary	1,383,170	1,317,231	1,383,170	1,345,427
Ireland	398,522	411,369	398,522	376,666
Italy	27,304,950	26,078,536	27,304,950	25,271,632
Lithuania	2,649,155	1,870,375	1,986,866	1,624,066
Netherlands	13,644,868	12,118,675	13,644,868	11,470,000
Poland	7,916,100	6,636,750	7,916,100	6,882,433
Portugal	3,265,877	3,009,030	3,265,877	3,018,380
Slovakia	2,290,555	2,292,788	2,290,555	2,190,190
Spain	14,374,353	14,603,763	14,374,353	14,660,434
Sweden	3,024,274	2,451,693	3,024,274	2,939,240
United Kingdom	19,389,832	18,138,697	19,389,832	17,668,435
EU-25	160,582,884	150,098,616	159,762,280	149,254,761

157

Table B.3: Gross allowances holding by country - Refining sector (CITL 2008)

Country	Gross long 2005	%	Gross short 2005	%	Gross long 2006	%	Gross short 2006	%
Austria	106,177	3.8					3,066	0.1
Belgium	1,057,519	19.0	53,450	1.0	947,801	16.8	246,580	4.4
Czech Republic	373,527	37.5			265,015	24.0	112,785	10.2
Denmark	324,438	35.1					44,477	4.7
Finland	432,149	16.2	11,419	0.4	227,381	8.1	234,089	8.3
France	2,034,497	11.7	7,855	0.0	1,771,833	10.0	975,282	5.5
Germany	764,682	2.8	785,434	2.9	1,317,909	5.0	239,179	0.9
Greece	17,599	0.5	222,832	6.1	37,799	0.9	703,278	16.3
Hungary	65,939	5.0			37,743	2.8	28,196	2.1
Ireland			12,847	3.1	21,856	5.8		
Italy	1,616,599	6.2	390,185	1.5	2,332,358	9.2	252,061	1.0
Lithuania	778,780	41.6			362,800	22.3		
Netherlands	1,526,193	12.6			2,174,868	19.0	99,248	0.9
Poland	138,723	2.1	17,238	0.3	415,661	6.0	137,981	2.0
Portugal	256,847	8.5			247,497	8.2	52,477	1.7
Slovakia			2,233	0.1	100,365	4.6		
Spain	319,538	2.2	548,948	3.8	444,496	3.0	287,205	2.0
Sweden	575,718	23.5	3,137	0.1	151,517	5.2	534,680	18.2
United Kingdom	1,689,308	9.3	295,918	1.6	1,801,636	10.2	259,215	1.5
EU-25	11,972,056	8.0	2,457,673	1.6	12,658,535	8.5	4,209,799	2.8

Table B.4: Net allowance holding and emissions abatement by countries - Refining sector (CITL 2008)

Country	Net Long 2005	(%)	Net Long 2006	(%)	Emissions change	(%)
Austria	-106177	-3.76	-109243	-3.86	3066	0.11
Belgium	1004069	18.01	943587	16.74	60482	1.08
Czech Republic	373527	37.47	265015	23.97	108512	10.88
Denmark	324438	35.11	-16875	-1.77	29159	3.16
Finland	420730	15.81	227381	8.06	159940	6.01
France	2026642	11.69	1704351	9.65	322291	1.86
Germany	-66477	-0.24	831946	3.14	-711175	-2.61
Greece	-205233	-5.64	-871107	-20.24	665874	18.31
Hungary	65939	5.01	37743	2.81	28196	2.14
Ireland	-12847	-3.12	21856	5.80	-34703	-8.44
Italy	1226414	4.70	2033318	8.05	-806904	-3.09
Lithuania	778780	41.64	362800	22.34	-246309	-13.17
Netherlands	1526193	12.59	2174868	18.96	-648675	-5.35
Poland	1279350	19.28	1033667	15.02	245683	3.70
Portugal	256847	8.54	247497	8.20	9350	0.31
Slovakia	-2233	-0.10	100365	4.58	-102598	-4.47
Spain	-229410	-1.57	-286081	-1.95	56671	0.39
Sweden	572581	23.35	85034	2.89	487547	19.89
United Kingdom	1251135	6.90	1721397	9.74	-470262	-2.59
EU-25	10484268	6.98	10507519	7.04	-843855	-0.56

Table B.5: Capacity, production and utilization by countries - Refining sector (CITL 2008, Eurostat 2008, Oil & Gas Journal 2008)

Country	Distillation capacity			Crude and feedstock consumption			Utilization rate (%)		
Year	2004	2005	2006	2004	2005	2006	2004	2005	2006
Austria	208,600	208,600	208,600	181,690	186,435	182,558	87.1	89.4	87.5
Belgium	803,013	857,629	790,629	846,391	731,241	725,356	98.7	92.5	90.9
Czech Republic	198,000	198,000	198,000	124,806	145,090	149,418	63.0	73.3	81.6
Denmark	176,400	176,400	176,400	165,172	152,602	161,097	93.6	86.5	92.4
Finland	251,800	251,800	251,800	221,499	207,218	249,533	88.0	82.3	99.1
France	1,968,348	1,996,488	1,975,794	1,791,352	1,760,124	1,749,219	89.7	88.5	90.3
Germany	2,323,200	2,428,192	2,417,418	2,402,729	2,448,592	2,395,075	99.0	101.3	99.1
Greece	401,400	413,000	413,000	415,794	420,845	441,505	100.7	101.9	104.4
Hungary[a]	161,000	161,000	161,000	135,777	151,723	156,672	84.3	94.2	97.3
Ireland	71,000	71,000	71,000	62,531	68,579	65,057	88.1	96.6	91.6
Italy	2,320,915	2,324,409	2,337,229	1,839,478	1,897,187	1,834,650	79.1	81.2	78.5
Lithuania	263,420	190,000	190,000	172,926	183,782	164,342	91.0	96.7	86.5
Netherlands	1,227,500	1,221,873	1,211,886	1,642,568	1,660,225	1,591,210	134.4	137.0	129.7
Poland	350,000	466,500	496,500	383,434	382,520	437,920	82.2	77.0	88.8
Portugal	304,172	304,172	304,172	279,622	288,998	296,357	91.9	95.0	97.4
Slovakia	115,000	115,000	115,000	118,342	118,528	115,091	102.9	103.1	100.1
Spain	1,271,500	1,271,500	1,271,500	1,224,176	1,241,216	1,262,599	96.3	97.6	98.9
Sweden	434,000	434,000	434,000	387,854	375,569	379,126	89.4	86.5	86.8
United Kingdom	1,825,390	1,876,939	1,887,068	1,894,743	1,775,461	1,683,187	100.9	94.1	90.6
EU-25	14,674,658	14,966,502	14,910,996	14,290,883	14,185,030	14,050,876	97.4	94.8	94.2

[a] Note: 'capacity' designates the primary distillation capacity. Utilization rate higher than 100% stands for further conversion of transferred feedstock.

Table B.6: Emission intensity by countries - Refining sector (CITL 2008, Eurostat 2008, Oil & Gas Journal 2008)

Country	2005 Emission intensity	2006 Emission intensity
Austria	0.080	0.082
Belgium	0.040	0.041
Czech Republic	0.035	0.037
Denmark	0.033	0.033
Finland	0.064	0.056
France	0.054	0.055
Germany	0.060	0.060
Greece	0.047	0.053
Hungary	0.043	0.043
Ireland	0.034	0.033
Italy	0.070	0.070
Lithuania	0.055	0.054
Netherlands	0.039	0.038
Poland	0.096	0.087
Portugal	0.058	0.057
Slovakia	0.098	0.096
Spain	0.065	0.065
Sweden	0.032	0.038
United Kingdom	0.058	0.059
EU-25	0.0568	0.0570

Emission intensity: ton CO_2 per ton of crude oil processed

161

B.2   Petroleum products production in Europe

	Crude intake	Refinery gas	LPG	Gasoline	Kerosene	Naphthas	Gas/diesel oil	Residual fuel oil	Sundry products
Oct. 04	60243	303	1363	12439	3658	3515	21579	8545	5427
Nov. 04	57370	335	1305	11987	3713	3352	20578	8140	4554
Dec. 04	62769	339	1552	12935	3726	4080	22920	9206	4403
Jan. 05	61437	273	1517	12918	3591	4028	22750	9464	4307
Feb. 05	54195	268	1470	11297	3121	3305	19672	7637	3268
Mar. 05	59958	284	1692	11932	3648	3918	21822	8850	4015
Apr. 05	57793	233	1744	11784	3613	3604	21428	8050	4579
May 05	59667	272	1757	11992	3946	3642	21435	8516	4813
June 05	57283	244	1641	11527	3566	3381	20561	8121	5114
July 05	60704	274	1706	12141	3801	3505	22065	8552	5516
Aug. 05	62509	311	1850	12575	4022	3941	22530	8711	
Sep. 05									
Oct. 05									
Nov. 05	62778	283	1391	12810	3842	3721	23192	8536	5053
Dec. 05	64853	318	1607	13793	3764	3741	24088	9410	4253
Jan. 06	63152	266	1618	12924	3845	3830	22961	9793	3732
Feb. 06	56219	225	1526	11472	3521	3466	20570	8128	3763
Mar. 06	61250	202	1677	12428	3894	3844	22162	8743	4640
Apr. 06	58992	267	1744	11807	3727	3360	21232	8572	4529
May 06	60942	277	1768	12925	3917	3103	21935	8250	5286
June 06	61415	251	1728	12527	3961	3357	21966	8641	5291
July 06	63073	255	1722	12899	4093	3181	22787	8774	5575
Aug. 06	64996	287	1723	13321	4347	3559	23454	8735	5542
Sep. 06	61150	248	1405	12694	4124	3317	22301	8216	5337
Oct. 06	61,121	279	1224	12864	3760	3073	22576	8575	5216
Nov. 06	60,371	238	1302	12412	3625	3493	22825	8251	4602
Dec. 06	63,023	284	1511	12991	3777	3779	23512	8945	4373
Jan. 07	62,893	306	1329	12508	3965	3587	22999	10123	3297
Feb. 07	56,357	309	1362	11010	3447	3514	20565	8182	3639
Mar. 07	59,524	271	1510	12069	3746	3668	21516	8333	4331
Apr. 07	58,016	250	1489	11747	3819	3073	21278	8045	4375
May 07	61,808	293	1566	12651	4038	3164	22150	8696	4667
June 07	60,238	269	1564	12483	3864	3164	21616	7756	5291
July 07	63,445	289	1662	13171	4280	3163	12183	8017	5344
Aug. 087	63,651	293	1699	13011	4368	3375	23556	7985	4950
Sep. 07	60,783	224	1426	12225	3847	3151	22799	8009	4778

Appendix C

Figures

This appendix gathers the different figures illustrating the different chapters that would not fit in the body of the text. Report to the list of figures at the beginning for a comprehensive index.

C.1 Refinery configurations

The figures in this section are drawn from Favennec (2001). They illustrate the three main types of refinery configuration found in Europe:

- Hydroskimming (simple) refineries

- Complex refineries

- Ultra-complex (deep conversion) refineries

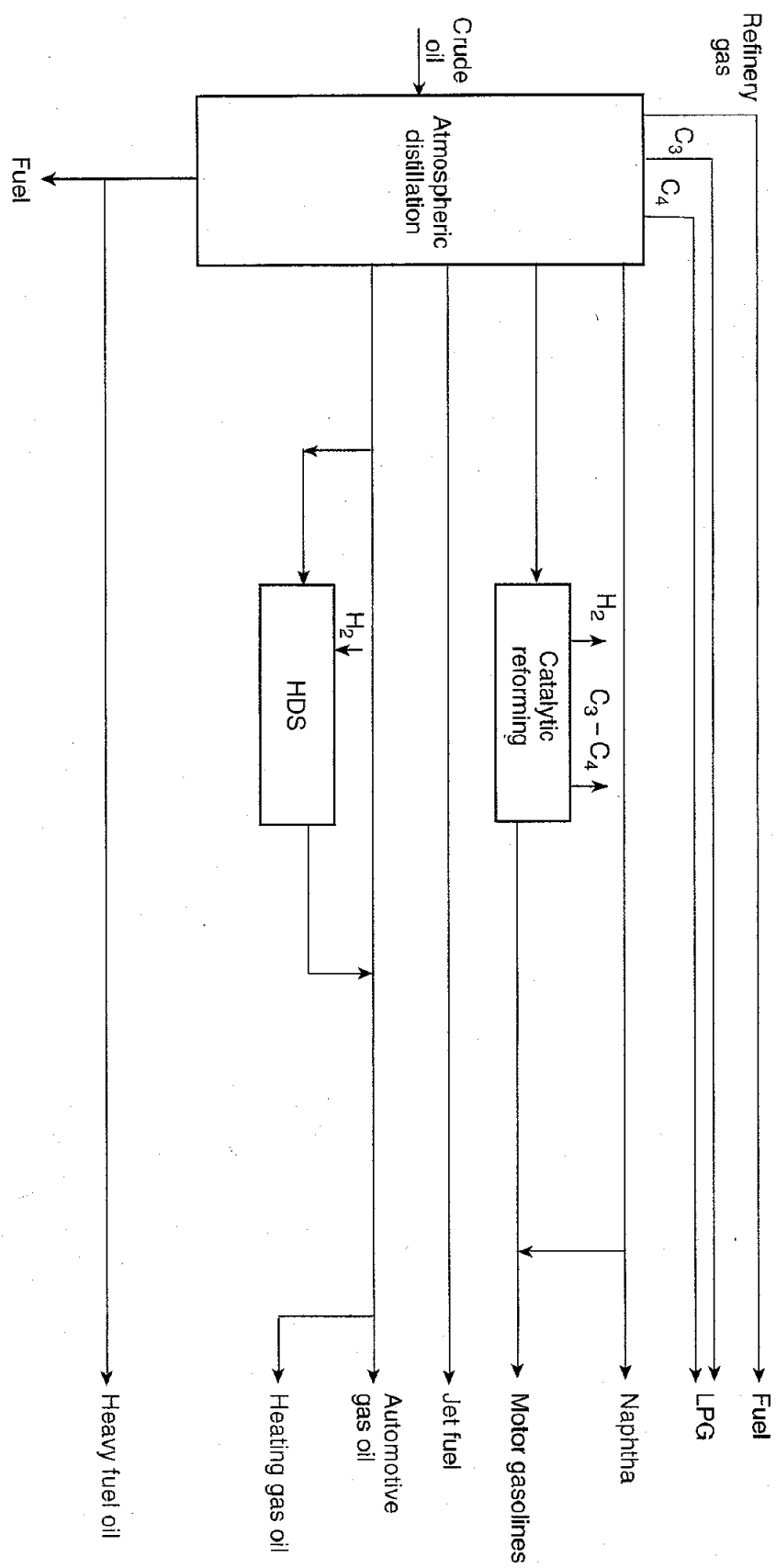More details on the technology of refineries is provided in Chapter 2.

Figure C-1: Hydroskimming refinery configuration (source Favennec (2001))

Figure C-2: Complex refinery configuration (source Favennec (2001))

Figure C-3: Ultra complex refinery configuration (source Favennec (2001))

Appendix D

Questionnaire

This appendix contains the questionnaire that was compiled, mailed to potential interviewees, and used as a basis for the interviews with the refinery operatives. For a description of the survey method, objectives and goals, see chapter 1. Section 1.3 specifically details the questions framed and the research objectives of the project, while paragraph 1.3.3 reports the list of the different interviewees that participated in the survey.

1. General information

Company/plant information
A) What type of refinery(ies) do you operate?
For example:
- *Simple, complex, very complex, highly integrated complex refineries?*
- *What type of products?*
- *What type of crude diet?*

B) How are your operations organized?
a. How are the refining and retail parts of your company integrated?

b. How are your refining operations distributed inside and outside of the EU ETS area?

Position under ETS
C) What was the situation of your company with respect to allocations?
a. Was it short or long on allowances under 'business-as-usual' projections?

b. Was it eventually short or long at the end of the period (before sales and purchases)?

Preparation to ETS
D) How has the company prepared for the first phase of ETS?
a. Has your company engaged in an audit of potential CO2 abatement opportunities in the short and the long run?

b. Has your company engaged in formal or informal industry and/or stakeholder discussions?

c. What sources of information were available for executives?

d. What were the main uncertainty points during the preparation to ETS?

e. What other steps did your company take to prepare for the trading period?

E) Are there other characteristics of your company that have special relevance to its response to EU ETS?

2. Operational changes and investment strategies

A) Have carbon constraints been taken into account in refinery operations?
If so, how was carbon priced? At the spot price evolving with market conditions? At a forecast price estimated by the company? Since when, with what results?

If not, why, and with what outcome?

For example:
- *Inclusion of a carbon cost in linear programming software*
- *Adjusted purchase price for different crudes depending on the carbon cost of processing them*
- *Adjusted sale price for different product slates depending on the carbon cost of producing them*

B) Have changes in refinery operations been undertaken?
If so, what were they, and how much did they cost per ton of CO2 avoided? What criteria led to the choice of such operational changes?

If not, why, and with what outcome?

C) Have changes occurred in trade, sales and procurement patterns?
a. Has the carbon price changed the picture for crude diet choices? If so, how?

b. What about the choice of petroleum products mix?

c. Have the trading patterns of your company evolved due to the introduction of a carbon price in the EU-25 area?

D) Have outsourcing opportunities been considered?
a. Has your company changed its policy regarding intermediate fuels procurement and trade at the level of refineries? Regarding finished products trade at the level of retail outlets?

For example:
- *Procurement of semi-processed products (e.g. Russian naphtha or diesel streams)*
- *Procurement of finished products outside EU ETS to be sold in retail outlets*

b. Has your company changed its policy regarding the generation of its energy needs?
For example:
- *Change in the products from the crude streams used for process heat*
- *Shift to own electricity generation/combined heat and power generation*
- *Outsourcing to external combined heat and power generation*
- *Outsourcing to grid electricity*

E) Have you invested capital in abatement opportunities (in existing facilities)?
    a. If so, for which investments? How much did they cost per ton of CO2 avoided? What criteria led to the choice of such investments?

For example: Ecofys and the European Commission detail the following potential abatement opportunities[1]:
- *Reflux overhead vapour recompression in distillation towers*
- *Power recovery*
- *Improved management of processes (automation/energy efficiency)*
- *More efficient hydrogen production*
- *Intermediate reboilers and condensators*
- *Air preheaters*
- *Staged crude pre-heater*
- *Application of mechanical vacuum pumps*
- *Improved catalysts at catalytic reformer and cracker*
- *Combined heat and power/cogeneration*

    b. Which one of these investments apply to your refinery(ies)?

    c. Which ones have already been undertaken in the past? Which ones have been undertaken as a direct result of ETS?

    d. Which ones are under study for the next phases? What other abatement opportunities which have been or will be studied by your company can you think of?

F) What long run carbon price signal would your company use for new facilities or capacity addition projects?
    a. What carbon price forecast does your company work with in terms of new facilities or capacity extension investment decisions within EU ETS? What about outside the EU-25 area?

    b. How does uncertainty over carbon price and allocation impact investment decisions?

G) Are there other characteristics of your company's operations and investment policies that have special relevance to its response to EU ETS?

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[1] Ecofys, 'Economic Evaluation of Emission Reduction of Greenhouse Gases in the Energy Supply Sector in the EU'

3. Organizational changes

'Ownership of EU ETS'
A) How is responsibility on allowances management distributed in your company?
    a. Centralized at the level of the company, or distributed by plant?

    b. Who or which division of the company is in charge of compliance?

    c. Who or which division of the company is in charge of allowance trading?

    d. Who or which division of the company is in charge of allocating allowances between the different plants?

B) How is responsibility on response to ETS distributed?
    a. Who or which division of the company is in charge of identifying abatement and investment opportunities linked to ETS?

    b. Who or which division of the company is in charge of eventual operational choices?

    c. Who or which division of the company is in charge of eventual investment choices?

C) How has such an organizational arrangement fared in the context of ETS?

Incentives to internalize EU ETS
D) What are the incentives for the different actors?
A question of concern is how incentives faced by managers in charge of compliance, operations and trading are aligned together and with company profit maximization.

    To what extent and through which instruments are EU ETS incentives internalized by managers in charge of these different tasks?

For example:
- *Carbon emission reduction objectives tied to compensation*
- *Emission targets review*
- *Benchmarking*
- *Emission objectives trumped by other overarching objectives, such as:*
  - *Profit maximization*
  - *Cost minimization*
  - *Performance and safety*

E) Are there other characteristics of your company's organization that have special relevance to its response to EU ETS?

4. Involvement in allowances trading

EU ETS: compliance burden or source of profits?
A) Which of these statements is closer from the perspective of your company on ETS:

[ ] 'What matters first and foremost is to focus on profits from the petroleum product markets, and to intervene in the EUA market only to the extent that is needed to ensure compliance'

[ ] 'What matters is to actively take advantage of all potential profits from the trading of EUA as long as they don't force changes in traditional refinery operations'

[ ] 'What matters first and foremost is to realize all profits possible from the production of petroleum products *and* the trade of EUAs, even if it entails modifications in the traditional operation of refineries'

Involvement in carbon trading
B) What was your company's policy on allowances trading:

    a. Regarding compliance:
[ ] Selling unneeded allowances/buying needed allowances upfront
[ ] Stocking more allowances than needed until end of the period to insure against a sudden rise in emissions
[ ] Waiting until the end of the period to ensure compliance by buying/selling EUAs
[ ] Other (please detail)

    b. Regarding corporate jurisdiction:
[ ] EU ETS is mainly a financial issue best dealt with by traders
[ ] EU ETS is mainly an industrial issue best dealt with by refinery operators
[ ] EU ETS is mainly a regulatory issue best dealt with by the environmental regulation department
[ ] EU ETS is a transversal issue best dealt with by an ad-hoc decision maker

    c. Regarding potential profits from ETS (non exclusive answers):
[ ] Engaging in financial trading to hedge or gain from the scheme
[ ] Engaging in the pursuit of CER credits from Joint Implementation/Clean Development Mechanism projects
[ ] Outsourcing management of allowances to third parties
[ ] Other (please detail)

C) Are there other characteristics of your company's carbon trading policy that have special relevance to its response to EU ETS?

5. Debate on the future of ETS

Allocation
A) How would the operation and investment patterns of your company be impacted by the following degrees of auctioning of allowances in the next phases of EU ETS:
- Total grandfathering of emissions with free allowances for new entrants
- Partial auctioning (with of without partial compensating cash transfers)
- Total auctioning (with or without partial or total compensating cash transfers)

Main lessons from Phase I
B) What are the main lessons from ETS for your company? In terms of refinery operations? Of organization? Of finance?

C) From your perspective, what lessons should all industrial operators impacted by ETS draw from this first phase?

D) Have the views of your company on these issues evolved since the beginning of EU ETS Phase I?

Other considerations and conclusions
E) Are there other effects or considerations related to your company's response to EU ETS that have not been covered in this survey?

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